Ground Water Recharge Projects in the Western United States

Economic Efficiency, Financial Feasibility and Legal/Institutional Issues (Part II)

A Cooperative Project by:

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This report is the second and final part of an ongoing economic, financial, institutional and legal review of ground water recharge projects in the western United States. The first report was a general conceptual framework for evaluating recharge opportunities and state-by-state summary of legal and institutional issues, which was completed in 1990. The extension by the Congress of this demonstration program, delays in the completion of the authorized recharge projects, and personnel changes, necessarily prolonged completion of this report. Hopefully, the result will be useful as Reclamation prepares its final program report to the Congress.

Reclamation and the project sponsors are to be commended for their efforts, in bringing these projects to fruition. This demonstration program has in fact had a significant influence on the spread of essential information, the development of legislation and administrative rules at the state level, and the transfer of appropriate technology, which will encourage and facilitate future recharge projects, programs and activities. Ground water recharge is an important alternative resource management tool, and its use is growing as a means of addressing challenging western water problems.

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GROUND WATER RECHARGE PROJECTS IN THE WESTERN UNITED STATES

ECONOMIC EFFICIENCY, FINANCIAL FEASIBILITY AND LEGAL/INSTITUTIONAL ISSUES (Part II)

INTRODUCTION

In response to concerns over declining water levels and ground water resource development and management challenges, Congress passed the High Plains States Ground Water Demonstration Project Act of 1983. It authorized the U.S. Department of Interior's Bureau of Reclamation (Reclamation), to undertake a westwide ground water recharge demonstration program. The stated objective of the program was "to move from the research mode on ground water recharge to the pilot demonstration phase, and to lay the groundwork for larger operational programs in the future." From a list of 41 project proposals submitted for consideration, Interior selected 21 for funding. Only thirteen subsequently reached the construction phase, which is ongoing. Ten projects have been completed so far.

Another provision of the legislation authorizing the program specifically directed the Secretary of Interior to "contract with the various High Plains States and other Reclamation Act States to conduct a study to identify and evaluate alternative means by which the cost of ground water recharge projects could be allocated among the beneficiaries of the projects within the respective states and identify and evaluate the economic efficiency of and the legal authority for utilizing ground water recharge in water resource development projects." In 1989, the Western States Water Council and Reclamation entered into a cooperative agreement to accomplish the required study.

The Council completed its initial report in October 1990. It outlined western states' experience with ground water recharge, or some times the lack thereof, and presented a general conceptual framework from which to evaluate the feasibility of ground water recharge programs and projects, compared to other alternatives. While addressing a broad general audience, this report also presented important economic principles for the development of appropriate cost sharing and financing policies and a detailed state-by-state review of legal and institutional issues. However, given none of the authorized projects had yet been constructed or operated, this initial report did not discuss specific case studies.

EXECUTIVE SUMMARY

In order to apply the general conceptual framework and economic principles from the initial report and evaluate individual projects, the Western States Water Council and Reclamation entered into a new cooperative agreement to prepare a number of case studies that would utilize information provided by sponsors and Reclamation to evaluate project effectiveness, identify economic and institutional problems, and recommend alternative solutions to improve public policymaking with respect to future ground water recharge programs and projects. Unfortunately, continuing delays in project construction and operation, reassignment of Reclamation personnel, and a general lack of data have made an analysis of projected and actual project costs and benefits impractical. However, there remains a wealth of information from which to draw valuable lessons for future policymaking.

While ground water recharge has been practiced in the West for decades, interest and experience with ground water recharge projects and programs are growing, prompted to a substantial degree by Reclamation's ground water recharge demonstration program. Recharge opportunities offer a practical and promising alternative for the storage of vast amounts of water, as traditional surface water storage facilities become harder and harder to get approved and constructed. Ground water recharge also offers other unique advantages. Overall, it is an important tool that can enhance opportunities for conjunctive use of water resources and serve as a means to maximize efficient and beneficial use. Ground water recharge should be considered as part of any comprehensive conjunctive water use and management program.

However, the effects of recharge activities are very site specific. Management decisions with respect to recharge opportunities should focus on the specific problem that needs to be addressed and the potential advantages of recharge projects and programs. Unfortunately, at this point in time, there is little data available to evaluate demonstration program recharge project costs and benefits. Detailed benefit-cost analyses have not been required by Reclamation or undertaken by the sponsors. Heretofore, project sponsors' willingness and ability to pay (or cost share) has been the primary measure of economic and financial feasibility. Further, recharge project costs have generally been recovered through general tax revenues or water and sewer bills, not individual assessments based on differential benefits. Still, enough information is available to recognize and evaluate potential federal and non-federal costs and benefits and justify program participation. Moreover, as these demonstration projects are completed and operated, they will provide an information base necessary for a more careful economic evaluation of future proposals.

While multipurpose ground water recharge projects are important, augmenting water supplies through aggressive conjunctive use is the primary purpose for most recharge projects. Further, most successful ground water recharge projects are municipal water supply projects, given higher water values. Recharge projects may provide a particularly valuable alternative for meeting peak demands. Still, agricultural recharge projects can also be successful by

utilizing existing infrastructure and low cost water supplies. Like surface water storage projects, ground water recharge projects offer an opportunity to augment supplies by storing water during "wet" periods or years, for withdrawal and use during droughts or other temporary shortages. As new demands for water in the West continue to grow, so will the importance of recharge programs.

However, recharge opportunities are not unlimited. Finding water available for recharge is a primary constraint. The extended drought of the late 1980s and early 1990s had a serious impact on many demonstration projects. In some cases, facilities stood idle or operated at a fraction of their capacity due simply to the lack of an available surface water supply for recharge.

State and federal environmental laws are also very important constraints on recharge activities. Federal legislative constraints include the Clean Water Act, Endangered Species Act, National Environmental Policy Act, and Safe Drinking Water Act. Federal water quality monitoring requirements and costs are a major issue. Some project sponsors withdrew from the program when monitoring costs became so high as to outweigh the benefit of an 80% federal cost share. More stringent federal and/or state non-point source pollution controls and ground water protection requirements would affect future recharge projects. The demonstration program should help to identify necessary and nonessential monitoring measures in the future.

Local planning and zoning requirements and other ordinances may also affect project costs and economic, financial or political viability. For example, in Utah, the Salt Lake County Water Conservancy District's recharge facilities are located in developed residential areas and landscaping requirements imposed by the county significantly increased project costs.

Of particular note, state water laws and administrative policies are changing to accommodate recharge activities. Reclamation's demonstration program has helped expedite these changes, which will pave the way for more projects in the future. States' primary concerns with respect to ground water recharge projects involve the potential waste or degradation of surface and ground waters. Given the numerous potential public costs and benefits, government involvement in recharge activities should continue. Appropriate government action should include regulatory oversight, and financial assistance where there is a particular public benefit.

Moreover, there are opportunities to use more water from federal Reclamation projects for recharge. This is an important finding that can help lead to greater operational efficiencies. While some federally developed waters are important to the operation of demonstration program projects, perhaps the best examples of recharge opportunities involve non-program projects. Some of these include Arizona's Granite Reef Project on the Salt River below Roosevelt Dam, the Las Vegas Valley Water District's recharge program using waters drawn from Lake Mead in Nevada, and the recharge of water from the federal Central Valley Project (and California State Water Project) in Kern County. Banking water through recharge activities offers water managers greater system flexibility and reliability.

As is the case in the Central Valley Project in California, future construction and operation of successful recharge projects will depend in large part on the ability of different agencies to

find common or compatible purposes and work out collaborative working arrangements. Future project financing and cost sharing arrangements will similarly depend on the value placed on different project benefits by different entities and their willingness to pay for those benefits. With respect to future cost sharing, again the primary purpose for most recharge projects is augmenting water supplies, which is mainly a private or local government responsibility. Federal fiscal challenges make it unlikely much new federal money will be available to promote or participate in private or local public recharge activities, unless a clear and overriding federal benefit can be demonstrated. States may be asked to help fill the void by providing assistance with financing, perhaps through existing state water project development programs.

Recharge opportunities may or may not be the best or least-cost solution to a particular problem. Evaluation of recharge projects is really no different than for any surface water project, recognizing there are different costs and benefits. A careful review of specific water problems, the advantages and disadvantages of a solution involving ground water recharge, and the availability of other alternatives will be the key to successful implementation of future projects and programs. However, there is also a need for greater public awareness of ground water management issues and recharge opportunities. Hopefully, Reclamation's demonstration program has helped raise such public awareness.

Recommendations

Given observations gathered from a review of Reclamation's demonstration program projects and non-program projects, the following recommendations are made for improving future ground water recharge programs. Cost sharing and financing agreements should be designed so that beneficiaries pay project costs, to the extent practical, in order to promote economic efficiency and equity. Federal, state or local participation in any ground water recharge project should be based on a careful assessment of the perceived problem and the potential public benefits from the project, just like any other water project. Public financing and cost sharing should be based on public benefits. Where there is a clear federal or state benefit (economic, environmental or otherwise), federal or state entities should participate and help pay for recharge projects.

While some projects may produce few if any federal or state benefits, to the extent that other private or public financing is not available for an otherwise worthy project, the federal or state government may still play an important and appropriate role by financing a project on a reimbursable basis, with appropriate cost recovery. Existing federal and state water project development programs may be appropriately utilized to encourage recharge. Moreover, federal and state funding for cooperative ground water resources research and data collection programs that focus on specific problems and solutions, with the potential for widespread public benefits, should continue.

Federal environmental oversight and regulatory requirements have substantially and perhaps unnecessarily increased the cost of some projects under Reclamation's demonstration program. Excessive federal and state oversight and regulatory requirements should be avoided. Water quality monitoring and other environmental protection requirements should be reasonably based on the

potential risk to the public health and welfare, given existing and potential future uses of recharged waters. Further, sponsors should be involved in the development and implementation of regulatory requirements and interagency agreements regarding their specific project.

Each state should examine its own legal and institutional systems to assure that they adequately address ground water recharge. Many states may need to carefully consider amending their statutes to encourage appropriate recharge activities. Recharge should be recognized as a beneficial use of water, and a right to recover recharged water should be established and reasonably protected (along with the public interest and the rights of third parties).

Further, public education and public participation programs that explain recharge project costs and benefits and involve stakeholders in the decisionmaking process should be encouraged.

Hopefully, this report and these findings and recommendations will be helpful in evaluating many recharge opportunities and identifying appropriate intergovernmental roles and responsibilities.

BACKGROUND

Ground water recharge is already practiced quite extensively in the Southwest. Recharge activities began in California a century ago, and widespread ground water recharge is practiced there today and in Colorado and Texas. An increased use of ground water recharge and conjunctive use strategies has more recently been demonstrated in Arizona, Nebraska, and Nevada. Other Western states are likely to follow and increase their ground water recharge activities in the future as demands on scarce water resources continue to grow and technical understanding of and capabilities for ground water recharge and recovery improve.

The technical and economic feasibility of ground water recharge and recovery has been proven, but it is very site-specific, and lack of site-specific information limits its use as a water management alternative in many cases. It has been proven to be a cost-effective alternative for providing peaking, seasonal and emergency or drought-related supplies in many parts of the West. However, recharge does not create water. Rather, it allows more efficient conjunctive use of water resources by providing greater control over the time and place of use.

The High Plains States Groundwater Demonstration Program has demonstrated the benefits and costs of ground water recharge and conjunctive use, and the lessons learned can be used to predict the success of ground water recharge activities over a broad range of geographic and economic circumstances. Other non-program ground water recharge projects are also providing valuable information.

Where ground water recharge may not now be economically feasible, given current uses of water, changes in either economic activities or the cost and availability of water may provide the incentives needed for future successful ground water recharge and recovery activities.

For example, water from the Colorado River that is surplus to current demands is being delivered to Arizona cities through the federal Central Arizona Project (CAP), and much of it is being used to recharge depleted aquifers. Later, population growth in southern Arizona and elsewhere in the Colorado River Basin is anticipated to lead to water demands that sometimes exceed available supplies, and the recharged water will be important.

Recharge as a Water Management Option

In evaluating the potential feasibility of any ground water recharge project, it is important to recognize the project will usually be part of a broader, comprehensive water management plan or strategy and ask a number of questions.

What is the problem?

Generally, in the West, the primary problem to be addressed is an inadequate water supply, given current demands. However, water problems vary and therefore so will the purposes for any water project. It is important to first clearly identify the problem.

What alternative solutions are available?

Available alternative management options should be identified and evaluated. Numerous options may be available, and ground water recharge may or may not be an appropriate solution to the problem. There may be more efficient, effective and less costly alternatives available. However, in some parts of the West,

other water management alternatives may have already been exhausted. Historically, western surface water supplies were developed first, when available, then as needs or circumstances required, ground waters were developed.

Can ground water help solve the problem?

Ground water supplies may offer unique management advantages, and there may be areas where ground water recharge can be used to solve management and supply problems. However, again, ground water recharge, like surface water storage, does not create water. It only allows better management of existing water supplies by storing surface water when excess supplies are available to be recovered during periods of shortage. It may provide an opportunity to conjunctively use existing resources more efficiently and effectively.

Integrated management and conjunctive use of surface and ground water resources may offer significant hydrologic and economic advantages. Moreover, ground water recharge may help address water supply or other management problems without causing serious negative environmental or other effects, or alternatively may provide economic benefits with the least social and environmental costs, compared to alternative projects.

Are ground water resources being mined?

Intensive development of ground water resources throughout many parts of the West has resulted in declining ground water reserves. Withdrawals in excess of natural recharge leads to the "mining" or "overdraft" of ground water resources. Temporarily exceeding safe and sustainable yields may be an efficient and acceptable practice at times to foster a region's optimal economic development, but the long-term adverse effects of ground water mining must be considered and dealt with or eventually the sustainable economic and environmental interests of a region may be impaired.

In authorizing Reclamation's Ground Water Recharge Demonstration Program, Congress recognized the potential value of restoring western ground water reserves depleted by years of mining. Particular concern was expressed over the declining water levels of the extensive Ogallala Aquifer that underlies parts of the High Plains states of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming.

Given declining ground water levels or artesian water pressures, and accompanying water problems, obviously artificial ground water recharge projects may be considered as an appropriate potential solution. Ground water recharge and conjunctive use of ground waters with surface waters provide an opportunity to make efficient use of limited water supplies.

Is enough information available?

Different hydrogeologic, geochemical and other aquifer characteristics, alternatives for supplying and storing water, and local or regional economic conditions (and the resulting effects on the value of water) create varying management problems or issues and determine the utility of ground water recharge as a management option. This type of information is critical for decisionmaking. Is it available?

Where ground water has been developed in the past and water levels are declining, there is a better probability that information on the geology of the aquifer and the quantity and quality of the water will be available to help determine the hydrogeologic and engineering

feasibility of recharge project opportunities. Where ground water resources remain largely undeveloped, a general lack of such information may be a serious obstacle to decisionmaking as it may be difficult to evaluate the feasibility of a recharge project, without incurring substantial costs to gather the needed information.

Is there water available for recharge?

This is often the most limiting factor. The extended drought from the late 1980s through the early 1990s was a serious impediment to the operation of many demonstration program projects. Often opportunities for ground water recharge are circumscribed by the availability of water for recharge, usually surface water resources. Common sources of surface waters include seasonally excess streamflows, any occasional floodwaters, and available treated wastewaters. The project in Hermiston, Oregon is unique in that it would have used shallow ground water to recharge a deep aquifer.

Does state water law address recharge?

Much of our earlier report on recharge opportunities addressed state water law. More and more states have enacted legislation that is specifically designed to facilitate conjunctive use and management of ground water resources and to recognize and encourage recharge. Perhaps one of the most tangible results of the federal demonstration program has been the enactment of such ground water recharge statutes. Prior to establishment of the program few states had addressed some important legal questions related to recharge. For example: Is it a beneficial use of water? Do recharge and recovery activities require a state permit? Does state law protect recharged waters from withdrawal or capture by other parties? Do state water quality protection laws preclude or discourage recharge activities? What is the effect of state (or federal) environmental laws?

Is the project economically efficient?

Economic efficiency, benefit/cost ratios and ground water recharge related costs and benefits are discussed in detail hereafter. However, it may be noted that these considerations are basically the same for any water resource project or management alternative. Also, there are limitations to economic analysis. It may be difficult or impractical to identify, quantify, and compare all of a project's potential costs and benefits. Determining efficiency also involves social and environmental costs and benefits that may not be easily quantified in monetary terms. Therefore, the project alternative with the greatest net monetary benefit may not be the best solution to the problem.

Is the project financially feasible?

Financial feasibility involves the project beneficiaries' willingness and ability to finance and repay direct project costs. This also deals with cost sharing, cost recovery, appropriate federal or other public financing, and related agreements. Project benefits may outweigh costs, and it may be economically efficient, yet it may not be financially feasible.

Is the project otherwise acceptable?

In addition to major economic and financial considerations, a project must also be socially, politically, and environmentally acceptable. Reclamation excluded potentially controversial projects from the demonstration program, but still concerns have been or may be raised over water quality, recharge of wastewater, and water transfers. Also, new projects may require new organizational and operational agreements.

ECONOMIC EFFICIENCY

Reclamation's demonstration program and other examples of the use of ground water recharge in the West illustrate how recharge technology may be an efficient alternative for addressing specific water resource management problems, particularly short-term, emergency and peaking water supply problems. Further, some recharge projects may also demonstrate opportunities to store vast amounts of water, as an alternative to large surface water reservoirs.

What is the value of water? Is a ground water recharge project economically efficient? Simply determining the average cost per acre-foot of water recharged and recovered often does not adequately address the value of the water or a project. When recharge projects are developed to meet emergency drought or peak demands, their costs are properly compared to the alternative costs for otherwise meeting those demands. Similarly, a different type of analysis is used for evaluating the benefits of artificial recharge for stabilizing agricultural irrigation water supplies and rural economies. What are the costs associated with greater pumping lifts, or with not having enough irrigation water to finish the growing season for a crop?

As used in this report, the term "economic efficiency" is meant to describe the efficient allocation of limited resources. It is generally measured and presented in the form of a benefit/cost ratio. A project is economically efficient to the extent that its benefits exceed its costs. However, optimal resource allocation weighs much more than economic benefits and costs, it involves maximizing environmental, social, and any other public and private benefits and minimizing the same types of costs. In other words, economic externalities or third party effects, must be taken into account.

Understandably, strict benefit/cost ratios were not used in the screening and selection of Reclamation's demonstration program projects. Ground water recharge technology is still emerging, and our knowledge is still growing. The demonstration program has expanded our horizons. With respect to program projects, there is usually good information on monetary project costs, which was used to assure that the cost sharing requirements were met, but very little information was compiled on project benefits, and external project costs. As experience with construction and operation of such project grows, so will our knowledge of expected benefits and costs. In the future, we should be able to better identify, quantify and use benefits and costs to calculate benefit/cost ratios and evaluate projects, and thereby better maximize overall economic efficiency.

Most demonstration project sponsors are only concerned with system-wide operational advantages available through the use of the technology, rather than with detailed benefit/ cost ratios and overall economic efficiencies. They focus on the least cost solution to a specific problem, not social and environmental values and other public interests. Therefore, in order to maximize efficient resource allocation, government intervention may be needed. This may take the form of a demonstration program, cost sharing, or grants and loans. In order to help sponsors, as well as federal, state and local governments, better evaluate the extent to which they should financially participate or otherwise promote ground water recharge opportunities, the discussion below addresses a broad range of project benefits and costs and the appropriate use of benefit/cost ratios in decisionmaking.

Benefit/Cost Ratios

In a purely rational decisionmaking model we would reduce all benefits and costs to comparable terms, calculate their present value, identify and examine alternative program or project options (and their benefits and costs), and select the alternative with the greatest benefit/cost ratio. This objective planning approach would ideally identify the best project or non-structural management alternative with the greatest social worth (or as defined herein the most economically efficient alternative). Such an idealistic approach is useful, but there are practical limitations.

In reality, the utility of benefit/cost analysis is limited by the availability of comparable information on project benefits and costs. Many benefits and costs associated with water resource projects cannot be easily identified. Many may not be easily quantifiable or reduced to comparable common units such as monetary terms. There are monetarily measured effects (apples) and there are non-monetarily measured environmental and social impacts (oranges). How do you compare apples and oranges (incommensurates)? Therefore, any benefit/cost ratio should be viewed as a decisionmaking tool to be used with care, skill and judgment.

California provides loans for ground water recharge projects financed with the state's bonding authority. Under its program, projects are initially ranked in order of priority for funding using benefit/cost ratios, which can be adjusted upward by as much as 35% in order to include otherwise excluded secondary effects and other important considerations. Given past experience, benefit/cost ratios are now only one of several considerations used in determining project priority. Further, the weight given the project's benefit/cost ratio has been reduced.

There are different ways to measure efficiency and compare alternative projects besides using benefit/cost ratios. Net benefits is one other way. In designing and economically justifying a project, the objective is to maximize benefits and minimize costs by adding benefits until an additional unit of benefit is equal to its marginal or additional cost, thus maximizing the net benefits. However, this type of analysis is subject to the same practical limitations, based of the availability of comparable information on project benefits and costs. The best project may not have the highest benefit/cost ratio or the greatest net benefits.

Benefit/cost analysis is still an essential step in the decisionmaking process, realizing any measure of economic efficiency is limited by the extent to which all project benefits and costs can be identified, quantified and compared. As used herein, project benefits and costs include all engineering, environmental, financial, legal, political, social and other costs. Many can be described and measured monetarily, but some cannot. Those benefits and costs that can be measured in monetary terms or dollars, called "pecuniary" effects, may be presented quantitatively and compared through means of a benefit/cost ratio, while non-monetary or "intangible" effects require a more subjective or qualitative review.

The following general discussion identifies and considers all benefits and costs: direct and indirect; primary and secondary; monetary and non-monetary; pecuniary and intangible; private and public; federal, state and local; and social opportunity costs. To the fullest extent possible all identifiable benefits and costs, particularly social opportunity costs such as environmental values supported by instream uses, should be carefully considered in analyzing economic efficiency and calculating benefit/cost ratios.

Ground Water Recharge Benefits

Ground water recharge project benefits and project purposes are discussed hereafter under the following categories: water supply, water quality, environmental (including fish and wildlife and recreation) and flood control. These are benefits common to other types of water management alternatives, but recharge projects offer unique opportunities to maximize such benefits. However, there may also be some greater risk associated with the realization of expected benefits from recharge projects due to a lack of experience and greater uncertainty associated with their design, construction and operation (compared to more widely used water management alternatives).

Water Supply Benefits

Water supply benefits are the most obvious reason for utilizing ground water recharge opportunities. Almost all of the current ground water recharge demonstration program projects examined are primarily designed to allow surface water supplies, when available in excess of current demands, to be banked in aquifers for recovery and use later when demands exceed supplies (typically during the summer or drought). Both physical and economic water use efficiency may be substantially increased through conjunctive use of surface and ground waters and artificial enhancement of natural recharge. Seasonal and cyclical differences in available water supplies and water use demands offer opportunities to increase the efficient and effective use of limited western water resources through aquifer storage and recovery projects.

Artificial ground water recharge projects can efficiently and cost effectively improve water supply system flexibility, resiliency and reliability. Flood waters and seasonally surplus waters are frequently used for artificial recharge. Recharge and recovery programs may offer a lower cost alternative than surface water supplies delivered according to a predetermined irrigation or municipal and industrial water delivery schedule under a firm water contract.

For example, in Kern County, California water districts have for many years recharged large quantities of surplus surface waters, when available, for recovery and use to meet peak and seasonal demands. In addition to utilizing local supplies better, water from the California State Water Project and federal Central Valley Project can sometimes be purchased at prices ranging from 25%-50% less than equivalent amounts delivered according to an irrigation demand schedule. The value of the water also increases in response to drought emergencies.

Conjunctive water management can also help avoid the need for development of expensive or otherwise impractical new surface water storage facilities. In many areas, there is a general lack of physically feasible sites for new surface water development and storage projects. The Salt Lake County, Denver Basin and Highline Well Field in Seattle are all demonstration program projects constructed in residential and other areas where topography, geology and a general lack of available undeveloped land make a traditional storage reservoir impractical.

Substantial cost savings can also be realized if already existing surface water storage and distribution systems, wells and water treatment plants can be utilized. Artificial recharge and recovery projects may offer lower capital and operation and maintenance costs than a typical dam and reservoir. Many demonstration program (and other recharge) projects have effectively retrofitted existing on-site wells to allow both recharge and recovery.

Sometimes an aquifer may serve as a substitute for a surface water distribution system, allowing water to be recharged at one location and withdrawn at another perhaps remote location. Arizona water law has been changed a number of times in order to allow the most effective use of recharge by crediting and debiting ground water accounts under a system that allows water to be recharged in one area and withdrawn in another. The amount of the credits and debits corresponds to the distance between the point the water is recharged and the point at which the water is recovered. This type of system-wide flexibility may hold promise in the Denver metropolitan area and other areas.

Ground water recharge can be utilized in the arid areas of the West to substantially reduce evaporative losses related to surface water storage (or virtually eliminate evaporative losses if water is recharged by injection). Such water conservation opportunities may provide important benefits.

Enhancing recharge may also reduce or help avoid problems associated with the dewatering of aquifers and the lowering of water tables, such as aquifer compaction and land subsidence, increasing pumping lifts and energy costs, potential ground water pollution and pollutant migration problems, and the long-term loss of an aquifer as a viable water supply. Such avoided costs may be difficult to quantify, but provide important water supply benefits. To the extent that recharge activities help restore the equilibrium between water supplies and demands, they may thereby help protect valuable existing economies.

For example, cooperative recharge efforts near Hollis, Oklahoma preceded Reclamation's program and were initiated to stabilize ground water levels and maintain the agricultural economy.

Water Quality Benefits

Water quality improvements can be an important benefit of the artificial recharge of surface waters. In some cases, surface water quality is better than native ground water quality. As an example, nitrate levels have declined in response to recharge activities at the York and Wood River projects in Nebraska. The higher quality surface waters help dilute and attenuate ground water pollution problems.

In other areas, ground water recharge projects are specifically designed to protect existing ground water supplies from contamination due to the migration of poorer quality waters, such as salt water intrusion in costal areas. In Orange County, California, wastewater is treated to tertiary levels and injected in a series of wells that create a hydraulic barrier (in gaps in a protective fault) to guard an alluvial fresh water aquifer that extends hundreds of feet below sea level.

Recharge may similarly be used elsewhere to avoid or reverse ground water overdrafting and thereby protect aquifers from the possible encroachment of lower-quality ground waters or possible contamination of existing water wells by checking the advance and spreading of any pollution plumes. Also in Orange County, the potential downward migration of pollutants from a number of hazardous waste cleanup sites has been avoided in part due to artesian water pressure maintained in part as a result of recharge activities.

Environmental and Recreation Benefits

Water quality benefits might be categorized under environmental benefits. However, there are other potential environmental benefits from ground water recharge projects related to open space, wetlands, fish and wildlife, recreation,

and environmental education that can be realized. Such benefits can also be important in building community support for artificial recharge projects. For example, the Upper Big Blue Natural Resources District in Nebraska sponsored the York Project in part due to the projected recreation benefits. Recharge Lake was constructed as part of the project. The reservoir covers some 50-55 surface acres, and impounds about 310 acre-feet of water. A boat ramp, picnic area and visitors display were constructed, along with foot trails along the reservoir. Fish and wildlife habitat were also created and enhanced.

Spreading basins and infiltration ponds create wetlands that may also be managed to provide habitat and other benefits for wildlife. Further, artificial recharge may also directly or indirectly help enhance streamflows. Artificial recharge may at times help preserve and augment instream flows, particularly during drought periods or when season streamflows are low, thereby conserving and protecting fish and wildlife habitat.

In Julesburg, Colorado a small local project, sponsored by an irrigation district with state support, is utilizing winter return-flows and a couple of spreading basins to create a mound of recharged water that moves slowly through an alluvial aquifer to the South Platte River. The primary purpose of the project is to augment late summer ground water supplies and raise water levels, thereby reducing pumping lifts. However, the spreading basins provide habitat for waterfowl and the mound of recharged water eventually reaches and is then discharged to the South Platte River, augmenting late summer streamflows and benefitting wildlife and endangered species downstream.

Wetlands, springs and other riparian areas may similarly benefit from augmentation due to recharge activities. The Snake Plain Aquifer in southeastern Idaho is a good example of how recharge incidental to irrigation has created an artificial hydrologic system. The Snake Plain Aquifer acts as a giant sponge, soaking up excess irrigation water diverted from the Snake River and then discharging it later downriver. Important riparian communities in the Snake River Canyon are now dependent on these discharges from springs in the Snake River Canyon, which support a number of endangered snails and other species.

To the extent that recharge technology may be used to optimize conjunctive use of surface and ground waters, streamflows may be better protected from diversions that might otherwise dewater certain stream stretches during drought or seasonal shortages. With careful planning and design, ground water recharge programs and projects can be operated to provide significant environmental benefits.

Flood Control Benefits

Floodwaters may be used as a source of recharge water using in-channel structures, retention basins, dry wells and injection wells. The diversion of flood waters (and other surface waters) for recharge can be an efficient and very effective resource management alternative, making more surface water storage space available for flood control by transferring storage to ground water aquifers. Flood control benefits from Reclamation's demonstration program projects have mainly been incidental to project sponsors' primary water supply augmentation objectives.

The Rillito Creek project in Tucson, Arizona (sponsored by the Pima County Flood Control District) was designed to capture flood flows, control streambank erosion and recharge the aquifer beneath the bed of the

Santa Cruz River using a diversion structure, sedimentation and recharge basins, and in-channel levees. However, the project was terminated. Studies showed that the frequency of storm events was lower that expected, costs were higher than anticipated, and geophysical constraints limited the amount of water that might be stored at the site. Further, the District was not able to secure credits under state law for the storage and use of the water to be recharged. These factors led to a reevaluation of the project and its flood control and other potential benefits. The project has produced a real-time "ALERT" flood warning system that is in use, and other project information will benefit another recharge project proposed at a site further downstream.

The Blaine-Gypsum recharge project around Hollis, Oklahoma is an agricultural project. It collects agricultural and stormwater runoff for ground water recharge using passive wells and a small impoundment that provides flood control benefits to part of the town. Again, the flood control benefits are incidental to the projects primary purpose, which is augmenting the area's ground water supply and maintaining its agricultural economy.

Ground Water Recharge Costs

All program and project costs may not be easily identified and quantified for comparison in a benefit/cost ratio. However, the major cost components (and some related considerations) are herein categorized and discussed as they relate to a water supply for recharge, water quality, project construction, operation and maintenance, legal and financial costs, and social opportunity costs, including environmental and political costs. Some costs may appropriately fall under more than one category, though they should not be counted twice. It is also important to recognize the role risk plays in estimating project costs for decisionmaking purposes, and a contingency allowance should be made for unforeseen costs.

Water Supply Costs

Securing a supply of water for recharge is one of the most important, if not the most important consideration, for any project. The primary constraint on the efficient and effective use of ground water recharge technology is simply the availability of water (at any price). The price of water or water supply cost includes water purchases or development costs, plus other costs associated with the operation and maintenance of recharge and recovery facilities and operations that are discussed further later.

To the extent that unappropriated waters are not available for artificial recharge (flood flows, seasonal excess streamflows, or treated waste-waters), economic and social opportunity costs can be significant and perhaps prohibitive. With some possible exceptions, ground water recharge projects do not compete successfully for water otherwise in demand for water supply purposes. Rather, it is water that might not otherwise be used directly for traditional purposes that is available for potential recharge. The value of water and the price to be paid for acquiring water for recharge is truly a function of supply and demand.

For example, the Rosedale-Rio Bravo project in California holds water supply and delivery contracts with prices ranging from $2.33 to $45.75 depending on whether the water comes from local, state or federal sources and whether it is a firm water supply or surplus supply delivered as available. Obviously, the availability and price significantly affect the cost of obtaining a water supply for recharge. The value and feasibility of any recharge project similarly depends on its use as a means

to take advantage of dynamic shifts in supply and demand, costs and prices, and facilitate the more efficient use of available capital and water resources.

The cost of obtaining a water supply involves the same type of development, storage, distribution and other costs associated with traditional projects, or the purchase of water for recharge from some entity with available water and facilities. An examination of Reclamation's demonstration program and other non-program projects reveals that in every case the most successful projects are utilizing existing infrastructure -- rehabilitating, retrofitting and adding facilities as needed -- or purchasing water when available from existing water projects.

The cost of water from recharge and recovery projects will always be higher than the cost of directly diverting and using available supplies, utilizing existing facilities. However, as noted above, the value of recharge projects is largely as an alternative means of storing otherwise surplus supplies, for recovery later. Of course, in calculating water supply costs, the fact that some recharged water may not be recoverable, must also be taken into account.

Water Treatment

Water treatment costs are particularly important. Many recharge projects are designed as part of a public water supply system. Both Seattle's Highline well field and the southeast Salt Lake County project use injection wells to recharge aquifers that are a source of drinking water. There can be substantial costs associated with treating the water to drinking water standards prior to injection. The York project abandoned attempts to demonstrate alternative cost effective water treatment methods for removing nitrates (for possible use by small rural communities) at its injection well because it could not consistently meet drinking water standards that require total elimination of all coliform bacteria colonies. The costs of meeting state and federal drinking water protection requirements, and specifically complying with the Safe Drinking Water Act's Underground Injection Control (UIC) Program requirements, are vital considerations.

Water Quality

Any risk of degradation of ambient ground water quality, given the costs of remediation, must be carefully considered and weighed appropriately in estimating project costs. Such costs might easily overwhelm any benefits from recharge, and as a result Reclamation and the Environmental Protection Agency entered into a memorandum of agreement to carefully monitor program projects and ensure any risks were acceptable. Essentially, the initial project screening process eliminated any questionable proposals from an environmental view point. Moreover, extensive and intensive water quality monitoring has been required during design, construction, and operation of program projects.

With few exceptions, potential water quality problems and related costs have not been a major obstacle to demonstration program project implementation. An unusual storm event and related runoff contaminated with atrazine initially raised concerns with the York project, but they were resolved. Monitoring costs imposed under the EPA/Reclamation agreement to avoid the possible degradation of ambient ground water quality have been substantial and perhaps excessive, in retrospect, given the lack of serious long term water quality problems with program projects. Non-program projects have been successful with less stringent and less expensive water quality monitoring requirements.

Of note, two proposed projects on the plains of eastern Colorado withdrew from the program due to the projected cost of water quality monitoring requirements, and the cost of other projects was increased greatly and very possibly disproportionately, given the relative risk. It would appear that reasonable risk and related appropriate monitoring costs will continue to be debated in the future as more ground water recharge projects are proposed.

Construction, Operation and Maintenance

Construction costs include all costs associated with developing the facilities and structures necessary for the delivery of water from the source to the recharge site, recharge, withdrawal, and delivery of recovered water to project customers or beneficiaries. Such costs also include purchases of land and easements.

Other costs include the operation and maintenance and repair associated with project facilities. Typical costs incurred will include the cost of pumping water; maintenance and repair of wells, pumps, delivery and storage and other operating systems; unclogging and other maintenance of injection and monitoring wells; and periodic cleaning to avoid the sealing of recharge basins/pits/ditches due to silting.

Legal and Financial

Legal and financial costs are incurred for: (1) securing water rights; (2) record keeping; (3) acquiring land and rights-of-way; (4) obtaining permits and other documents to recharge and recover water; (5) data collection and other work involved in meeting Federal, State, and other governmental requirements for environmental compliance; (6) resolving issues of uncertainty about legal requirements and liability; and (7) financing costs, including underwriting and marketing costs.

Environmental and Social Opportunity Costs

These costs can be divided into two categories. The first category is the opportunity cost of capital. This cost is reflected by the use of funds for a given artificial recharge and recovery project that otherwise could have been spent for alternative activities that benefit the community. The opportunity cost of capital merely reflects the fact that limited resources are available for public and private projects and care must be taken to maximize benefits.

The second category of social opportunity costs captures project effects that are not reflected by market transactions and cannot be measured as monetary economic effects. For example, this may include impacts on instream uses of water for recreation, aesthetic values, fish and wildlife, endangered species, or wetlands. There are some techniques that allow estimation of the cost of such environmental effects, but they are imperfect and expensive to use. It is often not practical to carefully estimate such costs because of a general lack of information about the effects that artificial recharge may have on environmental resources.

The High Plains Demonstration Program's screening process and "pilot scale" projects, helped avoid significant environmental costs. However, environmental and other social costs must be considered in evaluating the feasibility of future recharge projects. To some extent, by means of state and federal law, such costs have been institutionalized. For example, compliance with environmental statutes, rules, regulations and guidance help protect water quality, fish and wildlife, and wetlands. Environmental and other values have been incorporated in legislation as a means to protect public resources that might not otherwise be preserved, given the failure of a free market system to equitably account for such values.

FINANCIAL FEASIBILITY

It is important to note that economic efficiency and financial feasibility are not the same. Economic efficiency is measured using benefit/cost analysis. Financial feasibility is determined by project beneficiaries' ability and willingness to finance and pay for a project. While a project may have a benefit/cost ratio that is greater than one, and is thereby by definition economically efficient, it is possible that the beneficiaries may be either unwilling or unable to finance and repay project costs. Therefore, a project may be economically efficient, but not financially feasible.

A discussion of access to financial markets and provisions of financial arrangements are beyond the scope of this report, and this section focuses on principles for evaluating appropriate government participation in cost sharing and financing agreements for ground water recharge projects, or any other water development project. With the completion of Reclamation's demonstration program, there appears to be no reason to treat ground water recharge differently from any other water management project when evaluating possible federal participation.

It should be noted that at this point in time Reclamation's demonstration program cannot be carefully evaluated using benefit/cost analysis. This has truly been a demonstration program, and there is still insufficient information available to carefully weigh project costs and benefits, particularly benefits. Moreover, financial feasibility has been determined by the project sponsors' willingness to pay at least the required 20% non-federal cost share under the program. Cost sharing requirements were set by the authorizing legislation and are an arbitrary political estimate of the value of the program.

The table on the next page is a summary of project costs and cost sharing. Appropriate future financing, cost sharing and cost recovery agreements should be carefully tailored, with government participation, to conform to sound principles of efficiency and equity.

Ideally, all project benefits and costs could be reduced to comparable monetary terms and a benefit/cost ratio would then represent an all inclusive measure of value. Next, those that benefit from a project would be identified and allocated an appropriate share of the project costs. Financing and cost recovery agreements would then be negotiated. Realistically, all project costs, benefits and beneficiaries may not be readily identifiable. Moreover, many beneficiaries may not be willing or able to finance or repay their fair share of project costs. Therefore, a purely rational decisionmaking model becomes unworkable and benefit/cost ratios, as well as cost sharing and financing agreements become tools to be crafted and used with care and judgement.

Without generous federal financial support, many of the demonstration program projects would not have been built at this time. Even with an 80% federal cost share, some project sponsors were either not willing or were unable to pay 20% of the project costs. This appears to be due in part to the cost of extensive water quality monitoring and other requirements that were imposed under the federal demonstration program and different interagency agreements that do not apply to non-federal, non-program ground water recharge projects.

For example, as already noted, two proposed projects to demonstrate the recharge of water on eastern Colorado's high plains from

Summary of Demonstration Program Project Costs

Project	Start year	Total cost	Federal cost	Non-Federal cost	Sponsor cost share
		------ Thousand dollars ------			
Rillito Creek, AZ	1991	$4,836	$1,445	$3,391	70 %
Denver Basin, CO	1991	3,301	1,944	1,357	41
SW Irrigation, ID	1992	3,402	2,643	759	22
Equus Beds, KS	1995	6,400	3,200	3,200	50
Turner-Hogeland, MT	1990	603	483	121	20
Wood River, NE	1991	1,424	1,139	285	20
York, NE	1989	2,183	1,689	492	20
Washoe, NV	1990	1,775	1,420	355	20
Blaine-Gypsum, OK	1990	2,134	1,707	427	20
Hermiston, OR	1989	2,876	2,301	575	20
Huron, SD	1990	1,711	1,368	343	20
Hueco Bolson, TX	1989	632	501	131	21
Southeast Salt Lake, UT	1990	3,130	1,622	1,508	48
Highline, WA	1989	2,320	1,856	464	20
Total project costs		$36,727	$27,318	$13,408	36 % average

Source: United States Department of the Interior, Bureau of Reclamation, *High Plains States Groundwater Demonstration Program, Interim Report*, October 1997.

ephemeral streams, the Plains-Arikaree and Frenchman projects, were initially selected with the state as the sponsor. However, Colorado dropped its support for the projects primarily due to the proposed water quality monitoring requirements and related costs, which were more comprehensive than originally envisioned and in the state's view, unnecessary.

Project costs and benefits, and participants willingness to pay, are dynamic factors. Therefore, financial feasibility requires periodic reevaluation in view of changing circumstances. The City of Hermiston, Oregon sponsored a project to demonstrate the use of shallow ground water resources to recharge a deep aquifer that is the source of the city's well water. Production from one well had already been lost. Maintaining production from these wells was an important part of the City's future water supply plans. By using their deep wells as a source of water to met peak summer demands, a long planned diversion from the Columbia River and related distribution system could be downsized to save money. However, the initial injection well selected for recharge was later found to be unusable, water quality monitoring costs increased, and the recharge permit required by the state required that water recharged from the shallow aquifer not contain organic and volatile organic compounds. As a result, project costs escalated beyond estimates and the city decided to terminate the project.

As a result of the increased costs imposed as part of the demonstration program and the high federal cost share, an analysis of Reclamation's projects alone cannot present a clear picture of the feasibility of ground water recharge as a future water management alternative. Many non-program projects sponsored by both private and public entities have long been operated successfully without federal financing and cost sharing, as well as many of the restrictions and other requirements imposed under the federal demonstration program. In the future, given the experience and knowledge gained from the demonstration program and other projects, some costs might be eliminated and cost sharing percentages revised.

Cost Sharing and Cost Recovery

Simple common sense and economic theory agree that to promote efficiency and equity, project beneficiaries should pay project costs. However, this is "easier said than done." Identifying and quantifying private and public benefits and costs is just the beginning. The next step is to try and determine the incidence and distribution of project benefits (and external costs) among beneficiaries. This is essential to the design of appropriate cost sharing and cost recovery agreements. However, given many projects will have many diverse beneficiaries, allocating project costs could be difficult. Reclamation's demonstration program may provide only limited insight as most projects involved but one sponsor and the federal government. In the future, more complex cost sharing agreements between multiple beneficiaries will likely be necessary to ensure the financial feasibility of projects.

Next, cost recovery mechanisms must be considered. This involves establishing access to a source of revenue as the basis for financing a project. Again, project beneficiaries must be willing and able to bear their fair share of the cost burden. Government participation in cost recovery may be necessary and desirable. For example, recovering project costs from all the beneficiaries directly may not be practical. The administrative costs associated with recovering small amounts of money from numerous and diverse beneficiaries might be too high, or it might not be possible to exclude an individual or group from receiving project benefits, even

if they don't pay. In such cases, government participation may be needed to help correct market failures and take responsibility for recovering costs from beneficiaries using specific taxing powers.

After cost sharing agreements have been negotiated and cost recovery mechanisms established, other complex details of financial arrangements can be addressed. Again, the nature of financial markets is beyond the scope of this report, but the beneficiaries must be able to finance or obtain private or public financing for the project. Again, governments' broad taxing and spending authorities might be put to use to maximize economic efficiency and ensure a project's financial feasibility.

Reclamation's demonstration program and a review of other non-program projects has provided numerous examples of the importance of understanding the nature of project costs and benefits and addressing the interaction between beneficiaries and others if future cost sharing, cost recovery and financing agreements for ground water recharge projects are to be successfully executed.

For example, it's fair to say that without Reclamation's federal demonstration program and financial support, the Southwest Salt Lake County project would not have been built at this time. The Salt Lake County Water Conservancy District, the City of Sandy's, municipal water system, and the White City Water Company, a private purveyor, all serve intermingled parts of the southeast portion of the Salt Lake Valley in Utah. The southeast project was envisioned as a cooperative proposal, but Sandy and White City both dropped out early, leaving the District alone to sponsor the project. It involves injecting water treated to drinking water standards into an unconfined aquifer, and later recovering water to meet peak demands. However, any water exiting the parameters of the project might be captured by the other entities' wells, providing uncompensated benefits. At the time, Utah water law provided no explicit means of protecting recharged waters. Such tremendous uncertainty and lack of agreement between beneficiaries could be a major obstacle to a project's financial feasibility.

In addition to project benefits accruing to third parties, there may be problems due to external project costs borne by third parties, both public and private, that need to be taken into account and resolved. For example, alarms were raised following an unusual storm event that coincided with landowners' application of the pesticide atrazine to corn fields in the watershed above the York Project's Recharge Lake in Nebraska. Fearing contamination of domestic water wells in the area, EPA suggested breaching the dam, while the project sponsor, the Upper Big Blue Natural Resources District offered to provide bottled water to any household unable to use any drinking water well that might possibly be contaminated by recharge activities. Luckily, no atrazine was detected in the lower aquifer, nor any domestic wells near the project, but the event shows that external costs may affect financial feasibility.

The York project also illustrates that, to a large extent, many previously external economic project costs have actually been effectively internalized by the application of environmental law and other regulations (and the possible threat of lawsuits for damages).

In California, the Kern County Water Authority represents a number of water districts providing water for agricultural and municipal use around Bakersfield. The authority finances and shares the cost of the acquisition and underground storage of both local and imported

water supplies. It has an effective and unique arrangement to recover program costs. The authority is divided into a number of "zones of benefit," within which assessments vary, tailoring costs to benefits. Similar government participation may be appropriate elsewhere as a means of financing and recovering project costs from beneficiaries using specific taxing powers.

Given these and other examples from the case studies, it is easy to recognize that successful agreements must be carefully crafted through negotiations with multiple parties, and government participation, broadly defined, may often be appropriate.

Ideally, the lowest level of government capable of achieving the desired objectives should usually be responsible for project financing, cost sharing and cost recovery. This could mean the use of a special service district or similar entity or governmental agency, such as the Kern County Water Agency, or participation by cities and towns, counties, states and finally the federal government.

Government Participation

Government participation may be most appropriate and even necessary as a means of maximizing economic efficiency and equity and ensuring cost recovery and financial feasibility. With respect to ground water recharge projects and programs (as well as any other water management related projects and programs), there may be a number of circumstances that warrant some type of government participation. The following six general principles provide a simplified guide for participation:

(1) The government is a direct or indirect beneficiary of the project or program.

(2) The government is in the best position to finance and recover costs associated with direct project benefits.

(3) The government is in the best position to finance and recover, or bear, costs associated with indirect project benefits.

(4) The project or programs meets government goals and objectives.

(5) The government has created or established some right served by the project or program.

(6) The government has previously made some commitment or promise.

The federal government may often benefit directly from artificial ground water recharge when there are benefits for federal irrigation projects, endangered species, water quality, wetlands and other national interests and objectives. None of the demonstration program projects were primarily designed to produce direct federal benefits, but some address federal interests. For example, the Wood River Project in Nebraska provides a water supply for an artificial wetland that was designed to create habitat for the endangered whooping crane.

A number of non-program projects utilize federal surface water projects as their source of supply for recharge, and the conjunctive management and operation of surface and ground water resources and projects will be even more important in the future. For example, ground water recharge and aquifer storage and recovery activities in Arizona and Nevada are utilizing federal facilities on the Colorado River and the Central Arizona Project to maximize the beneficial use of their surface water allocations in the face of increasingly scarce supplies, given continuing high growth. On a smaller scale, ground water recharge may

be used in the future to increase the reliability of federal project yields.

The construction and operation of many projects may also produce significant indirect federal benefits. For example, the Lower South Platte Water Conservancy District operates a small project near the town of Julesburg, Colorado. Constructed with state financial aid, it is designed to use winter irrigation return flows to raise ground water tables near the river and reduce pumping costs for irrigation. However, by recharging water through spreading basins on the upper edge of the alluvium of the South Platte River, the project creates an underground wave or plume of water that slowly moves down gradient and whatever additional water that is not intercepted by the pumps is eventually discharged into the South Platte River, augmenting later summer streamflows and thereby helping ameliorate interstate problems downstream that are related to low flows.

Government financing may be appropriate to promote economic efficiency even though the project may not directly or indirectly benefit the government. However, such projects should not be subsidized, so as not to encourage inefficient or inequitable resource use. Rather, the government might finance a project's capital costs, but ensure it is repaid with interest at its cost of borrowing. The federal demonstration program was financed using general appropriations. State and local financing can be accomplished using general fund appropriations, general obligation bonds, revenue bonds, or special funds.

California uses general obligation bonds to provide financial assistance for ground water recharge projects. While this is the only specific state-finance recharge program, most western states help finance water development projects and various programs might be used to allow a state to finance and share the costs.

The federal government sponsored the High Plains Program projects to meet the perceived need for demonstrating ground water recharge technologies over a variety of different geographic regions and because of other factors. The demonstration program investment was intended to result in a number of practical research and demonstration benefits related to project construction, operation and maintenance. These include expanding and applying our knowledge of engineering, hydrogeology, and geochemistry as they relate to ground water and ground water recharge. Further, many other questions with respect to environmental, institutional, legal, political, and social issues have necessarily been addressed. The lessons learned from this demonstration program have already and will in the future help facilitate the appropriate use of ground water recharge as an alternative management solution to many water problems in the western United States.

The federal government has recognized or created a right of access to safe drinking water by enacting specific legislation. Most of the more successful demonstration program projects and many non-program projects are specifically designed to ensure the reliability of safe municipal drinking water systems, and as such help assure such rights are protected. Moreover, recharge projects may benefit from recent amendment of the federal Safe Drinking Water Act to provide financial assistance through state revolving funds.

Where government has previously made some commitment or promise, principles of equity dictate the government should fulfill such obligations. Conceivably, the conjunctive management of federally developed surface

water supplies and ground waters could serve as a possible means of fulfilling federal trust responsibilities and/or other commitments with respect to securing water to satisfy Indian water rights, interstate compact agreements and environmental needs, etc.

Arizona, Nevada and California already use ground water recharge as an important water management option. In the Lower Colorado River Basin, extended discussions involve marketing water on an interstate basis using water banking and ground water recharge as potential means of addressing growing demands on the use of limited surface water resources. Reclamation and western states are searching for answers to many related, complex water management problems. Ground water recharge projects and programs will very likely be a very important part of many solutions.

Federal Participation

Federal participation in water projects has been evaluated and justified in the past based on certain specific principles and standards or guidelines for analyzing benefits and costs that have been categorized under four separate accounts: national economic development (NED); environmental quality (EQ); regional development (RD); and social well-being (SWB). With respect to future federal investments in ground water recharge projects and programs, the previous discussion helps illustrate the possible application of other similar and consistent criteria, for appropriate federal financial participation, based on principles of efficiency and equity.

In years past, emphasis was placed on maximizing NED benefits when justifying federal participation. Other effects were not ignored, recognizing that the project with the maximum national economic benefit might not be the best alternative solution to a specific problem. However, in recent years, growing emphasis has been placed on partnerships and greater non-federal cost sharing. Often, federal project participation now involves serious negotiations over all aspects of new projects, from design to construction to cost sharing and financing. Again, financial feasibility is being determined more and more by a non-federal sponsors' willingness to pay a larger share of federal project costs, with less emphasis placed on NED benefits.

Regional Benefits

Ground water recharge facilities produce tangible regional benefits as a result of federal expenditures for construction and operation and maintenance. While such benefits may help justify federal participation, often they may only represent a federal transfer of wealth from one region to another, with no net NED benefit.

The Bureau of Reclamation has computed input-output multipliers for the seventeen western states, specifically related to water supply project expenditures, using multipliers generated by the Bureau of Economic Analysis, U.S. Department of Commerce, and the RIMS II, series A-1 input-output multiplier tables. The multipliers encompass the states of Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming. These can be used for estimating the employment and earnings generated by the federal expenditures on recharge projects.

The following general multipliers are suitable for estimating the average impact of expenditures within Reclamation's seventeen-state region. Considerable variation exists between locations.

Earnings and Employment Multipliers
Input-Output Multipliers
(per million dollars in expenditures)

Construction

	Direct	Indirect	Total
Earnings	.2420	.5800	.8220
Employment	7.0	24.9	31.9

Operation, Maintenance and Replacement

	Direct	Indirect	Total
Earnings	.4200	.4083	.8283
Employment	14.3	18.7	33.0

Regional Earnings and Employment Benefits

Construction Expenditures	$13,368,000
* Total Earnings Multiplier	.8220
	$10,988,496
Operation & Maintenance	$ 4,456,000
*Total Earnings Multiplier	.8283
	$ 3,690,905
Total Household Earnings	**$14,679,401**
Construction Expenditures	$13,368,000
*Employment Multiplier	31.9
Total Person-years Employed	
Operation & Maintenance	$ 4,456,000
*Employment Multiplier	33.0
Total Person-years Employed	
Total Employment	**573**

Reference: Bureau of Reclamation, 1992. Memorandum, December 17, 1992, "Input-Output Multipliers for 17 Western States," Acting Chief, Economics Branch, Assistant Commissioner-Resource Management, Bureau of Reclamation.

County-level multipliers could be used to estimate any local/county economic effects of federal expenditures on individual projects, but they are prohibitively expensive to develop.

To illustrate the meaning of the regional multipliers, federal construction expenditures of $1 million would generate $242,000 in direct household earnings and $580,000 in indirect household earnings, for a total regional benefit of $822,000. The same expenditure would result in seven person-years of direct employment and 24.9 person-years of indirect employment, for a total of 31.9 person-years of employment.

Further analysis provides an estimate of the aggregate economic effects that the High Plains program has had on the region's economy. This includes an expenditures of approximately $27.3 million for the thirteen projects that are completed or are to be completed (1989-94 nominal dollars). Federal expenditures total $17.8 million. As illustrated above, the total regional benefits from federal expenditures for construction and operation and maintenance of recharge program projects is equal to the sum of the products of those expenditures times the appropriate multipliers. The total multiplier effects for construction expenditures and operation and maintenance are about the same (.82 and .83 for earnings, and 32 and 33 for employment). The difference means little for purposes of estimating total regional benefits,

but based on available data, 75 percent of federal expenditures are estimated to be for construction ($13,368,000) and the remainder on operation and maintenance ($4,456,000).

Federal funding of High Plains projects was crucial to their implementation, with a couple of exceptions, and it was assumed that federal expenditures were used for either construction or operation and maintenance. For projects where data are available, construction expenditures ranged from less than 20 percent to over 60 percent of total project costs. Operation and maintenance expenditures range from about 10 percent to more than half of total project costs.

High Plains Program expenditures by the federal government on artificial recharge and recovery projects amounted to $17.8 million spent in local economies. Based on the above estimates, those expenditures by the federal government produced benefits worth nearly $15 million and 573 person-years of employment to households in those areas. Additional benefits to local economies from this increased income and employment include additional income and sales tax revenue, retail and wholesale spending, and increased inputs and outputs in other sectors of the regional economy.

Artificial recharge must be an integral part of comprehensive water management. Costs and other effects of recharge must be weighed against alternative uses of public monies and alternatives for providing water to users. Sometimes ground water recharge can be an interim solution to a long-term water supply problem, but its use could be limited as a long-term solution due to the cost and availability of surface water supplies to recharge aquifers in areas that are experiencing increased growth and accompanying increased demand for those surface water supplies as well as existing ground water supplies. As an example, the Washoe County project facilities in Nevada stood idle and underused for an extended period of time when there was no water available to be withdrawn from the Truckee River. However, many ground water recharge projects will be financially feasible and particularly valuable as part of a comprehensive water management program that also includes water conservation, public education, development of new surface and ground water supplies, and other activities in concert with ground water recharge.

LEGAL AND INSTITUTIONAL ISSUES

There are a number of complex legal and institutional issues that have been addressed as part of Reclamation's demonstration program, which has helped advance our understanding of recharge as a water management option, over geographically and geologically diverse areas. Again, while simple recharge technology has been practiced for over a century in southern California and elsewhere in the Southwest, the demonstration program has greatly increased the extent and range of its use. Similarly, more and more complex legal and institutional concerns have arisen.

In the Los Angeles basin in the 1800s, the diversion of local streams to spreading basins and recharge pits or the use of instream structures to enhance natural recharge probably raised few if any concerns. It would likely have been seen as not much different from diversions for irrigation under the appropriation doctrine. However, today, any proposed project faces an extensive array of required reviews and permits. Many focus on state water law and state and federal environmental protection laws.

The City of Seattle's Highline Well Field Project has demonstrated that even in the relatively water-rich Northwest, ground water recharge can be a valuable management tool. Seattle uses injection wells to recharge, store and recover treated drinking water from local surface water sources. By augmenting local ground water supplies, Seattle can meet peak summer demands without more costly capital improvements to increase the capacity of its surface water delivery system. This is perhaps one of the least controversial of all the demonstration program projects (as no serious legal and institutional issues were raised), but such aggressive use of ground water recharge as a management option opens up many new concerns related to protection of drinking water quality, wellhead protection, and the diversion of water from instream uses for recharge, etc.

The demonstration program has forced project proponents and governments to address many more such complex institutional and legal issues. Perhaps one of the most significant program benefits will be the legal and institutional changes that have taken place to facilitate development of current and future ground water recharge opportunities.

However, not all the issues that have been raised have been resolved. Many states have only recently enacted specific legislation or adopted rules and regulations to govern ground water recharge and recovery activities. Moreover, the application of state and federal law, particularly state water laws and federal environmental laws, will continue to be refined as the use of ground water recharge grows.

State Water Law

State water laws and administrative policies are changing in order to accommodate recharge activities, and Reclamation's demonstration program has helped expedite these changes. For the first time, some states have been forced to consider how they would handle regulation of recharge and recovery activities. In response to an earlier survey of state ground water law, under Part I of this study (October 1990), some states developed new administrative policies and procedures for the approval of recharge projects.

Arizona has the most comprehensive recharge, storage and recovery statutes in the West. Other states have also enacted legislation specifically addressing ground water recharge, including Idaho, Nevada, Oregon and Utah.

Utah law did not define and protect a right to recover recharged water until after the Southwest Salt Lake County project was begun. Other states, particularly California, have promoted ground water recharge opportunities within the context of existing surface and ground water codes.

Western states' primary concerns with respect to ground water recharge focus on the allocation, use and potential waste of surface waters and the possible degradation of ground water quality. In many cases, resolving legal and institutional questions and concerns may be the primary constraint or obstacle to the successful construction and operation of a proposed project.

Again, any project must first secure a supply of water for recharge. Every western state regulates the appropriation and use of surface water and most regulate ground water use. In reviewing any request to appropriate water for recharge, the first questions a state water rights administrator will ask are: Is there water available for recharge, and is the proposed use a beneficial use of water?

Surplus water in the West is scarce! While recharge and recovery activities hold promise for providing greater opportunities for more efficient use, competing demands for a limited resource forces states to carefully evaluate any new proposed use. Demonstration program projects have been able to identify and secure a state water right to utilize different types of surplus waters, including seasonally surplus streamflows, treated wastewater, floodwaters and tailwaters, and even shallow ground water.

Unfortunately, in some instances there may not be unappropriated water available for recharge. Rights to the use of water in the West are based on first use or seniority, but even a water right is no guarantee. The Washoe County Project in Nevada leased or transferred rights sufficient on paper for project purposes, but drought dried up the source of supply, the Truckee River, and delayed the testing and operation of project facilities for two years.

Ground Water Recharge Laws

Reclamation's demonstration program has forced some states to consider for the first time whether or not ground water recharge, or the recovery and reuse of recharged waters, is a beneficial use. Some states have specific statutes defining recharge to be a beneficial use, while others administratively recognize the recharge and recovery of water for a specific use as beneficial under existing water codes. A related question that involves legal concerns with respect to prohibitions on wasting water is: How much recharged water can be recovered?

Some recharged water may be irrecoverably lost and unavailable for future recovery and use. Given the lack of knowledge and possible geologic uncertainties associated with many if not most aquifers, as well as any consumptive operational requirements or inefficiencies, state water right administrators must consider such losses. Typical losses include evaporation from spreading and infiltration basins, ponds and pits, backflushing injection wells as part of routine maintenance procedures, and deep percolation or migration of recharged waters beyond the reach of recovery wells.

Quantifying and evaluating such losses is a problem for state water rights administration and management agencies. Evaporative and other operational losses can be relatively easily estimated. However, calculating losses due to deep percolation or migration is much more difficult. The most practical administrative

approach seems to be to limit recovery to a specified amount of the water recharged. Percentages fluctuate between states and range from recovery of 80% to 100% of the amount of water recharged.

Arizona has a fairly complex accounting system with recharge credits and debits that take into account where and when the water is recharged and recovered. State law limits the amount withdrawn accordingly and dedicates a percentage of the water recharged to the long-term restoration of depleted water tables.

Another related legal question involves the intermingling of recharged surface waters with native ground waters. Recharged waters may be inseparable from native ground waters. It may also be difficult or prohibitively expensive to distinguish or mark and trace the migration and recovery of recharged waters. In Utah, it is assumed that any water recovered is the same water that was recharged. Actually, this may or may not be the case, but where waters and water rights are intermingled, this appears to be the most practical administrative solution to an otherwise problematic issue.

The Southwest Salt Lake County project tried to use naturally occurring isotopes in the surface water injectate for determining flow paths and "fingerprinting" the water. The results were disappointing. Dye tracer tests were rejected as undiluted dye might reach municipal water wells. Five natural inorganic constituents were tested as potential tracers with varying success. Sulfate and fluoride were feasible indicators. A study of major ions was also conducted. The studies found the injected surface waters mixed well with the native ground water and even after recovery of 200% of the amount of water injected, the recovered water still showed surface water characteristics. Therefore, the waters may be indistinguishable.

As recharge activities may affect the exercise of numerous rights of different entities over either a relatively small or an extended geographic area, it is very important to clearly define administrative procedures for accounting for the recharge, storage and recovery and reuse of the water. Given the practical difficulty in accounting for specific waters, the focus should be on the amounts and not the actual waters.

In southeast Salt Lake County, the conservancy district holds rights to the use of local native ground water resources, in addition to its recharge and recovery permit, allowing greater operational flexibility. The district may choose to withdraw more ground water than its recharge and recovery permit would otherwise allow, using its rights to native ground water.

When and where the recharged water may be recovered is another legal question. The Denver Basin Project in Colorado, sponsored by the Willows Water District, forced the state of Colorado to address these issues. The District was totally dependent on ground water pumped from a deep aquifer with insignificant natural recharge and growing municipal uses. As the ground water is considered nonrenewable, any use is mining that would eventually lead to depletion of the resource and possible economic dislocation. Recharge is a feasible solution.

The Denver Water Department holds surface water rights on the South Platte River, and during the winter has unused treatment capacity available. It provides potable surface water for recharge by the District, which has been operating a 1,500-foot-deep injection and recovery well since March 1992. Under an agreement between the two agencies, the District pays for the water when it is withdrawn rather than recharged. Separately, a new agreement also provides the District with treated surface water for direct use.

Colorado water law addresses ground water recharge and requires a permit for beneficial use of injected water. It allows the recovery or "remote extraction" of 100% of the water recharged from within a five-mile radius of the injection well. The District may bank water for up to five years and may withdraw up to that amount of water in any one year if needed. These limitations were imposed in order to protect interrelated ground water rights held by other entities, while still allowing ground water recharge project operators some flexibility.

However, given the confined nature of this aquifer, which has been described as a huge bathtub, it might be possible and even desirable to allow the withdrawal of recharged water from more remote locations. While state law has yet to authorize and approve any such arrangement (and none has yet been proposed), it is conceivable water could be recharged, banked underground, marketed and later recovered or withdrawn elsewhere in the Denver Basin using the aquifer as a readily available storage and distribution system. Any potential or perceived injury to other parties would be a major obstacle to such a proposal.

Further, similar aquifer storage and recovery projects might serve as an acceptable alternative to the construction of more surface water storage reservoirs as a means to meet the metropolitan Denver area's growing water needs. The environmental impacts could be substantially smaller and more acceptable than past surface water storage proposals such as the extremely controversial Two Forks dam and reservoir project vetoed by the Environmental Protection Agency.

In Arizona, credits for water recharged in one part of the metropolitan Phoenix area may be debited when withdrawn elsewhere, perhaps across the valley. Water recharged near Gilbert on the east might be credited against withdrawals or debits near Sun City, over 30 miles to the west. However, there may not be any clear hydrogeologic connection between the recharge and withdrawals, and this has lead to some concern and debate over whether or not the current state ground water accounting laws and policies may therefore actually encourage continued mining in some areas, contrary to safe yield management goals.

For future ground water recharge projects to be successful, such legal and institutional issues should be clearly defined and addressed. Some states may need to redefine beneficial use to include recharge and recover and adapt their administrative rules, regulations and procedures accordingly. Some states may need to enact specific legislation to address and encourage ground water recharge. Each state should examine its own legal and institutional systems to ensure they adequately address ground water recharge. Some states may not yet have found there is sufficient interest in ground water recharge projects to merit any major changes to existing laws, but as interest continues to grow and more projects are proposed, these states will also need to further refine their existing laws and policies.

Ground Water Quality Protection

Protecting ground water quality is primarily a state responsibility, and EPA has little or no regulatory authority to address problems and require remedies. Ground water is a very important and often an irreplaceable resource. Ground water may be a community's sole source of drinking water, or it may be vital to the continuing maintenance and growth of an area's economy. Every western state has some strategy for the protection of ground water, and any possible degradation is a major concern that

must be addressed with respect to ground water recharge projects.

Sources of possible contamination vary and need to be identified as part of a comprehensive protection program. Different uses of land and surface waters can threaten ground water quality and are regulated by states. Unregulated activities can also affect ground water recharge projects. As mentioned earlier, non-point source pollution due to the use of atrazine on corn fields threatened the York Project in Nebraska. While of particular concern as part of this demonstration project and program, similar potential contamination problems could be found in hundreds of other natural and man-made impounds throughout Nebraska and similar plains states. Other possible threats to ground water quality, due to agricultural runoff, may be found as a result of the use of other pesticides, fertilizers and herbicides. Without careful attention, ground water recharge projects could increase the potential for serious contamination.

In this particular instance, given the cooperative agreement between the federal Environmental Protection Agency and Bureau of Reclamation, the demonstration project could have and might have been stopped had the problem not been the result of an isolated incident that has not been repeated. Also, no contamination of off-site domestic water wells was found.

State and local governments are primarily responsible for the control of agricultural non-point source pollution in general and ground water in particular. Indeed, the Upper Big Blue Natural Resources District is a political sub-division of the state of Nebraska charged with addressing rural water quality problems. Part of the reason for their demonstration project was to demonstrate potential alternative treatment methods for ground water with high nitrate levels, due to the agricultural use of fertilizers. Further, project results show that nitrate levels in ground waters surrounding the project have gone down. This can be attributed at least in part to the recharge of better quality waters.

Another problem related to water quality is the lack of reliable real-time monitoring technologies, which has raised concern among project managers and state and local officials. For example, the Salt Lake County Water Conservancy District's Southeast Project uses water from a local treatment plant, but also takes raw water directly from an underground aqueduct and treats it on-site prior to injection. It uses both a standard coagulation, filtration and disinfection process and a back-up ultraviolet system. The raw water supply is a diversion on the Provo River, which winds through a narrow canyon with an adjacent two-way road that supports heavy truck traffic. Any accidental unreported spill of petrochemicals or other compounds could contaminate the water and if undetected by periodic grab sampling, could be directly injected into the aquifer, causing serious problems. This scenario points out the need for both improvements in continuous monitoring capabilities and adequate plans for emergency management and notification in case of a spill threatening water supplies.

Federal Environmental Laws

A number of federal environmental statutes may be applied to protect ground water quality and other values. These include the federal Safe Drinking Water Act, the Clean Water Act, the National Environmental Policy Act, and the Endangered Species Act. These may serve as either an aide or an impediment to the future use of ground water recharge.

Safe Drinking Water Act

There are a number of programs and regulatory actions taken under the authority of the Safe Drinking Water Act (SDWA) that might apply to ground water recharge activities. Many states have assumed primary regulatory and enforcement authority. SDWA standards are used for measuring water quality and ensuring supplies are suitable for potable uses. Maximum contaminant levels (MCLs) have been set for scores of possible contaminants, and these have been used to evaluate the impact of demonstration projects on ground water quality. Both injection wells and spreading basins could serve as conduits for contamination.

Injection wells require a permit under the SDWA's Underground Injection Control program, which was primarily designed to protect ground water from contamination related to the disposal of hazardous wastes by deep well injection. There are a number of different categories of regulated injection wells. Ground water recharge wells are Class V wells, a miscellaneous category.

Under SDWA regulations, an aquifer or portion thereof that supplies potable water or is capable of supplying a public water system is defined as an "underground source of drinking water." Once so designated, no federal funds may be spent on any activity that might lead to contamination and create a public health hazard or that would lead to a violation of any drinking water rule. Further, the EPA Administrator is also authorized to take emergency action to protect public health from imminent and substantial danger. Separately, the SDWA's wellhead protection program and other programs might be used to help protect ground water recharge and recovery wells and related water supplies from contamination.

There have been few problems under the demonstration program, but cause for concern remains. Appropriate regulatory action requires consideration of both the source of the water for recharge and the use to which the recovered water is to be put, and the risk of contamination that would render an aquifer unfit for its designated uses.

For example, federal demonstration project sponsors and agency officials struggled with the appropriate level of monitoring to require as part of the program. Initially, EPA demanded that every project test for the entire array of possible drinking water contaminants, whether or not the recharge project was designed for municipal or agricultural use or whether or not there was any reasonably likely source of the contaminant in the watershed. Even with an 80% federal cost share, some of the proposed monitoring and testing requirements proved to be too burdensome for some project sponsors.

The two projects proposed by the state of Colorado on its eastern plains were intended to demonstrate the use of small impoundments on ephemeral streams (dry arroyos) to tap any occasional floodflows to enhance natural recharge. No municipal or domestic water supplies would have been affected, and the state considered the required monitoring and testing for potential drinking water contaminants excessive and unnecessary and withdrew support for the projects.

Similarly, the Blaine-Gypsum Project in southwest Oklahoma was designed to stabilize water levels in an area around Hollis that depends on the aquifer to support irrigation and its agricultural economy. While the Blaine-Gypsum Aquifer is defined by federal law as a potential underground source of drinking water (40 CFR 144.3), it is not now a supply for any domestic or municipal uses due to the high total

dissolved solids (TDS) levels ranging from 3,000 to 30,000 micrograms per liter (mg/l).

Moreover, the project was actually designed to upgrade rudimentary practices. For years, landowners have diverted local streams to dry wells or sinkholes to take advantage of the karst geology and raise water tables, with significant results. However, little thought was given to any water quality impacts, and one purpose of the federal demonstration project was to examine the effects on the aquifer. Still, EPA's extensive water quality monitoring and sampling requirements were considered overly stringent by the state and the sponsors. An agreement accommodating all interests was eventually reached. While detectable levels of some herbicides and pesticides and other contaminants have been found, none exceeded SDWA MCLs, established to protect human health. Further, again, the aquifer is currently used only for irrigation and not as a potable water supply.

Outside of the demonstration program, neither the practices in Oklahoma, nor the proposed impoundments and spreading of waters in eastern Colorado would likely have fallen under SDWA or the EPA's jurisdiction. However, these practices fell under a special memorandum of agreement governing the program between EPA and Reclamation.

Of particular note, recent amendments to the SDWA authorized the appropriation of federal funds to create and capitalize state revolving funds (SRFs) for financing drinking water infrastructure needs, similar to the existing SRFs for addressing water quality needs under the Clean Water Act. These funds may provide another means of financing recharge projects. New federal source water protection provisions may also affect ground water recharge.

The Clean Water Act

While the Clean Water Act has been proven to be an effective means of protecting surface waters from contamination from point sources, it is not as effective in controlling non-point sources of pollution and doesn't require regulation of "discharges to ground water." However, new watershed protection initiatives could affect ground water recharge projects.

Any works necessary for the diversion of surface waters for recharge would likely require a permit under Section 404 of the Clean Water Act (CWA). This requirement has been used as a means of reviewing and regulating the development of many water projects. While issued by the U.S. Army Corps of Engineers, under Section 404(b)(1), EPA may veto a permit under some circumstances. Denver's Two Forks Project is a prominent example of EPA's use of its veto in the West.

Moreover, in California's Sacramento - San Joaquin River Delta and San Francisco Bay (Bay-Delta), EPA has exercised its authority to review and approve water quality standards set by states to protect designated uses of waters. Surface water diversions affect water quality, but only the State Water Resources Control Board (and not EPA) regulates water diversions and allocations under state law. Therefore, EPA has sought to use its CWA authority to disapprove state water quality standards for salinity and other measures of water quality and force the state to limit Bay-Delta diversions.

Endangered Species Act

The Endangered Species Act is another example of federal environmental legislation that may serve either as a serious impediment to the development of ground water recharge opportunities or as a reason to promote such

development, depending on the circumstances. The initial screening process eliminated many potential demonstration program projects with possible environmental concerns, and none of those now operating or under construction have raised serious questions with respect to impacts on endangered species. However, given the number of listed and candidate fish and other aquatic and terrestrial species, in the future, any new diversion of surface water for ground water recharge may likely face some type of required review under the Endangered Species Act.

For example, the lower reaches of the Provo River in Utah support habitat for the June Sucker, a listed species. The Southeast Salt Lake County Project diverts water upstream, but the U.S. Fish and Wildlife Service has determined that there is no serious impact. Neither were relatively insignificant diversions from the Cedar River in Washington for Seattle's Highline Well Field Project considered a threat to protected salmon. However, in California, non-federal efforts to develop and expand recharge activities on the Kern River alluvial fan have been complicated by concerns over impacts on listed species such as the blunt-nosed leopard lizard, San Joaquin antelope ground squirrel and kit fox.

The Kern County Water Agency owns and for many years has operated a very successful recharge project in the area using a number of different spreading basins. The California Department of Water Resources purchased thousands of acres of land adjacent to the Kern County project from Tenneco, which managed farms on the land. The purchase was part of a proposal to use these lands along the State Water Project's aqueduct for the recharge, storage and ultimate recovery of water and thereby increase the reliability of much of southern California's imported water supply. The state has since transferred the project to local agencies, which are part of a larger proposal to ultimately recharge and store up to one million acre-feet of water.

Concern over endangered species weighed significantly in the decision to terminate the project in two different ways. First, as already mentioned, environmental concerns have led to limitations on diversions from California's Bay-Delta to protect different fish species, including the Delta smelt and winter-run chinook salmon. In addition, EPA's failure to approve required state water quality standards, in part due to current diversions, has also limited the amount of water available. Existing state and federal water contractors have not received their full federal allotments in many years. Water that is surplus to other water rights that might possibly have been diverted and available for potential recharge has been reduced, if not eliminated by these environmental demands.

Second, once the lands were retired from farming, the entire open space became potential critical habitat for endangered lizard, squirrel and fox species. Any new development became subject to incidental "taking" restrictions under ESA Section 9, and preparation of a related habitat conservation plan (HCP) was required and has been completed.

The project was transferred to the Kern Water Bank Authority, described hereafter, which hopes to expand its current recharge operations using local water supplies. In return for the land, the agency relinquished certain rights to receive imported water from the State Water Project. Whether or not the agency will be able to expand and develop new recharge opportunities remains to be seen.

On the other hand, ground water recharge may be part of the solution to pressing problems related to compliance with the Endangered

Species Act. For example, a number of species live in and around several springs dependent on discharges from the Edwards Aquifer in Texas. Over the past several years, state and federal officials have debated the best means of protecting the springs and related endangered species, while at the same time ensuring water is available for growing municipal water supply needs. While no acceptable answer has yet been found, ground water recharge has been considered as an alternative that might play an important role.

Similarly, artificial recharge is an element in the complex mix of hydrologic circumstances that now support the discharge of waters in the Big Springs area on the Snake River in Idaho. Again, these springs support listed endangered and threatened species, and again managed recharge may be a part of any solution to the problems. The project near Julesburg, Colorado has already been mentioned as providing a potential benefit to endangered species on the Platte River downstream due to its likely effect of augmenting lowflows in late summer.

There are likely to be many other future uses of recharge opportunities for the direct and indirect benefit of endangered species.

National Environmental Policy Act

The National Environmental Policy Act (NEPA) requires federal agencies to prepare an Environmental Impact Statement (EIS) for any "major federal action significantly affecting the quality of the human environment." Heretofore demonstration program project reviews have resulted in a finding of no significant impact, given their careful screening and temporary nature. However, continuing operation of these projects beyond the five-year demonstration period has raised questions regarding the possible need for a new NEPA review and possible preparation of an EIS. Given the costs involved and the apparent lack of any serious environmental concerns, project sponsors would obviously like to minimize any required review. In the future, federal participation in ground water recharge projects might require more extensive and costly NEPA actions.

CONCLUSION

Westwide interest in ground water recharge is growing, along with experience with the technology and its costs and benefits. Most High Plains Demonstration Program projects have truly been "pilot" scale projects, and modest amounts of water have been recharged. However, the technical efficacy, economic efficiency and financial feasibility of artificially enhancing recharge has been demonstrated across a broad range of geographic, political, legal and institutional boundaries, in areas where recharge technology has previously been unused or little used.

Most High Plains Demonstration Program project sponsors plan to continue or expand recharge operations. These and other operating non-program projects throughout the West will help serve as examples for future artificial recharge enhancement projects. The ever-increasing demands on limited western water resources require more innovative and efficient management options. Conjunctive use of surface and ground water resources, and artificially enhanced ground water recharge, should be considered as part of comprehensive management programs.

Decisions with respect to recharge opportunities should focus on specific problems and the particular potential advantages of recharge projects and programs. Generally, the problem is an inadequate water supply. There are three related, but more specific problems: (1) meeting peak system demands; (2) meeting demands during drought; and (3) ensuring the reliability of long-term water supplies. In many projects, both those in the High Plains Program and those separately funded by other local and state sponsors, all three problems are important.

Recharge can be part of the solution to these problems and a means to store water in aquifers for recovery to meet peak demands and demands during drought, or as a means of replenishing a depleted aquifer and helping achieve or restore a balance between recharge and consumptive uses, thus helping ensure the reliability of long-term water supplies. Ultimately, vast amounts of water may be recharged, stored in ground water aquifers, and later recovered. Recharge should be viewed as a means to an end, and a solution to a specific problem. While there are many potential benefits, it is not a panacea.

In addition to the water supply benefits, the High Plains program has also demonstrated that there are other significant purposes for enhancing natural recharge: (1) flood control; (2) fish and wildlife habitat enhancement; (3) to maintain or create recreation opportunities; and (4) to beneficially reuse treated wastewater.

In weighing recharge opportunities, costs and cost sharing arrangements must be carefully considered. Extensive water quality monitoring and evaluation of the impacts of ground water recharge associated with a variety of program projects has been undertaken. The general absence of deleterious effects on ground water quality is valuable information for future regional, state, and local recharge efforts. Excessive regulatory oversight should be avoided, in part to help reduce monitoring costs. Similarly, all environmental protection

requirements should be reasonably based on any potential risks to the public health and welfare, given existing and potential future uses of the ground water.

Cost sharing and financing agreements should be designed so that beneficiaries pay project costs, to the extent practical, in order to promote economic efficiency and equity. Public or governmental cost sharing and financing should be based on perceived public benefits. Where there are clear benefits, government participation is necessary, again to promote efficiency and equity. Government participation, at all levels, should be based on a careful assessment of public costs and benefits. To the extent that an otherwise worthy private project is unable to secure private financing, the use of public funding, with full cost recovery, may be appropriate to promote efficiency.

Federal demonstration program project cost sharing and financing may be viewed as an appropriate venture capital investment that has expedited and facilitated the development of artificial recharge projects that otherwise might not otherwise have been possible at this time. Significant research and water supply benefits from the federal program projects have accrued to local and state sponsors. While program project's economic efficiency and financial feasibility was largely determined solely by the sponsors willingness to pay the required minimum cost share, in the future cost sharing and financing arrangements will be much more complex and should carefully take into account public and private costs and benefits in negotiating federal participation or other government involvement. Reclamation's engineering and water resource management experience and expertise make it an appropriate potential lead agency for future federal recharge project and program participation.

The greatest opportunities for future successful artificial recharge projects are in urban areas of the arid West with growing populations. To be cost effective, large service area populations and higher-valued municipal and industrial water products are necessary for direct well injection, with its drinking water treatment requirements. Economies of scale make it easier for large urban areas to develop recharge projects and programs relative to rural areas. Urban water treatment plant capacities also generally are underused during the low-demand season, and surplus winter water can be efficiently used when available for injection and underground storage.

Agricultural users have had relatively inexpensive sources of water in the past, either from surface storage and delivery projects designed for crop irrigation or from ground water. However, declining ground water levels and the increasing value of water for urban and municipal uses, and environmental and wildlife purposes, have raised the cost of water and limited access to existing supplies, which has also led agricultural producers to seriously look at ground water recharge and conjunctive use to help ensure the reliability of their supplies and stem or slow the declines in local ground water basins. In agricultural areas, spreading basins are commonly used to enhance recharge while avoiding the higher costs associated with direct injection wells, such as water treatment costs and more rigorous water quality monitoring requirements. Several large-scale spreading basins for ground water recharge have been developed by sponsors outside Reclamation's High Plains Program for agricultural (and urban uses). Greater economies of scale can be achieved, which allow all users to benefit.

Perhaps the defining trait of artificial recharge is its site-specific nature. Widespread opportunities exist for recharge and conjunctive

use in both urban and agricultural areas, but each potential project is unique. Expected costs and benefits must be evaluated to determine whether or not ground water recharge can be an appropriate part of the solution to a specific problem. As related to the physical sciences, the project must be technically sound, requiring careful design consistent with principles of civil and mechanical engineering, hydrology, and geochemistry. It must also be economically efficient, financially feasible, and legally and politically acceptable. Project sponsors and other proponents must consider all of these factors in evaluating project feasibility.

The primary physical, institutional and economic constraints all seem to be related to the availability, reliability and cost of a supply of water for recharge. Physical availability is perhaps the most important factor, but almost equally important are legal and economic factors. Recharge opportunities are greatest where existing infrastructure -- water storage, treatment and delivery systems, as well as existing production wells -- can be used for both recharge and recovery. In addition to the obvious physical and economic advantages, such development also generally means that many of the institutional and legal issues will have been addressed, at least in part.

Successfully securing various required rights, permits, findings and opinions, or other documentation, as well as the lack of legal and political opposition and action, serve as a measure of legal, institutional and political acceptability. They also serve as non-market measures of economic externalities, i.e., project costs borne not by the sponsors, but by the public and other private third parties. Whether or not such requirements and the costs of compliance are reasonable and appropriately approximate external project costs may be very difficult to determine. Indeed, legal and institutional constraints were mentioned by managers and project sponsors as major issues and often significant obstacles to the successful implementation of federal and non-federal artificial ground water recharge projects and programs. Environmental concerns and costs, particularly protection of endangered species and water quality, were frequently mentioned as significant hurdles. While not insurmountable, these constraints add substantially to project development costs and should be carefully reviewed -- by both project sponsors and all levels of government. Excessive regulatory requirements should be changed or removed.

On the other hand, ground water recharge projects may offer important opportunities to restore native fish and wildlife habitat and otherwise enhancement of significant environmental benefits. Projects that use spreading basins and in-channel works to enhance recharge may be specifically planned and managed to provide benefits for wildlife. In urban and suburban areas, such management of open space and wildlife may be particularly important in helping secure local governments' political support and financial support, given their willingness to pay for such benefits.

Similarly, federal participation in future ground water recharge projects and programs will be based on political perceptions of the national interest and federal benefits. Again, willingness to pay for project benefits appears to be the most important measure of financial feasibility and federal participation will likely be constrained due to prominent concerns with respect to the growing federal budget deficit. However, the Congress has appropriated funds for additional support of recharge projects outside of the High Plains Program, which may indicate a willingness to promote this promising technology. Still, any future large-scale federal programs to subsidize ground water recharge

projects appears unlikely. That does not mean future federal participation in recharge projects will not be important. There are a myriad of ways in which federal agencies can help promote appropriate recharge opportunities and maximize national interests and federal benefits while minimizing any out-of-pocket federal expenses.

One of the stated reasons for the initiation of the High Plains Ground Water Recharge Demonstration Program was to address the possible integration of this promising technology into existing federal surface water development projects and programs. Under the program, the governors of Reclamation states recommended projects for selection and participation. Integration with federal water projects was not a primary state objective. As a result, none of the High Plains program projects were specifically designed to be integrated with existing federal water projects. The Southwest Salt Lake County Project does recharge water obtained indirectly from the Provo River and Reclamation's Deer Creek Project.

Further, broad federal development of western water resources directly and indirectly affects the availability of water for recharge. Of the thirteen ongoing program projects, at least five are within basins where either federal project development and operation or federal regulation of non-federal projects affects water supplies. Moreover, a number of non-program recharge projects utilize waters from federal projects. Specifically, the Salt River Project, one of Reclamation's earliest projects, supplies water for the Granite Reef Underground Storage Project east of Phoenix. The Las Vegas Valley Water Conservation District recharges Colorado River waters diverted from Lake Mead behind Hoover Dam. The Kern County Water Agency and other public and private entities around Bakersfield, California import federal water, when available, from the Central Valley Project. Some non-federal recharge projects use federal project water exclusively, while others recharge substantial amounts of federal water and non-federal water supplies for recharge.

By integrating existing federal and non-federal water projects with artificial recharge, non-federal project sponsors have been able to take advantage of lower costs and existing storage and conveyance facilities, retrofit existing production wells for recharge and recovery, and also use economies of scale to develop cost-effective artificial recharge projects that meet their water service demands. In contrast, the High Plains program projects in Washoe County, Nevada and the Denver Basin of Colorado had to purchase and secure small amounts of rather expensive water and related water rights for their demonstrations over a short period of time.

The integration of future recharge projects with large federal surface water development projects appears to be a very promising area for investigation. Such conjunctive management of precious water resources and existing capital promises synergistic returns that may help create new and more reliable water supplies. Further, there may be potential cost savings using existing public and private water works. Expanded federal government participation is probable and perhaps inevitable as all levels of government seek to do more with less and cooperate to achieve cost savings while continuing to provide necessary services.

Federal participation and continuing support for artificial ground water recharge activities should focus on promoting and enhancing the efficiency and equity of water use throughout the country (as has been

presented in some detail in this report). Moreover, federal action or participation may specifically seek to minimize litigation, public resistance, and political costs associated with surface water development, storage and management projects. This may include minimizing any potential damage to the environment, or possible degradation of ecosystems and wildlife habitat, which may also minimize related large financial burdens that may be imposed on water users.

The use of the appropriate technology is important to cost-effectively enhance ground water recharge. Spreading basins generally appear to be the most cost-effective solutions to declining ground water levels, particularly in agricultural areas. Direct injection avoids the evaporation losses associated with surface water spreading, but at significant costs. To justify the additional costs for water treatment, injection and recovery, water values should match the additional marginal cost for injection well construction and operation relative to spreading basins. These costs generally are justifiable only for urban areas with significant ground water overdraft and other long-term water supply problems or problems meeting short-term peak demands.

The higher costs for High Plains Program projects relative to non-federal non-program projects should not be surprising. The non-federal program projects are more pragmatic grassroot efforts that focus on the most cost effective means of serving a variety of limited purposes. In contrast, most High Plains program projects would not have been built without federal financial assistance and much of the difference in construction, operation and maintenance costs can be attributed to the many additional regulatory requirements, administrative overhead and other costs associated with a true federal research and demonstration program. For example, ground water quality monitoring requirements were much more extensive and intensive under the High Plains Program and account for some of the higher costs.

Also, federal program projects have faced high start-up costs involving construction of new facilities, land purchases, planning, design, and other activities and costs. Most non-federal projects have taken advantage of existing federal, state, or other water supply projects. Therefore, construction costs have been lower.

Again, without federal financial support and a generous federal promise to pay up to 80% of the projects' costs, many of the demonstration projects would not have been built, as other less costly alternatives existed or no action would have been taken (at least not at this time). Federal assistance also helped to reduce the risk faced by local sponsors that might otherwise have been unwilling or unable to shoulder the financial burden, not knowing exactly what the costs and benefits might be. However, without a doubt, federal financial participation and cost sharing increased the regulatory requirements and other related administrative costs. Such costs were a burden without which program projects could have been constructed and operated less expensively.

All non-federal projects have significant net economic benefits based on the water users willingness to pay for the recharge projects. These projects have been developed either because of the relative cost effectiveness of artificial recharge relative to other alternatives or because of a general lack of alternatives other than artificial recharge.

In all the federal demonstration program projects and the non-federal projects studied, current water supplies still exceed demands for

at least part of the year, and therefore ground water recharge, banking and later recovery during times of periodic peak demands or short supplies offer opportunities to more effectively and efficiently utilize existing and future water supplies, thereby helping to ensure greater system reliability and flexibility in the future.

Findings and Lessons Learned

Recharge opportunities offer a practical and promising alternative for storing significant amounts of water.

Interest, experience and success with ground water recharge projects and programs are growing westwide.

In many areas, ground water recharge is already an effective water management tool, critical to economic and environmental welfare.

The highly variable and uncertain nature of natural precipitation and runoff in the West is a reason for, and obstacle to, recharge projects.

Finding water available for recharge is a primary constraint on successful programs.

Ground water recharge enhances the conjunctive use of water and maximizes the efficient use of capital and natural resources.

Ground water recharge, storage and remote recovery offer both technical and political opportunities and difficulties.

Ground water recharge may create multiple benefits and beneficial uses.

It may provide an alternative to otherwise unacceptable development of surface waters.

It may provide significant and salable recreation and wildlife benefits.

Ground water recharge, storage and recovery may also provide regional benefits.

The effects of recharge activities are very site specific and may be uncertain.

Little data were available to critically evaluate demonstration project costs and benefits.

Benefits and costs could have been more carefully defined, accounted for and evaluated.

Project sponsors' willingness and ability to pay (or cost share) was the primary measure of economic and financial feasibility.

Willingness-to-pay is a decisionmaking tool that may be an adequate substitute for a detailed benefit-cost analysis.

Willingness-to-pay varies widely between individuals, groups and government according to their values and perceived benefits.

Willingness-to-pay is not always an equitable mechanism for resource allocation.

Willingness-to-pay and cost recovery are interrelated.

Project costs have generally been recovered through general tax revenues or water and sewer charges.

The primary purpose for ground water recharge projects is to ensure the reliability of existing water supplies.

Ground water recharge can restore and maintain water supplies and related benefits.

Unit costs of water are sensitive to such factors as project scale and production levels.

Given economies of scale and higher water values, municipal ground water recharge projects have a higher probability of success.

Successful agricultural recharge projects have used existing infrastructure and low cost water, and may help maintain rural lifestyles.

Banking water through recharge activities offers water managers greater flexibility in meeting peak demands and providing protection from drought.

Without Reclamation's demonstration program and financial support, most of the federal projects would not have been built at this time.

Given numerous potential public benefits, government involvement in recharge activities will likely continue.

Legal and institutional issues are as important as technical and economic concerns and constraints.

Ground water recharge arrangements will facilitate more water transfers in the West.

There is an opportunity to use more water from federal water projects for recharge.

State water laws and water rights administration are changing to accommodate recharge activities while ensuring waters are not wasted or degraded.

Indian water rights issues are important.

State and federal environmental laws are important constraints on recharge activities.

Baseline data gathering and monitoring water quality and quantities are major expenses.

More stringent state or federal non-point source pollution controls and ground water protection requirements would affect recharge projects.

Discharges to ground water through infiltration are not clearly regulated.

Small impoundments significantly increase recharge.

The availability and cost of land for spreading basins are important constraints.

Local planning and zoning requirements can substantially increase municipal recharge project costs.

It is unlikely much new federal money will be available to promote or participate in private or local recharge activities unless a clear and overriding federal benefit or cost savings can be demonstrated.

Future construction and operation of successful recharge projects will depend in large part on the ability of different public and private agencies to cooperate, find common and/or compatible purposes and work out collaborative working arrangements.

There is a need for greater public awareness of ground water management issues and recharge opportunities.

There may be a public aversion to commingling surface and ground water supplies in some areas that may impede the use of ground water recharge.

Public education and participation may help minimize conflicts and opposition.

Recommendations

Recharge projects and programs should be considered as part of any comprehensive and conjunctive water management program.

Management decisions with respect to recharge opportunities should focus on specific problems and the particular benefits and costs of recharge projects and programs.

Unforeseen costs should be anticipated and project planning should cover contingencies and provide sufficient flexibility, perhaps through phased project implementation, to facilitate future "go/no go" decisionmaking.

Cost sharing and financing agreements should be designed so that beneficiaries pay project costs, in order to promote economic efficiency and equity.

Public and private entities should cooperatively encourage the careful evaluation of recharge opportunities and collaborate on appropriate projects.

Where there is a clear public interest or benefit -- federal, state or local government participation is necessary.

Federal, state or local participation in any ground water recharge project should be based on a careful assessment of the potential public benefits, just like any other water project.

Public financing and cost sharing should similarly be based on benefits.

To the extent that private financing is not available for an otherwise worthy project, public financing on a reimbursable basis, with full cost recovery, is appropriate.

Federal and state governments should continue to fund cooperative ground water resources research and basic data collection programs.

Water quality monitoring and environmental protection requirements should be reasonably based on the potential risk to the public health, given existing and reasonably foreseeable future ground water uses.

The potential environmental benefits of ground water recharge should be recognized and explored.

Excessive government regulatory and oversight requirements should be avoided.

Federal and state surface water projects should be used as appropriate to encourage and integrate recharge opportunities.

Sponsors should be directly involved in the development and implementation of any interagency agreements regarding a specific project.

Each state should examine its own water codes and other legal and institutional systems to assure that they adequately address ground water recharge.

Some states should carefully consider amending their statutes to encourage appropriate recharge activities.

Public education and public participation programs that explain recharge project costs and benefits and involve stakeholders in the decisionmaking process should be encouraged.

RILLITO CREEK - TUCSON, ARIZONA

BACKGROUND

As early as 1959, the U.S. Geological Survey and University of Arizona prepared a study of the recharge potential of Rillito Creek, an arroyo or dry streambed, in Tucson. Later, in 1980, Arizona's Ground Water Management Act led to a basic feasibility investigation of recharging storm water runoff. The Pima County Board of Supervisors adopted what it called the Rillito Creek Flood Storage/Ground Water Recharge Natural Riverine Preservation Project in 1986. A multiple use proposal, it incorporated significant recreation features. In 1987, a cooperative agreement was reached between Pima County, the City of Tucson and the Arizona Department of Water Resources that defined their support for a project designed to demonstrate artificial enhancement of ground water recharge. A more detailed feasibility study was completed in 1990.

In 1991, as part of the federal High Plains demonstration program, an intergovernmental agreement was signed between the Bureau of Reclamation and Pima County Flood Control District, the local sponsor. It provided federal funds for monitoring surface and ground water quantity and quality. However, soon thereafter a preliminary design report and 1993 flooding that eroded the banks at the recharge site revealed a number of technical problems, which together with institutional obstacles regarding alternative waters for recharge eventually led to abandonment of the storm-water recharge project, as proposed, in 1995. However, much of the experience gained and information gathered is being used to help plan and design a project to recharge reclaimed water in the Rillito Creek channel and effluent further downstream.

Project Purpose and Description

Rillito Creek was designed to demonstrate the feasibility of recharging storm water. It would have been the first project of its kind in Arizona, impounding and infiltrating storm water in an unregulated, ephemeral streambed. It offered an opportunity to capture and store scarce water resources in this Sonoran desert region, where perennial streams and feasible surface storage opportunities are rare.

In addition to flood control and water supply purposes, development of off-stream recharge basins, and ponds and wildlife habitat with a system of trails and interpretive and educational study centers, were to have been constructed for recreational/aesthetic purposes.

It also involved the expansion of the an existing ALERT system, a network of real-time stream and precipitation gages. This part of the project was completed and has improved the Pima County Flood Control District's ability to monitor storm events in the Rillito Creek watershed and respond in a timely manner.

The original concept was to retrofit an existing bridge with gates or install an inflatable dam that would be used to capture flood flows and increase in-channel recharge. As illustrated on the next two pages, the proposed project site was located within the stream channel between Swan and Craycroft Roads in Tucson, just below the confluence of Tanque Verde Creek and Pantano Wash. Again, these are ephemeral streams. The watershed boundaries are defined by the Santa Catalina, Rincon, Whetstone and Santa Rita Mountains to the east and south.

Rillito Creek Project Location Map

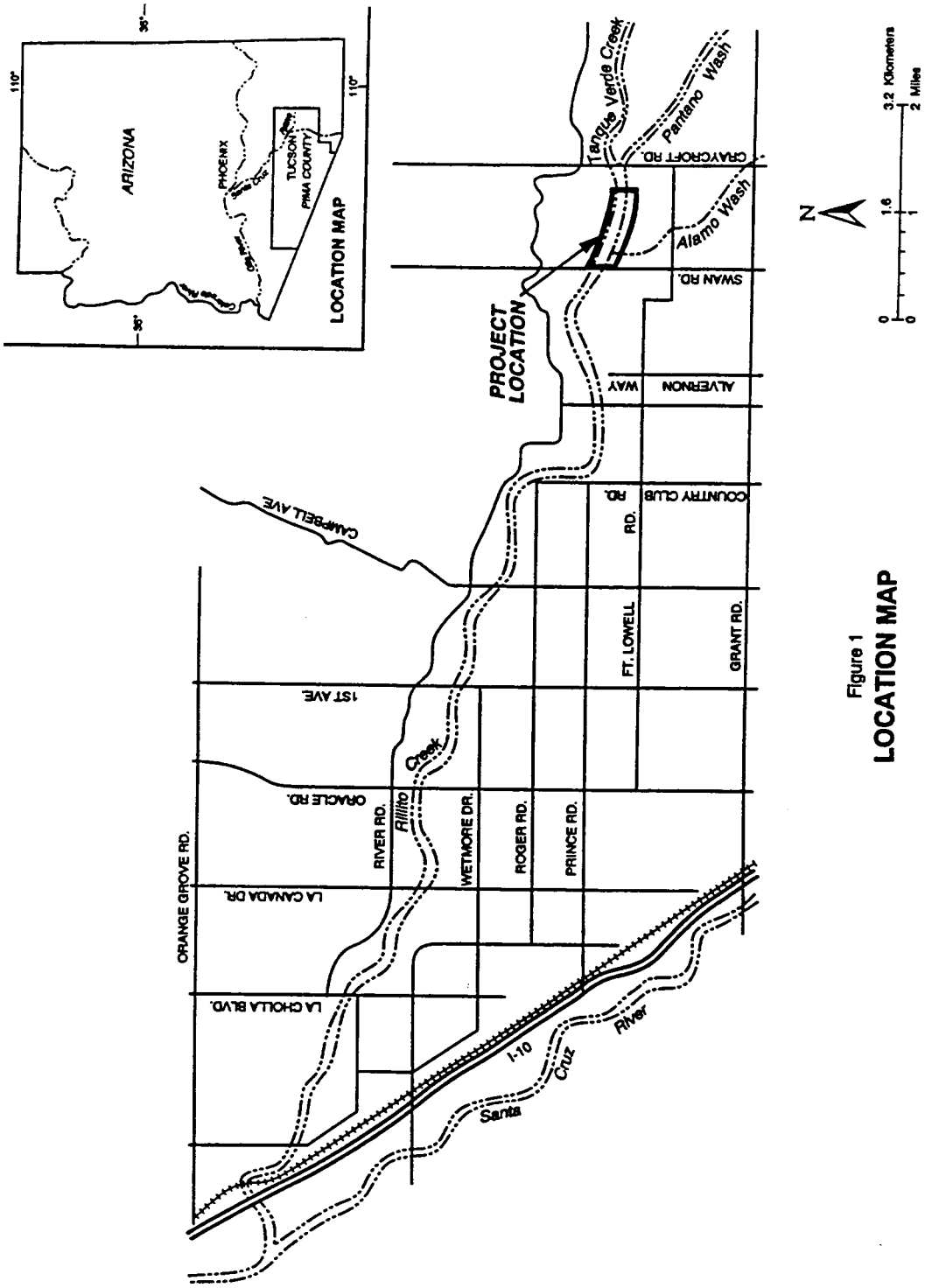


Figure 1
LOCATION MAP

Source: Final Report-Rillito Creek Project, Pima County, June 1996, pp. 1-2

Santa Cruz Watershed Map

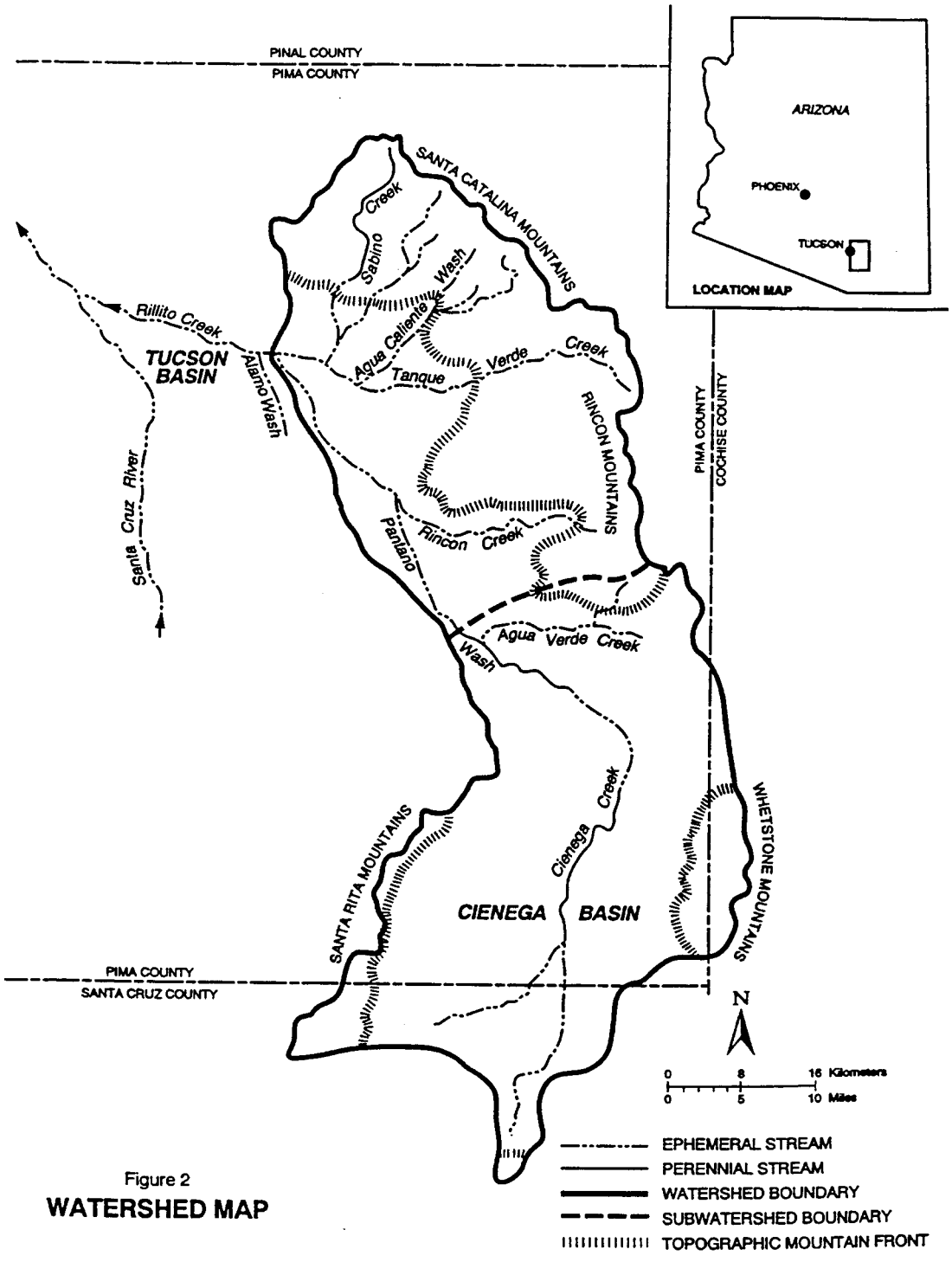


Figure 2
WATERSHED MAP

Source: Final Report-Rillito Creek Project, Pima County, June 1996, pp. 1-10

Rillito Creek was once a marshy stream, dammed by beaver, and lined with cottonwood, ash and willows. Grasses, mesquite, salt brush, and wolfberry covered its floodplain. Settlement brought grazing and other agricultural development, pumping ground water for municipal use lowered the water table, and later sand and gravel mining, stream channelization and urban encroachment heavily impacted native vegetation. Severe storms and flooding also caused streambank erosion. Together, these activities and events led to elimination of the marshes and the creation of a wide dry stream channel. Today, storm events provide the only water, and it seldom reaches the Santa Cruz River downstream.

An illustration of the original site layout is shown hereafter. It shows areas where riparian habitat restoration was planned, as well as the recharge basins, interpretive centers, foot paths and equestrian trails. It also shows planned bank stabilization and one of the inflatable dam site alternatives. The dam was designed with "bookend" fuse plugs that would blow out to prevent overtopping of the stream banks in the event of a very severe storm and flood. The area designated as a septic basin was to have been a constructed wetland to help treat polluted urban runoff from Alamo Wash.

Landscaping the banks with native plants would have provided wildlife habitat and an aesthetic buffer for adjacent low-moderate density residential neighborhoods. Other area land uses include a hospital, schools, small strip shopping centers, and horse pastures. The land within the channel is mostly owned by the Pima County Flood Control District, while the banks and surrounding areas are privately owned. Archeological sites were identified north of the project during an early survey, and these were avoided in designing the project.

Water Supply and Recharge

Average precipitation in southwest Tucson is around eleven inches per year, increasing with elevation to 25-30 inches per year in the surrounding mountains. About fifty percent of the annual precipitation falls during the months of July, August and September in the form of heavy local thunderstorms. Winter storms generally spread light to moderate precipitation over a larger area. The local ground water basins are recharged naturally by these storms and infiltration from runoff in the streambeds. Recharge zones along the base of the local mountains are also important.

The Tucson area has long been dependent on local ground water supplies, which have been mined historically. Natural recharge totals about 70,000 acre-feet per year, with current demands reaching two or three times that amount. Within the project area, water tables were once 5-15 feet below the surface of the ground. Water levels around the area have dropped from 75-105 feet. Tucson is one of Arizona's active ground water management areas, with long-term safe yield goals, per capita use limits and extensive conservation programs. As previously described, the Rillito Creek project was designed to recharge an average of 3,500 acre-feet per year.

Tucson Water supplies most homes and businesses. Its central well field, south of the project site, supplies much of the municipal water. In general, the Tucson ground water basin is a single unconfined alluvial aquifer, subdivided into different beds and formations consisting of silts, sands and gravels. Porosity and permeability of the relevant geologic formations and aquifers is generally good, but variable. It ranges from 20 to 35% and 1.3 to 94 feet per day. The Fort Lowell Formation,

underlying the project site, has an average porosity of about 30% and permeability ranging from 20-94 feet/day.[1]

However, while sediments on site are highly transmissive, to the south and west, geologic structure of lower permeability limit overall storage capacities. Further, the hydrologic data base that was developed during the project investigation also raised concern that the amount of stormwater available for recharge might be less than originally estimated.

In 1985, the District funded a University of Arizona study that found most flow events peaked at less than 240 cubic feet per second (cfs) and infiltrated the streambed before reaching the Santa Cruz River.[2] It recommended bypassing such flows, unless there was another specific reason to encourage recharge at the project site, and using off-channel basins for capturing and storing peak flows. The construction of additional off-channel recharge areas would also resolve expected problems with in-channel sedimentation from the impoundment of stormwater, which would reduce recharge rates substantially. However, a large amount of land would be required to provide significant flood control benefits, and available land is limited and expensive.

Alternatives to the use of stormwater as the source of water for recharge were considered, but in 1995, they appeared infeasible at the site, prompting the District to abandon the project. Tucson Water would not agree to the use of its reclaimed or potable water, including treated CAP water, that could have been delivered to the site via its existing distribution system, but is now negotiating over the use of District lands and monitoring wells for its own regional recharge test. Some 6,000 to 8,000 acre-feet of water would be released upstream of Swan Road for about nine months, beginning in the fall of 1999. The use of untreated CAP water has not been considered, due to the lack of any nearby delivery system.

Water Quality

Ground water is generally of good quality, and better quality than imported CAP surface supplies. Tucson Water's interior well field, which surrounds the Rillito Creek recharge site, has an average concentration of total dissolved solids of 205 milligrams per liter (mg/l), well below the 500 mg/l recommendation for public water supplies. The chemical characteristics of the ground water are mostly calcium-sodium bicarbonate or calcium bicarbonate.

When Tucson Water first tried to deliver imported CAP water, customers complained about problems -- due to differences in pipe and water chemistry -- with corrosion, taste and odor. Therefore, the City Council stopped using CAP water. Other institutional problems, to be discussed later, created obstacles to the use of CAP water for infiltration and recharge by the flood control district.

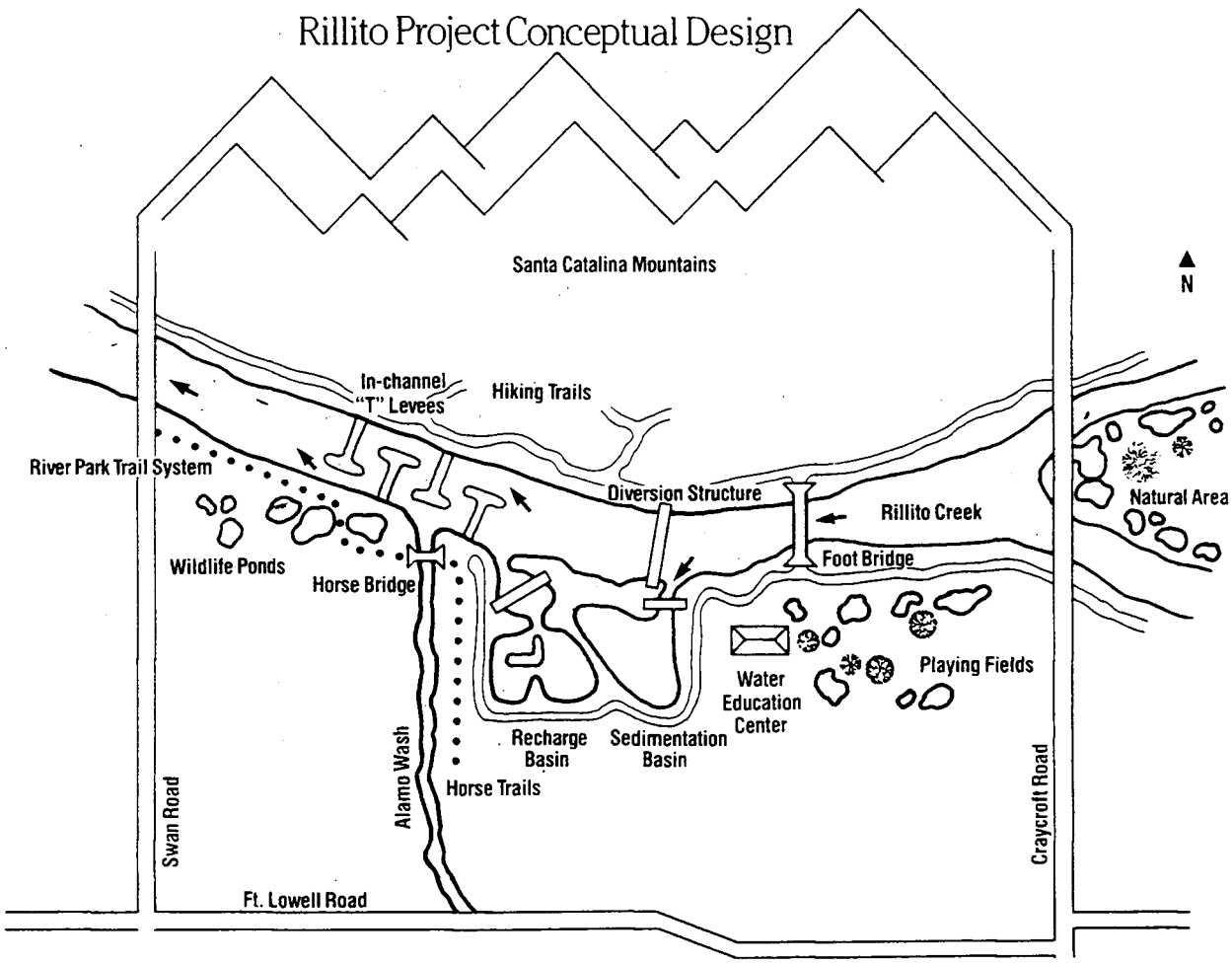
As mentioned above, the project was designed to handle any urban storm runoff, from Alamo Wash, contaminated with heavy metals and organochlorine pesticides -- due to adsorption, none were found in ground water.

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[1]Final Report Rillito Recharge Project, Pima County and USBR, p.1-17.

[2]Cluff, C.B., Katz, L.T. and Scoville, A.L., "Effects of Channel Stabilization in Tucson Stream Reaches on Infiltration and Recharge," Volume 2, Natural Streamflow Study, 1987.

Rillito Creek Project Site Layout



This conceptual design shows the use of water spreading basins that create a large surface area where water is ponded and allowed to infiltrate into the groundwater.

Source: Rillito Creek Project (brochure), Pima County Flood Control District, p. 9

ECONOMIC EFFICIENCY AND FINANCIAL FEASIBILITY

As described heretofore and hereafter, the Rillito Creek is unique. While it would appear to be an efficient means of using scarce water resources, institutional constraints primarily led to its demise. The apparent lack of economic or other incentives for different entities to work together and cooperate to maximize potential project benefits and reduce costs made pursuing its completion infeasible for the flood control district. That is not to say the money spent was wasted, as the ALERT flood early warning system will provide future benefits, and the studies may help Tucson Water with its plans for a possible recharge project at the site.

Project Costs and Cost Sharing

The budget for the Rillito Creek Project totaled $4.836 million, one of the most expensive in the federal demonstration program. However, the local share of the cost was 70%, compared to the 20% minimum required.[3] In 1992, construction and operation costs were estimated to $2.815 million and $125,000 per year. This included $737,000 for in-channel recharge facilities, $295,000 for off-channel facilities, and $1,093,000 for recreation facilities.[4]

An analysis of the costs requires a complex review of past and potential project partners. The initial feasibility study cost $825,180 and was funded equally by the Pima County Flood Control District, Tucson Water Department and Arizona Department of Water Resources. However, the latter both declined participation in construction and operation of the facility.

The original project report did not include the cost of a foundation for the inflatable dam and fuse plugs. The preferred alternative plan was designed to be compatible with and use a U.S. Army Corps of Engineers' erosion control project that would use soil cement to stabilize the stream banks and a grade-control soil-cement invert stabilizer structure across Rillito Creek. The intent was to use this as the foundation for the proposed inflatable dam. In order to reduce their costs, the Corps proposed moving the control structure downstream, but this jeopardized the County's recharge project.

The recharge project costs rose along with changes to the designs of the two projects and related cooperative agreement. The Corps agreed to build and keep the structure at a location best suited for the recharge project if the County would pay the additional cost. This included new design considerations such as bank stabilization elevations, the need for additional toe-down due to additional scour and stability changes.

The additional scour, caused by narrowing flows between the fuse plugs and over the dam when it was deflated, would require additional soil cementing at an added cost of $75,000. A subsequent report identified additional stabilizer modifications that would be needed, including a cutoff wall and widened top slab to serve as the foundation for the dam. The cost increase would have been another $400,000. The cost of piers to which the dam would be anchored had yet to be estimated.

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[3]High Plains States Groundwater Recharge Demonstration Program: Interim Report, Bureau of Reclamation, October 1997, p. 10.

[4]Ibid, pp. 28-29.

Other uncertainties and unforeseen events would have affected project costs. Material for the fuse plugs was to have come from on-site excavation of the off-channel retention basins, but if the soils proved too fine, replacement materials would have added to the costs. On the other hand, a January 1993 flood that widened the creek channel led to a new alignment for bank stabilization work that reduced estimated excavation costs for the West County recharge basin by $45,000.

Also of note, the County determined that its ALERT system, already understaffed, would need another four full-time equivalents (FTEs) in order to be operated at a level needed to successfully manage the recharge project.

The cost of construction of the recharge facilities alone was estimated to be $1,364,820 and included engineering costs and contingency funds. Over 20 years, at a 7% interest rate, the annual capitalized costs would be around $130,000. Annual operation and maintenance costs and replacement of the dam in 30 years would add another $61,000 per year for a total cost to recharge 3,500 acre-feet of water of about $55/acre-foot.

This estimate does not include the cost of land acquisition and feasibility studies. The former would have been incurred anyway for flood control purposes and to maintain open space, while the latter were much more extensive than would usually be required for a typical recharge project. The land and river park development costs were also excluded as Pima County intends to develop the park whether or not the recharge project is constructed.

From a broader economic view, the project could still be an efficient use of resources.

Project Benefits and Beneficiaries

The project purposes and benefits have been described earlier and include flood control, water supply and recreation. Not all the benefits would accrue to Pima County. Further identifying and quantifying the incidence of the benefits would require more study. Tucson Water's central well field would benefit from any enhanced recharge, but in 1995, it was not interested in helping finance construction of the District's project. Other small domestic and irrigation wells in the area would also benefit.

Under Arizona law (described extensively elsewhere in this report in relation to the non-program Granite Reef Project near Phoenix) Pima County has no right to recover and market the water that would be recharged. Again, stormwaters usually seep into the sediments of the streambed anyway before escaping the boundaries of the state's active management area (AMA), and thus the state would not grant the flood control district a right to recharge, store and recover any water, which it might in turn market. As a result, with no right to the water recharged, the District would have no means to capture the water supply benefits.

Project Financing and Cost Recovery

Given the project's general flood control and recreation benefits, but no means to profit and recover construction costs related to any recharge activities, the County could not justify financing those portions of the project. Even though it might be an economically efficient and physically feasible project, without other local, state or federal help to share project costs, the project was not financially feasible. Given other priorities for capital improvements, and limited access to some project benefits, the County decided to terminate the project.

LEGAL AND INSTITUTIONAL ISSUES

The primary considerations that led to abandonment of Pima County's Rillito Creek Project were first legal and institutional. It is important to note that legal and institutional issues were deciding factors -- equal to or more important than the many other considerations in deciding to terminate the project. Without legal access to all the project benefits, the county flood control district could not feasibly finance the project, even if it were an economically efficient use of natural resources.

State Water Law

Briefly, Arizona water law is designed to promote efficient resource use. Tucson lies within an Active Management Area (AMA). Under state law, neither Pima County, the flood control district, nor any other party could get credit for recharging stormwater within the AMA, primarily because the state determined that the stormwater would most likely have infiltrated into the aquifer before leaving the AMA anyway. Ironically, this determination was made in part in response to a legal challenge to the project made by downstream irrigation interests on the Santa Cruz River. As stormwater from Rillito Creek rarely reaches the river, the state ruled that there would be no harm to the irrigators' interests from construction of the project. However, without state-approved recharge and storage credits, any subsequent withdrawals of ground waters within the AMA would be counted by the state as an increase in its per capita per day use, which is limited and carefully regulated under state law and through AMA accounts.

The only means for the County or District, or any other entity, to obtain storage credits under the law and any related economic benefits would be to recharge imported water at the site or develop a site downstream to capture and recharge waters that would otherwise leave the AMA. As the flood control district could not secure the use of sufficient effluent for recharge at the site, nor CAP water allocated to Tucson water, it was left without the means to produce water supply benefits recognized under state law. Again, Tucson Water is now considering the use of a mixture of treated CAP water and reclaimed wastewater (tertiary-treated effluent) which would provide water supply benefits recognized by the state.

Tucson Water Augmentation Authority

The now defunct Tucson AMA Water Augmentation Authority was created in 1990 in order to help achieve the goal of safe yield (S.B. 1556).[5] The Authority was governed by a board of directors appointed by the governor. Among its powers and duties, the Authority was to cooperate with other governmental agencies and coordinate matters relating to augmenting AMA water supplies and developing water plans. The authority was specifically directed to "...coordinate water conservation efforts to encourage pooling the resources of all operating units in the active management area to maximize conservation of the existing water sources in the active management area."[6] To accomplish this, the authority was allowed to: acquire and sell or exchange water and water rights; negotiate and execute agreements to use existing facilities to transport water; and construct, maintain and operate projects.

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[5] 45 ARS 105, 133, 578, 611 and 615.

[6] S.B. 1556; ARS 45-1954

In order to finance operations of the Authority, the legislature allowed that after a permanent board assumed office, it could levy an annual ground water withdrawal fee of up to $2/acre-foot, in lieu of that portion of the state's ground water withdrawal fee levied for augmentation. It would have been collected by the state, but transferred to the Authority. In order to cover the Authority's start-up costs, the legislature also directed that fees for augmentation collected within the AMA prior to the formation of the Authority be loaned to the Authority. The Authority was also given power to assess other water supply fees, including extraction fees, development impact fees, connection fees, user fees, replenishment fees, administration fees, and penalties for unpaid fees.

The Legislature later reformulated the Authority as a special water district, the Santa Cruz Valley Water District.[7] However, without the support of the Tucson City Council, the District was disbanded. Of note, it had levied a $1.50 per acre-foot augmentation fee and sought and received legislative authority to levy an ad valorem tax, but subsequent political opposition within the AMA lead to the repeal of both and ultimately the demise of the District.

Local control of water supplies is a major issue. Tucson Water is controlled by the Tucson City Council, and both are responsible for managing water to met long-term needs. The best use of CAP water is a major concern for Tucson and the Arizona Department of Water Resources. Without using CAP water, Tucson cannot meet state safe yield goals and continue to grow. The Central Arizona Water Conservation District (CAWCD) is also involved, as the operating entity for a ground water replenishment district created by the state, which covers Tucson and other areas (as described as part of the Granite Reef Project case study). The District may provide the means for greater local cooperation and financing future ground water recharge and water banking activities around Tucson.

Other Social and Political Considerations

Other social and political considerations raised regarding the Rillito Creek Project included the public aversion to the use of available CAP water supplies, given the water quality and aesthetic concerns raised by Tucson Water's customers. However, as demand for water continues to increase with growth, despite conservation efforts and other active water management and use controls, CAP water will become an important source of supply.

The recharge and subsequent recovery and use of CAP surface waters may be acceptable in the future and preferable to the direct use of this lower quality water. Should Pima County and the flood control district be able to secure rights to CAP or other sources of water for recharge, the project may prove feasible.

Filtration ponds may also prove to be preferable to injection wells, but there are other issues illustrated by the Rillito Creek project. The costs of land and other land uses limiting off-site alternatives for expanding the recharge basins raised some concerns as did the un-known extent and location of former landfills or dumping along the creek banks.

[7] ARS Title 48.

CONCLUSIONS

The Rillito Creek Project was designed as a multipurpose project to provide flood control, water supply and recreation benefits.

As part of the project feasibility study, it was found that there would be limited general flood control benefits.

While it was ultimately abandoned, it did help demonstrate the type of information necessary to evaluate the feasibility of controlling floodflows and recharging stormwater and aided future project planning.

The project helped improve the Pima County Flood Control District's ability to monitor storm events and respond in a timely manner through expansion of a real-time network of streamflow/precipitation gages.

Increased flood control benefits might have been realized with the expansion of off-channel recharge basins, but this would have required a lot of land and available land is limited and expensive.

Similarly, given the same research into the frequency and intensity of local storms and the local hydrology, it became apparent stormwater was not a sufficient source of supply for significant recharge.

Institutional circumstances precluded the District from securing Central Arizona Project water as an alternative source of supply for recharge.

With no firm water supply for recharge, there were no water supply benefits, and recreation was the only remaining purpose.

Recreation benefits from the River Park could be achieved without the expense of constructing the recharge facilities.

The original project site was also found to be geologically constrained due to a lack of aquifer storage capacity.

No significant conflicts were identified, with respect to cultural resources, despite the proximity of the project to archeological sites.

Similarly, no adverse ecological impacts or negative effects on endangered species were identified.

Given the high quality of local ground water resources, any possible degradation would be a significant problem.

While some concerns were raised over potential contamination of ground water from urban runoff from Alamo Wash, adsorption seems to eliminate the threat.

Given the public aversion to the direct use of imported CAP water -- due to problems with corrosion, taste and odor -- Tucson Water is now seriously looking at ground water recharge as a necessary and more acceptable water supply management practice.

With respect to the Rillito Creek Project, there apparently were no political advantages to encourage different local entities to work together, but that may be changing.

Unforeseen design and other changes also raised projected project costs substantially.

DENVER BASIN, COLORADO

BACKGROUND

The Denver Basin project is located in Englewood, a suburb of Denver, Colorado. The Willows Water District (Willows) is the project sponsoring agency. A "special district," under the laws of the state of Colorado, Willows was created by a decree of the Arapahoe County District Court on January 8, 1974. At that time, Denver's suburbs experienced unparalleled growth, and the influx of new residents made Arapahoe County one of the fastest growing areas in the nation.[8]

The District was created primarily to meet residential demands, but some commercial business use has evolved around its residential base. Willows covers an area of about 2,300 acres and currently provides water to about 6,000 homes and businesses, or about 20,000 consumers. All uses are metered, and average use per tap is 0.5 to 0.6 acre-feet per year, or around 200 gallons per day (gpd) per capita. Some water is provided for parks. When it was organized, surface waters were not available and Willows developed ground water supplies.

Total water use in Willows averages about 3,300 acre-feet of water, with 2,300 acre-feet of ground water provided from 21 wells. The additional 1,000 acre-feet of water is provided by Denver Water, the metropolitan area's largest water purveyor, under an "interruptible agreement" that provides surplus water during years when surface water supplies are adequate.

Average water deliveries total 2.4 million gallons per day (mgd), and the District has a peaking capacity of 14.4 mgd through its system of pumping stations and reservoirs. Only one or two of Willow's wells are operated to meet base demands (household water needs) during the colder winter months. During July and August, operation of all 21 wells is required to meet peak summer needs that are three to four times the base demand.

Willows' wells are located throughout the District and Douglas County. They draw water from the Denver, Arapahoe and Fox-Hill Laramie aquifers in the Denver Basin. Two superwells designed especially for Willows produce 1,500 gallons of water per minute from the Arapahoe aquifer. The District has a reputation for technological innovation. Two clear water reservoirs hold a total of 8 million gallons of water, or about an eight-day supply in winter, but only a one-day supply during peak summer demands. An average of 1.5 million gpd is currently provided by Denver Water under a recent agreement.

In the past, Denver Water limited its service exclusively to its own retail customers. It serves a population of approximately 900,000, with nearly 500,000 taps for some 260,000 residential, commercial and industrial users across a 450-square mile service area. While most users have been hooked up to meters over the last several years, many Denver Water taps remain unmetered. Average annual water use for each tap in its system is three-quarters of an acre-foot, but, for planning purposes, demand is estimated at one acre-foot per tap or 500,000 acre-feet per year.

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[8]Willows Water District, 6970 South Holly Circle, Suite 200, Englewood, Colorado 80112-1066; (303) 770-8625; Fax 770-9864; and e-mail: willows@usa.net.

In the past, Denver Water was opposed to commingling ground water with its surface supplies, perhaps because local ground water has a higher mineral content. However, in 1988, the Willows Water District, Denver Water, and Parker Water (a water district located south of Denver in Douglas County), cooperated in an 18-month aquifer recharge demonstration project. The study concluded a larger well and more advanced equipment were needed to complete the research.

The Bureau of Reclamation, through the High Plains States Groundwater Demonstration Program, offered financial and technical assistance that made a larger project possible. The necessary agreement was executed on December 13, 1990. Other cooperating agencies include the Environmental Protection Agency (EPA), U.S. Geological Survey, and U.S. Fish and Wildlife Service. The High Plains Program accelerated the development of the Willows recharge project. Without federal assistance, the project may not have been built.

Project Purposes

Enhancing natural recharge using South Platte River water in the Denver Basin is mostly about "insurance," and the efficient use of available water resources. Willows' short-term goal was to show that artificially injecting and storing surface water in the Denver Basin aquifer for later withdrawal and use was economically, institutionally and technically feasible. The completed project provides the cooperating agencies with valuable data on the feasibility of artificial recharge opportunities and may serve as a model of deep-well injection for other projects under similar conditions. However, Willows' District Manager, Khanh Le, believes that further economic analysis of ground water recharge will support its use for banking water to provide for drought needs.

Over the long-term, the conjunctive use of surface and ground waters -- and enhancing recharge to maximize efficient resource use -- is one way to secure a more stable metropolitan water supply for the future. Artificial recharge will help augment existing ground water supplies by using surplus surface water supplies, when available, thereby leaving as much water as possible in the aquifer for future use. Conceivably, an expanded conjunctive use system of recharge and recovery wells could provide significant storage and other benefits.

Given the geology of the Denver Basin, it might also be possible to extract recharged waters at remote locations, using the aquifer in lieu of an expensive surface water distribution system. However, there are a number of legal and institutional concerns to be overcome. State law currently limits remote extraction, in order to protect other water uses and users, given a general lack of information regarding recharge and ground water movements.

Project Description

The Willows Water District's Denver Basin Project consists of one "super well" that was retrofitted for recharge by injection. Well A-6A is 1,580 feet deep with a 30-inch bore, 20-inch casing, and 600-horsepower pump. It is state-of-the-art and is used for production and injection. The pump is set at a depth of 1,200 feet, with injection to a depth exceeding 1,500 feet. Up to 2,000 gallons per minute (gpm) could be extracted, but withdrawals are limited to 1,500 gpm by the 600-horsepower pump. Average pumping rates are 300 to 400 gpm. A computerized system stabilizes storage tank supplies and controls pumping rates.

Water Supply and Recharge

The Denver Basin's Arapahoe aquifer formation is Willows' primary water source. The formation consists of sandstone and conglomerate material that provides high-quality drinking water. It is a confined aquifer under artesian pressure that lies more than 1,000 feet below the surface. The depth of the Arapahoe and the costs of development and operation of deep wells precludes its use for agriculture.

The Arapahoe aquifer (beneath Willow's service area) is defined under Colorado law as "non-tributary" to any stream, i.e., there is no significant surface discharge. The Arapahoe formation is estimated to hold approximately 200 million acre-feet of water. While it is an ample source for Willows' water use, there is virtually no natural recharge, and if mining continues, at some point in time, it may be uneconomic to pump water. State law limits mining based on a projected 100-year supply, but some estimate the useful economic life of the aquifer may be only 50 years. Use of the aquifer by other entities is a factor complicating the matter and creating further uncertainty. The Department of Natural Resources began studies of the economic life of Denver Basin aquifers and conjunctive use in the Southeast Denver metropolitan area in 1997.

Willows acquired from Denver Water reliable access to renewable surface water supplies and has established a state-of-the-art water supply system to commingle and conjunctively use local ground water and surface waters. As the aquifer has been pumped for many years, there appears to be ample storage space for injected surface water. Based on current information, an estimated 150,000 acre-feet might be stored without causing any imbalance. Willows envisions that perhaps two to fifteen Arapahoe injection wells could be operated in the Willows' controlled areas of the basin in the future, each injecting 1,000 acre-feet/year.

Denver Water agreed to provide up to 500 acre-feet or 163 million of gallons of water per year for recharge, for six years. This water is taken during its off-peak winter season from its Foothills treatment plant. The plant has a capacity of 200 million gallons per day (mgd) or about 600 acre-feet per day, only a fraction of which is used during the winter months. The raw water supply comes from Strontia Springs and storage in Chatfield Lake, a U.S. Army Corps of Engineers' reservoir on the South Platte River. After treatment it is delivered via Conduit 111, a 60-inch pipeline connected to Willows' system, and from there to the injection well. Telemetry connections allow Willows to manage the Conduit 111 flow. This interconnection was constructed in 1989 as an emergency source of supply. It now serves as a long-term and a peak supply source.

In 1992, the District also purchased "replenishable" surface water rights from ranchers and estates through the Big 6 and Crooked Creek Ditch companies in Grand County. Under a mutually beneficial agreement with Denver Water, the rights are diverted for use through the Moffat Tunnel into Denver's system. During the peak-use summer months, Willows receives an equal amount from Denver Water. In August 1995, Willows executed a master water distribution agreement (No. 240) with Denver Water to gradually supply all Willows' needs within 15 years.

Willows' injection runs from March 1992 through June 1996 placed approximately 1,283 acre-feet of water in storage in the Arapahoe aquifer. Over five injection seasons, injection

rates varied from 450 gallons per minute (gpm) to over 1,000 gpm covering durations of from seven to 42 days, with the total amount in acre-feet (af) injected per season ranging from about 110 af to 475 af. Only two percent of the water has been pumped for "backflushing" to clean and maintain the well, for 98% efficiency.

Recharge Summary
(in acre-feet)

Seasons	Injected	Pumped	Storage
1991-1992	109.7	3.0	106.7
1992-1993	341.3	4.7	443.1
1993-1994	174.8	3.3	614.6
1994-1995	475.4	8.4	1,081.3
1995-1996	204.3	2.9	1,282.7
	1,305.5	21.3	1,283.2

Water Quality

The Arapahoe aquifer is high quality water. The only treatment required prior to distribution is chlorination. The injectate for recharge is compatible surface water treated to drinking water standards before injection, and no other treatment is required upon recovery. Baseline samples were collected and analyzed for both the native ground water and the injectate to define their water quality parameters. Analytes included volatile organic chemicals, pesticides, trihalomethanes, and inorganics, as well as radiological and biological analytes, and iron and manganese.

Water quality field parameters measured included temperature, specific conductance, pH, Eh, dissolved oxygen, and total and free chlorine concentrations. During the pump cycles, suspended solids in the discharge water were also measured.

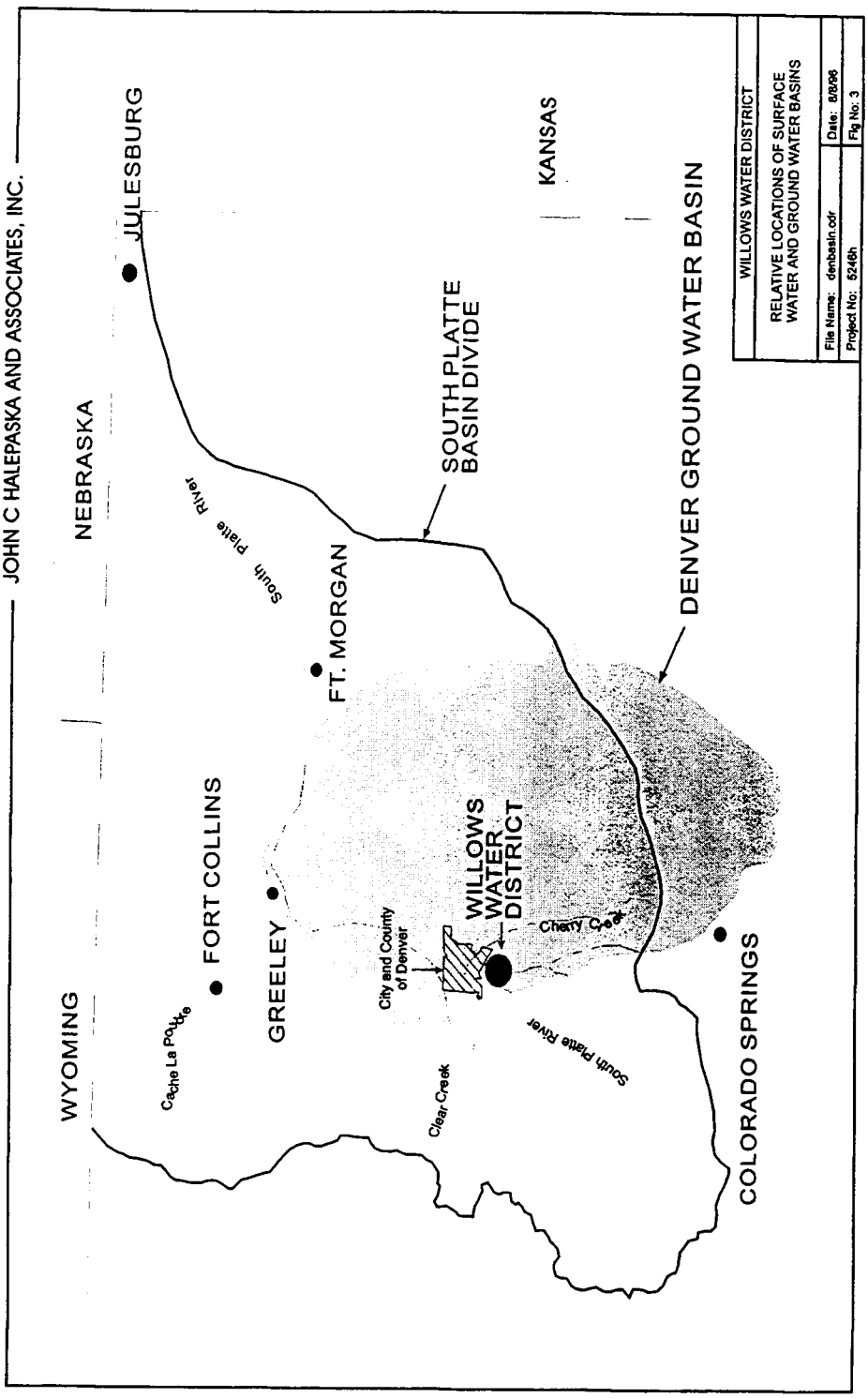
No harmful long-term water quality trends are evident. Samples from the injectate, injection/recovery well and a monitoring well have all been well below all federal and state standards. A quality assurance/quality control (QA/QC) program was established to ensure that the data collected was complete, accurate, representative and comparable. This program was designed to provide measurements that were of known quality, technically sound, statistically accurate, properly documented and representative of the media being measured. EPA approved the QA/QC plan.

Water temperature changes have caused some concern as Strontia Springs water is some 30° F colder than Arapahoe aquifer water. As a result, the introduction of the colder water into the warmer aquifer has increased viscosity overall and reduced pumping efficiency and yields. A reduction in the well specific capacity, defined as the flow rate that can be achieved from a well per unit of water level drawdown, results in additional pumping costs to pump the same amount of water from the well. Declines in well specific capacity continued as more cold water was injected into the Arapahoe Aquifer. However, over time, as the large cold water mass stabilized, so did well specific capacities. As the colder water warms, the negative effects will diminish.[9]

Also of note, great care was taken not to expose the aquifer to the atmosphere, and injection rates and pressures were varied in order to avoid breaking suction and in training air in the injectate.

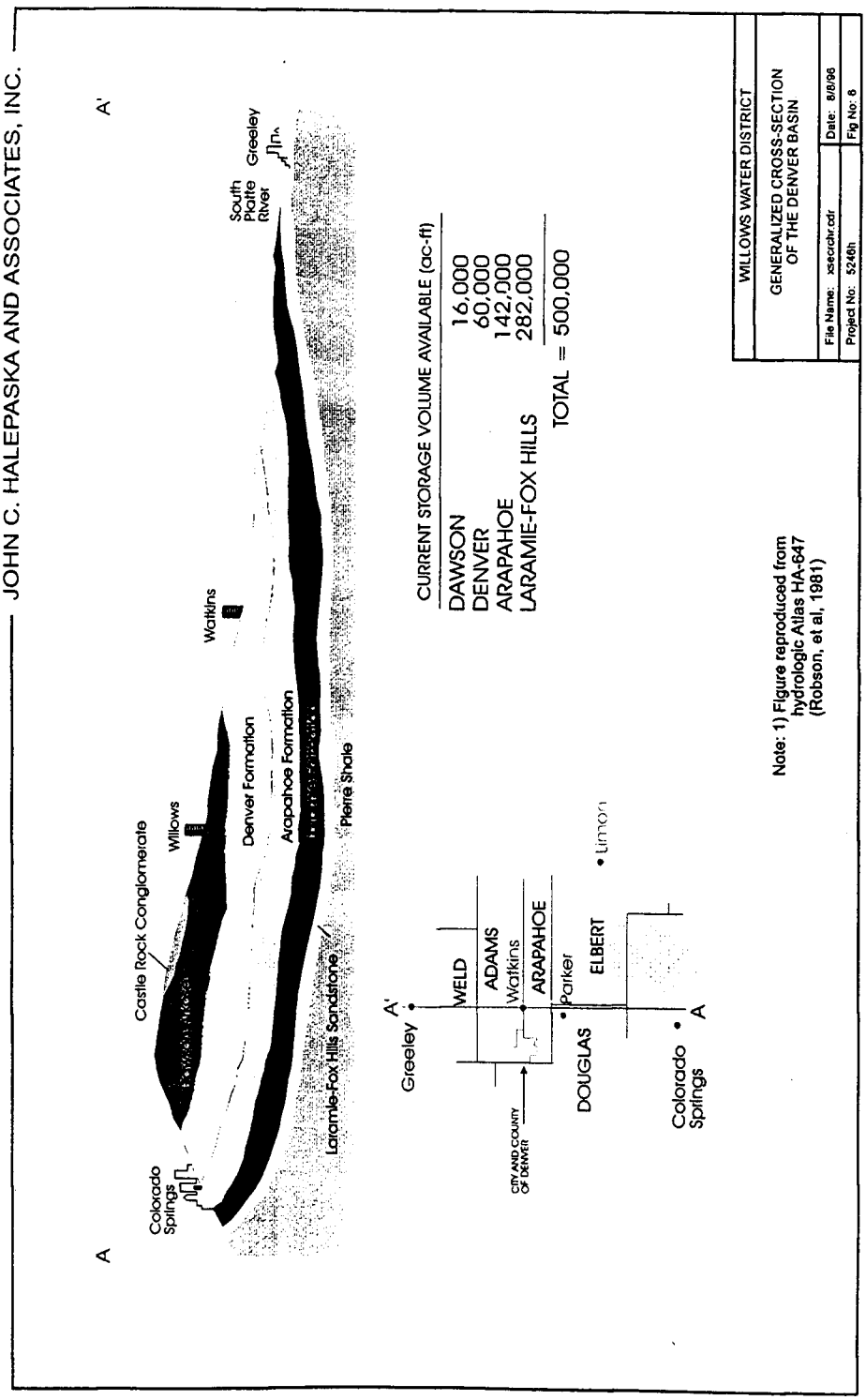
[9]Final Report, Denver Basin Aquifer Recharge Demonstration Project, John C. Halepaska & Associates, Inc., January 1997, p. 31.

The Willows Water District
Denver Ground Water Basin and South Platte River Drainage



Source: Final Project Report, John C. Halepaska and Associates, Figure No. 3

Denver Basin Formations



Source: Final Project Report, John C. Halepaska and Associates, Figure No. 6

ECONOMIC EFFICIENCY AND FINANCIAL FEASIBILITY

Banking surplus surface waters to augment ground water supplies provides protection from drought and is a practical water management alternative to meet peak summer demands. Willows' Manager, Mr. Le, believes the project is also economically efficient and financially sound. However, no specific macroeconomic and hydrologic evaluation is available which carefully considers the possibility of storing a lot of water in the aquifer over a long period of time. It is also difficult to estimate future costs and the value of any water that might be stored.

Still, given its particular advantages, a recharge and conjunctive use strategy can be competitive compared with other water supply alternatives in certain circumstances. A major advantage of such a strategy is the opportunity to maximize the use of existing facilities and their off-peak operating capacity. Existing production wells may be retrofitted for much less than the cost of developing a new well. Water treatment plant capacities, under utilized during the off season, may be more efficiently operated. There is more flexibility with the availability of raw water supplies, which may be diverted when demands are low. Existing distribution system infrastructure may be used. Water may be stored in a less environmentally invasive way. These are important advantages.

Also, on a much smaller scale, greater efficiency and economies of scale appear to have been realized with respect by the size of the Willows project injection well and pump. One 1,500-gpm well can produce enough water to serve 1,075 households, while a typical 300-gpm well serves 215 households. However, the technological limitations and the marginal costs calculated for the project to go even "bigger" indicate that it would be a poor investment.

Project Costs and Cost Sharing

The original authorized cost of the Willows project was $3,066,978 in 1990, with a federal contribution of $1,739,551. The federal share was increased by $80,000 to fund well rehabilitation in 1994, $65,000 to expand the scope of work in 1995, and another $74,500 to continue the demonstration through fiscal year 1996. The total federal share was $1,959,051 and the total budget $3,288,578. The remaining non-federal cost share then is $1,329,227 or 40% of the total. Early project costs are presented in detail on the next page.

Willows' share of the project's costs have been primarily for the land, pumphouse, in-kind management and other similar services, as well as the cost of the existing pumphouse, 600 horsepower motor, computer and telemetry equipment, and other facilities. One additional monitoring well, beyond those developed by the Willows District for its own monitoring program, was required under the High Plains Program. Federal monies paid for retrofitting the production well for injection, constructing a pipeline, and the consultant fees. According to Willows, such federal financial assistance was critical to the successful development and construction of this project.

Of the non-federal cost, Willows' share is about $550,000, spread across its service population. Denver Water's contribution of treated surface water for injection is nearly $750,000 or the price Willows would have had to pay for its use up-front. Denver Water's wholesale cost of off-peak season water from the Denver Water Board is $1.15 per 1,000 gallons. Denver Water's costs are distributed across a larger service area.

Denver Basin Project Budget

(as of June 30, 1992)

FY 1991:

Federal contribution:		($ 64,444 over-budget)
Pre-project costs =	$ 17,500	
Well A-6A =	543,201	
Injection retrofit =	373,162	($115,162 over budget)
Monitoring well installation =	109,259	($ 741 under budget)
Instrumentation =	11,111	($ 889 under budget)
Data collection and evaluations =	40,551	($ 13,449 under budget)
Analytical costs =	6,249	($ 28,751 under budget)
Project management =	14,009	($ 4,639 over budget)
Reporting =	4,473	($ 10,527 under budget)
Subtotal	$ 1,119,515	
Sponsor's share:		
Pre-project costs =	$ 30,000	(budgeted same)
Additional well A-6A costs =	214,427	(budgeted same)
Legal fees =	3,350	(budgeted $10,000)
DWD water =	000	(budgeted $156,000)
Subtotal	$ 247,777	
Total FY91	$ 1,367,292	

FY 1992:

Federal contribution (over budget by $70,922 or an additional $6,478)

Injection retrofit =	$ 50,351	(nothing budgeted)
Pump removal/installation =	000	($ 8,000 budgeted)
Data collection and evaluations =	39,039	($55,000 budgeted)
Project management =	15,636	($ 9,370 budgeted)
Reporting =	8,532	($15,000 budgeted)
Analytical costs =	15,291	($35,000 budgeted)
Subtotal	$ 128,839	
Sponsor share:		
Legal fees =	$ 3,584	($10,000 budgeted)
DWD water =	48,341	($174,000 budgeted)
Subtotal	$ 51,925	
Total	$ 180,764	

The estimated cost of recharge and recovery is $2.45 per thousand gallons, using existing facilities. Some of the major project costs included retrofitting the well to allow injection, the cost of the water recharged, operation and maintenance (O&M) costs of the well, water quality sampling costs, and costs to recover the water. The well retrofit costs included the pipeline interconnection, vault installation and modifications to accommodate injection. It is assumed that required equipment will have a 20-year useful life, the cost of the water is Denver Water's current wholesale rate, O&M and monitoring costs would be about half those for the demonstration project, and recovery costs are similar to Willows current electrical costs for pumping from the Arapahoe aquifer. These costs are summarized below.

Injection/Recovery Costs
(per 1,000 gallons)

Well Retrofit	$ .06
Cost of Water	1.65
Operation and Maintenance	.19
Water Quality Sampling	.10
Pumping/Recovery	.45
Total	$2.45

Source: Final Report - Denver Basin Project, Table 6

Project Benefits and Beneficiaries

The Denver Basin recharge project directly benefits the Willows Water District and Denver Water. The recharged water is first available for use by Willows. If the District uses the water within its service area, it will pay Denver Water the wholesale price (at time of extraction), minus any costs Willows incurs for injection and recovery. Also, artificially enhancing natural recharge has raised the head in Willows' wells, thus lowering pumping costs.

Denver Water may recover the recharged water to supply its own customers, after paying Willows for its costs. Of note, Denver Water is also responsible if the water is somehow "lost," by deep percolation or migration, etc.

The conjunctive use of surface and ground waters could provide significant benefits to Denver Water by "smoothing out" its capital cost requirements related to supplies and demands. The tremendous idle water treatment capacity could be more fully utilized during the fall through spring, injecting treated water for withdrawal around the peak summer demand season with only chlorination needed before putting the water into its distribution system. Recharge and recovery becomes especially attractive if water can be injected at locations adjacent to available sources of water for remote extraction/withdrawal in areas where peak demands may be difficult to meet with Denver Water's existing distribution system.

Long-term storage of large amounts of water for meeting peak demands or for protection against drought would also be significant. For example, if 5,000 acre-feet of injected water were banked each year and allowed to accumulate over a ten-year period, then 50,000 acre-feet (or approximately one-tenth of the normal annual water use in Denver Water's service area) could be available to significantly reduce the negative effects of any future drought.

All of the metropolitan area will benefit indirectly from the demonstration project and the potential augmentation of future water supplies.

Project Financing and Cost Recovery

Willows Water District is a quasi-municipal corporation, authorized to provide utility service to a specific geographical area.[10] The District's annual budget averages about $1.5 million per year for operations, maintenance and water acquisitions. Its revenue comes from water use fees, tap fees, interest income, ad valorem property taxes, and specific ownership taxes. Its board determines fees, which are designed to ensure "reasonable use" of its finite water resources. Its operating expenses are covered from a water fees fund, as well as ad valorem property taxes, which also are the basis for debt service. The District is financially sound. Its general obligation bonds have Aaa and AAA ratings, by different rating services.[11]

Effective January 1, 1998, new 3/4 inch taps cost $7,660 and money from new customer connections is used to help pay for the high-capacity production and injection well. However, residential areas are almost "built out." Only about three percent of the land remains available for building and the District's unallocated taps number just a few hundred. Therefore, Willows future role is mainly to maintain its water system in prime operating condition, while assuring its customers a reliable, cost-effective and long-term supply.

Willows' average cost per 1,000 gallons of chlorinated ground water is $.90, compared to Denver Water's wholesale cost for treated drinking water of $1.15 during the colder months and $1.45 during the six-month outdoor watering season. [Denver Water's more current wholesale rate is $1.65 per thousand gallons.]

As Willows is a relatively small district and the incidence of project benefits are general, there appears to be no need to attempt to identify and define and allocate specific benefits to different water users. Project costs have been paid from general revenues. Denver Water's costs have been similarly distributed across its service area.

Denver Water's $750,000 opportunity cost for supplying the water for the project, spread across the 500,000 taps in their service area, is about $1.50 per tap/customer.

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[10]Colorado Special Districts Act.

[11]Information pamphlet published by the Willows Water District.

LEGAL AND INSTITUTIONAL ISSUES

Colorado law did not specifically address recharge as a primary project purpose and there was no legal framework to allow for the injection, storage and extraction of recharged water in the Denver Basin when the Willows project was proposed. However, ground water recharge activities have been undertaken in Colorado since the 1960s and conjunctive use of surface and ground waters has been encouraged by the state as a means to maximize beneficial use. Given experience and the need to specifically address the present and future use of recharge and recovery technologies, state water administration has evolved.

Legal issues appear to have been resolved with respect to the project, but the future large-scale use of recharge and recovery programs raises a number of legal questions related to maximizing the benefits of the technology while continuing to protect the state's water resources and other water users. The potential economic benefits of remote extraction have been mentioned. The legal ramifications are discussed below, along with the state's new artificial recharge extraction rules and initial approach to regulating ground water recharge and recovery activities. The implications of such projects as an alternative to surface water reservoir storage are also discussed.

State Water Law

Artificial recharge has been recognized administratively as a beneficial use, though the state does not issue permits for recharge. Surface waters could be spread or injected under a valid water right. Moreover, recharged waters could be recovered, with the state issuing a general well permit for the withdrawal of recharged water. However, before a well permit was issued, a project operator was required to demonstrate that dominion and control over the recharged water had been retained and withdrawal of the recharged water would not cause injury to any other well or water right.[12] In this same manner, the recovery of recharged waters could be controlled and limited to protect the rights of the project operator through the state's general authority to permit ground water extraction.

At the request of the Willows Water District, in 1993, the Colorado Division of Water Resources considered the issue of the extraction of injected waters and the State Engineer's Office issued a permit to Willows to extract water recharged by injection specifically through and from well A-6A. The permit requires that any water recharged be extracted within five years.

On April 13, 1994, the Colorado State General Assembly passed Senate Bill 94-097 and directed the State Engineer to promulgate reasonable rules to govern the permitting and use of waters artificially recharged into the Denver Basin to "effectuate the maximum utilization of these aquifers through the conjunctive use of surface and ground water resources." Under this authority, and utilizing data gathered as part of the demonstration project, the state held public hearings and adopted the Denver Basin Artificial Recharge Extraction Rules, effective July 1, 1995.

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[12]Colorado response to Western States Water Council questionnaire, March 15, 1990.

Artificial Recharge Extraction Rules

The purpose of the rules and regulations is to enable the State Engineer to account for and administer the orderly extraction of water which has been artificially recharged into any of the Denver Basin bedrock aquifers, and to prevent injury to existing water users and water rights holders. The rules recognize that the naturally occurring waters of the Denver Basin bedrock aquifers are essentially nonrenewable by natural processes, and that artificial recharge using surface water or other ground water available during periods of low demand or excess capacity can prolong the life of this valuable resource. Water recharged may be left in the aquifer, resulting in lower rates of decline in local or regional water levels, or extracted during periods of drought, thus maximizing the conjunctive use of the waters of the state.

The rules and regulations apply only to the bedrock aquifers of the geographic Denver Basin, i.e., the Dawson, Denver, Arapahoe and Laramie-Fox Aquifers and the extraction and use of waters artificially recharged.[13]

Whereas Willows initial well permit only allowed recovery of recharged waters from the same dual purpose injection well, the new rules provide for the extraction or withdrawal of artificially recharged water through an existing well, or through a well specifically constructed for that purpose. Before issuing an extraction permit, the State Engineer must first determine that water was legally recharged and that it is physically available for extraction without injury to other water rights and in compliance with all applicable statutes and rules.

The 1995 rules define and limit the use of remote extraction wells, i.e., any well other than that used to inject the water, in both confined and unconfined aquifers. With respect to a confined aquifer, water may be extracted from a remote site located within the same contiguous extraction parcel, but in no case more than five miles from the farthest injection site. A contiguous extraction parcel is defined as a parcel overlying naturally occurring ground water decreed or permitted to the applicant, with no part that is totally separated. If at any point between the injection and extraction sites the aquifer becomes unconfined, as determined by the State Engineer, the rules governing unconfined aquifers apply and limit remote extraction to within 1,000 feet from the farthest injection site.

The rules also specifically address artificial water banking and limit the amount of water available for extraction. Artificially recharged water may be banked or retained in the aquifer indefinitely by the person or entity injecting the water, and such a right may be assigned, but the maximum amount of artificially recharged water that may be extracted from an aquifer through any one extraction well in any one calendar year shall not exceed five times the maximum amount of water injected into that aquifer in any one calendar year, and in no case shall exceed the total amount of water injected.

Ultimately, one of the major benefits of ground water recharge and the extraction of water at remote locations could be the use of an aquifer in lieu of an expensive distribution system. Significant savings might be realized if water could be recharged into a confined aquifer and extracted elsewhere when and

[13]Cover memorandum from Glenn Graham, Office of the State Engineer, dated September 18, 1996, accompanying a copy of the artificial recharge extraction rules.

where the water was needed and could be tied into an existing distribution system. However, technical and legal questions would have to be answered. The State Engineer may allow extraction from a non-contiguous parcel if an applicant can show compliance with the intent of the rules to protect the public safety, health and the environment, as well as prevent injury to other existing water users and water rights.

Federal Environmental Laws

In addition to securing required state well permits for extraction and monitoring, Willows also had to get authorization from EPA for the injection of treated water under the Safe Drinking Water Act's Underground Injection Control (UIC) program (for a Class V injection well). The application of federal environmental statutes has limited new surface water development and may have a significant and determining effect on the future use and expansion of recharge and recovery projects and programs in the Denver Basin.

The Two Forks Project

Denver Water's senior water rights to the South Platte River provide it with an ample surface water supply, but the growing suburban areas surrounding Denver could face shortages and restrictions on future development without development of additional water supplies. This has become an important metropolitan issue. Over a decade ago, concerns over the potential for Denver to annex surrounding lands and communities led to a state constitutional amendment prohibiting the city from annexing land without permission from the county that would lose it. This created a unique political situation, and left Denver with excess water supplies -- for the present.

In this context, the city has sought to use its water as a bargaining chip in negotiations over a number of issues meriting metropolitan cooperation, i.e., schools, hospitals, cultural facilities, its new airport, etc. The city would help other metropolitan communities meet their water needs, in return for cooperation on other projects. However, before committing to making its water available to surrounding communities, Denver sought to guarantee a dependable future water supply for its citizens by increasing available surface water storage on the South Platte River.

Denver proposed the Two Forks project as a means of providing some security and as the keystone for cooperation among metropolitan water providers. The $400-$500 million dollar dam would have created one million acre-feet of new storage with a yield of 90,000-100,000 acre-feet of water per year to help meet the needs of a metropolitan population projected to be 2.25 million by 2010. However, it would also flood a 28-mile stretch of the South Platte River upstream from Denver, including Cheesman Canyon, prized for its fishery and whitewater recreation. The debate over the dam deeply divided Colorado's leaders and citizens, and raised issues of national interest.

For eight years, the Denver Water Board and other co-sponsors sought support for the Two Forks project. Denver sold shares in the project to 42 other towns and water districts, which together constituted the Metropolitan Water Providers (MWP). Willows purchased a two percent share in the project in hopes of augmenting its ground water supplies.

MWP also spent some $40M for one of the most comprehensive/expensive environmental impact statements ever, only to have a lengthy and complex environmental review culminate

in the U.S. Environmental Protection Agency's veto of a federally required 404 permit, under the Clean Water Act, to build the project. EPA reasoned that other less environmentally damaging water supply alternatives were available, but made few suggestions.

While Colorado Governor Roy Romer expressed serious concerns about the present need for the Two Forks Project, and about the consequences for the environment, he recommended approval of a permit for the project, finding that it would serve Colorado in three principal ways. First, it would allow the metropolitan area water providers to jointly develop and share interim supplies. Second, it would preserve the fragile institutional relationships among the water providers in the metropolitan area. Third, it would serve as a structural long-term source of supply in the event that other alternatives could not be utilized.[14] The governor's recommendation was based on institutional and environmental considerations.

Without the Two Forks project as a catalyst for cooperation among metropolitan water providers, new competition for water to attract or support suburban growth threatens wasteful and fragmented water development along the Colorado Front Range--with its own potentially serious adverse environmental consequences.

Denver Water turned its attention to other water supply and management alternatives, including water conservation. It also agreed to participate and provide water for the Willows Water District's proposed ground water recharge demonstration project as a potential innovative water supply strategy for meeting the Denver area's growing water needs.

Given the Denver Basin Project as a model, an expanded conjunctive use system of recharge and recovery wells could provide the same storage and possibly the same institutional benefits from metropolitan cooperation that the Two Forks project was designed to achieve, without the environmental costs.

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[14]Governor's comments submitted to the U.S. Army Corps of Engineers regarding the proposed Two Forks project as reported in Western States Water, # 863, November 30, 1990.

CONCLUSIONS

The Willows project is the most significant in the country that uses a deep, confined aquifer of sandstone-conglomerate material for injection, storage and recovery of potable waters. Demonstration of its technical and economic feasibility could be a valuable model for application in other parts of the country.

The capital stock in Willows and Denver Water are largely idle during the off-peak, winter season. Use of idle water treatment and delivery capacity makes better use of expensive capital investments in these water systems.

However, Denver Water's aversion to commingling surface and ground waters required construction of a separate pipeline parallel to one of Denver Water's existing pipelines, in order to avoid commingling Willow's ground water with Denver Water's surface water. This institutional bias could become an interesting part of the ongoing debate on providing water to the burgeoning Denver area.

Denver Water and Willows, both being urban water supply entities, are in a position to pay for the relatively costly infrastructure needed to provide a readily available drought supply through aquifer recharge and recovery.

The Colorado Division of Water Resources developed regulations for the remote extraction and use of injected waters at remote locations within the Denver Basin under the direction of the legislature and in response to development of the Willows project.

Greater economic benefits from injection and withdrawal can be realized if remote withdrawals from the aquifer prove feasible.

The opportunity to use existing injection wells and develop future injection capabilities (where surface water can be delivered cost effectively) while withdrawing water where the greatest demands exist could yield substantial savings in the future for distribution and delivery systems that otherwise may be required to use injected water.

Denver Water and Willows cooperation in this successful project could lead to increasing acceptance of aquifer storage and recovery (ASR) activities. Conjunctive use may become important in providing seasonal storage of Denver Water and other water districts' supplies, given that extraction from remote wells is also allowed.

The same water supply and institutional benefits from metropolitan cooperation that the Two Forks project was designed to achieve, might be realized through an aggressive ASR program, without the environmental costs.

YORK, NEBRASKA

BACKGROUND

The York project is located near York in southeastern Nebraska, about 50 miles west of Lincoln, on the eastern edge of the Ogallala aquifer. The Upper Big Blue Natural Resources District (NRD) is the project sponsor. With rich, black soil and what was once considered an almost limitless supply of ground water, the Big Blue area is one of the most prosperous farming regions in the world. Average precipitation is around 26 inches per year, but significant variability is not unusual. In 1939, an 80-foot hand dug well near Henderson, one of the first deep wells in Nebraska, provided water to irrigate 70 acres of corn. With a steady water supply, harvest yields jumped from 30 to 70 bushels per acre, and deep well irrigation was soon established.[15]

Nebraska is second in the nation in irrigated acreage, behind California, and ahead of Texas. The Upper Big Blue is one of the most intensely irrigated areas in the state with over 10,400 deep wells (about 16% of the total in Nebraska) supplying one million acres (of 8 million acres irrigated in the state). The Upper Big Blue NRD covers nearly 3,000 square miles or 1,827,840 acres. The District includes all or part of nine counties, and has a population of more than 55,000. About 96% of the District is agricultural land, and about 67% is irrigated.

Since the early 1950's, irrigated agriculture has provided a basis for reliable crops and stable farm income. "York and the surrounding area is rather prosperous, with the towns doing well and the farmers more-or-less doing well. The key is irrigated land."[16] An average farm is about 1,000 acres. Class I irrigated farmland is valued at between $2,500 and $3,000 per acre, compared to $1,000 to $1,800 per acre for dry land and $500 to $800 per acre for pasture.

Declining water tables are a major concern of the Upper Big Blue NRD, given the importance of irrigated agriculture to the local economy. Water levels dropped between five and 30 feet from about 1960 to 1980. However, as a result of changes in farm economics, tillage practices (such as minimum tillage), and more efficient irrigation methods (such as the use of center pivot technology), water levels have recovered.

There are separate upper and lower aquifers. The deep aquifer is under pressure, and is the major source of supply. During the irrigation season, local concerns center on its rapid drawdown. Once irrigation wells start up, water levels drop by about three feet within two weeks, and gradually recover after the irrigation season ends. Ground water levels are closely monitored and measured each spring and fall.[17] Spring readings are the better measure of water table changes because of the influence of irrigation pumping on the fall readings.

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[15] Your NRD, a pamphlet published by the Upper Big Blue NRD.

[16] Personal interview with John Turnbull, General Manager, and Jay Bitner, Upper Big Blue Natural Resources District, May 14, 1992.

[17] Ibid

Spring 1991 ground water level readings showed a slight increase across the District, compared to a drop of nearly a foot the previous spring. Fall 1991 measurements showed an average decline of 2.4 feet, compared to a district-wide average rise of .35 feet recorded the previous fall. The most noticeable swings in 1991 water levels occurred across the southern part of the NRD near the towns of Harvard, Sutton, Fairmont and Exeter, along U.S. Highway Road 6. Seasonal declines ranged from 2.8 to 13.6 feet.[18] Erratic precipitation directly influences irrigation demands, ground water pumping, and water tables.

The Upper Big Blue is one of several state-approved ground water management areas (for quantity), and the District's board has adopted rules requiring agricultural users to report the "number and location of ground water use acres and wells" under their control. Any well not reported is considered to be illegal. Annual ground water pumping is limited to 16 inches of water per acre. The District has authority to require measuring devices, limit withdrawals (from wells with a capacity greater than 100 gallons per minute), regulate well spacing (1,000 feet to one mile), adopt a rotational use system, and if necessary, place a one-year moratorium on pumping. The NRD may issue cease and desist orders that may be reviewed and enforced by order of a state district court.

[18] "District Average Groundwater Level Remains Same as Last Year According to Spring Measurements," Blueprint, quarterly newsletter of the Upper Big Blue NRD, July 1991, and "District Average Groundwater Level Drops Over Two Feet According To Fall 1991 Measurements," Blueprint, January 1992.

Across Nebraska and within the Upper Big Blue NRD, there are also serious concerns over water quality. High levels of nitrate-nitrogen from fertilizer and the herbicide atrazine threaten both surface and ground water quality in many areas where corn is irrigated. Pesticides are also found in late spring runoff. Under state law, the Upper Big Blue NRD has established a ground water management area (for quality).

While discussed further later, NRDs also have authority as a political subdivision of the state to levy taxes, within limits, on all private, real property within the District. Taxes are collected by the counties, and expended by the District's elected board of directors for various projects and programs.

Project Purposes

The York project is truly a multipurpose project that fulfills specific goals set forth in the Upper Big Blue Natural Resources District's general master plan, as well as the Bureau of Reclamation's High Plains ground water recharge demonstration program. Under a cooperative agreement, the Environmental Protection Agency (EPA) is also involved, and has its own agenda and objectives.

One project purpose is to demonstrate the effectiveness of recharge from small reservoirs as a means of maintaining ground water levels. The York Project demonstrates artificial recharge opportunities using both spreading basins and injection wells. The information collected is perceived by the District as even more valuable than the additional agricultural water supply. The data will be used to analyze the effectiveness of different artificial and natural recharge methods, and perhaps most importantly the effects on ground water quality.

Another purpose is to test and evaluate the effectiveness of different water treatment methods for removing herbicides, as well as other pollutants that threaten local domestic and municipal water supplies.

Recreation is another significant project purpose. Again, the York project was part of the NRD's long range general master plan, but as a recreation project, it was given a low priority for local funding.

Municipal water supply is not a local problem and is not a project purpose, except to the extent that the information on water treatment methods may be valuable in the future. The use of some wells in the NRD has been lost due to pollution, and municipal wellhead protection programs are important.

Project Description

The York recharge project consists of a dam and reservoir, spreading basins, and an on-site water treatment facility and injection well. It is testing the practicality and effectiveness of recharge from reservoir seepage, seepage from the two spreading basins, and direct injection after treating water to drinking water quality standards. The dam is on an intermittent stream (tributary to Beaver Creek) that drains about 7,500 acres of land, nearly all irrigated cropland, and creates a reservoir named Recharge Lake. The reservoir has a surface area of about 50-55 acres and a normal storage capacity of 310 acre-feet. The dam's chute spillway was designed to maximize water storage and conserve land.

Two small recharge basins and the injection well are used for artificial or "intentional" recharge. The west basin is an old oxbow stripped of vegetation, while the east basin was a corn field that was excavated to a depth of three feet. Untreated water is diverted into these basins for recharge over a period of 30 to 70 days. Basin maintenance includes chiseling to a depth of eighteen inches with a tractor (to increase recharge rates and reduce retention time by about seven days).

Recreation components of the project include a small visitor display, picnic facilities, fishing access, a boat dock, and wildlife habitat and other plantings.

A water treatment plant, with a capacity of some 100 gallons per minute, will test and demonstrate a new technology using activated carbon pre-coat filtration and ozone oxidation to remove herbicides from the water supply. The plant filters out solids (for disposal to a landfill) and reduces pollutant levels. Some treated water will be recharged by injection. The plant is designed to run eight to twelve hours per day, and similar facilities could be used in the future to treat contaminated municipal ground water supplies for small communities of 200 to 800 people. The project will help provide information to compare the cost effectiveness and efficacy of the experimental treatment technology with reverse osmosis and ion exchange processes currently used by local municipalities. The treatment plant will be dismantled at the end of the demonstration period.

Paired monitoring wells at eight sites surrounding the project are used to test and evaluate the effects of recharge on ground water quality. These well sites are shown hereafter on the project map.[19]

The project was completed in the spring of 1991, and the new spillway was soon tested by a 100-year storm event. The new reservoir filled and overflowed, with no apparent problems. However, the timing of the storm unfortunately coincided with the application of

[19] Project map provided by the Upper Big Blue NRD.

the pesticide atrazine by local farmers to their corn crop. Tainted agricultural runoff filled the reservoir with unusually high levels of atrazine that began appearing in the monitoring wells down gradient. This raised significant concerns over potential ground water contamination and liability, as well as interagency conflicts over what should be done.

Water Supply and Recharge

The intermittent stream on which the project sits provides only about one-quarter of the water supply for the project, and runoff from the small watershed cannot provide stable reservoir levels for recharge and recreation. Therefore, another source of supply had to be found. The York Cold Storage Company is a refrigerated storage facility nearby that uses ground water for its cooling system. The process water is unchanged chemically, and was discharged to another creek. This water was acquired, and it is now delivered to the project via a buried pipeline that can carry up to 450 gallons per minute.

Unexpectedly, a much larger share of the water recharged has come from recharge through the reservoir bed. The spreading basins have also recharged more water than estimated. Problems with equipment and the treatment process delayed the use of the injection well for recharge, and pumping to backflush filters and test overflow safeguards actually created a debit against the amount of project water recharged, as shown below. The sources of supply and total amount of water recharged from December 1990 through April 1992 were as follows:

Estimated Recharge
(acre-feet annually)

Reservoir	312 af
Basins	24 af
Injection well	156 af
Total Recharge	492 af

Actual Recharge

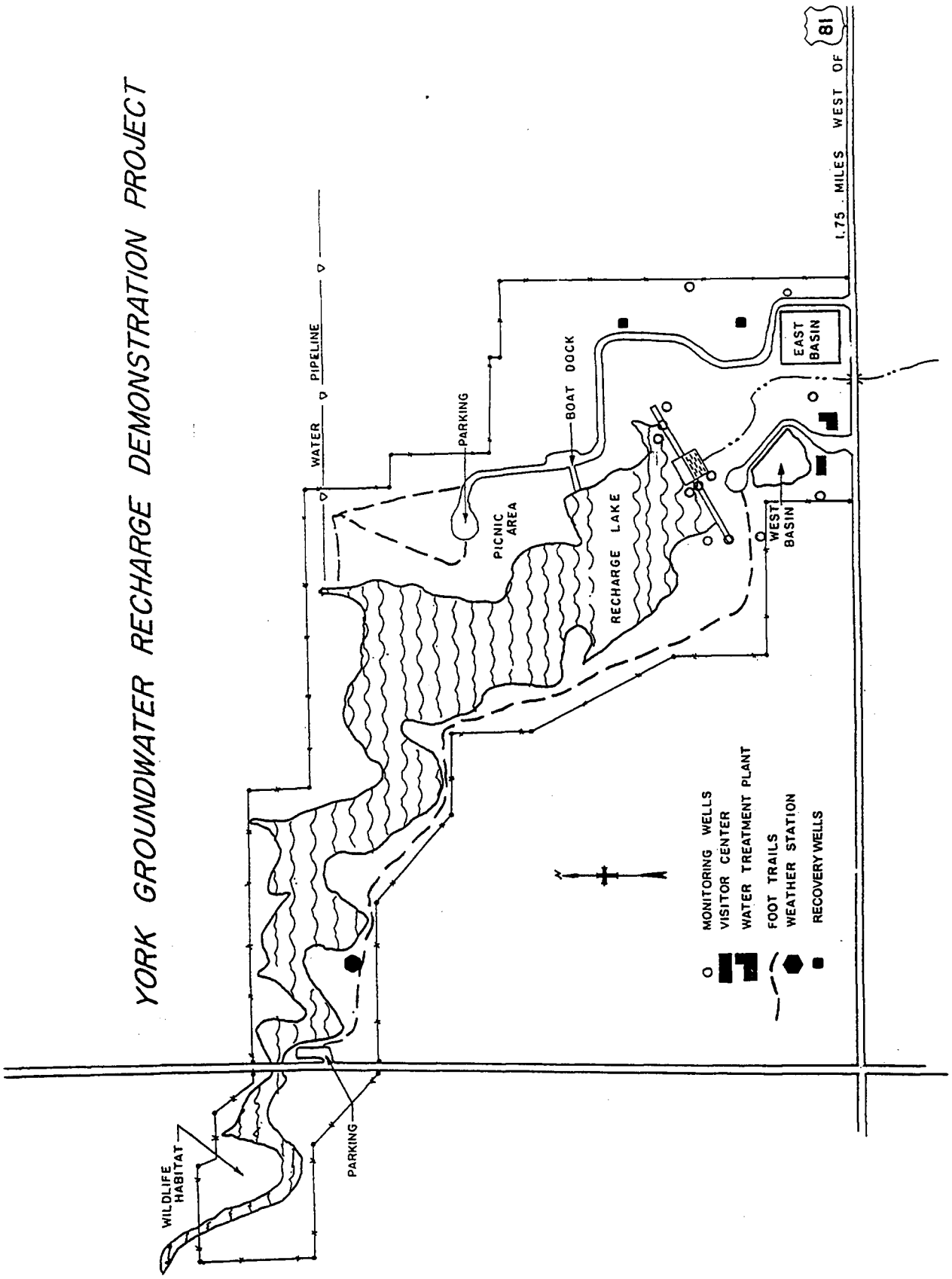
Reservoir	881 af
Basins	39 af
Injection well	- 3 af
Total Recharge	917 af
Inflow	
Cold storage pipeline	790 af
Watershed runoff	240 af
Total	1, 030 af
Less	
Evaporation	83 af
Storage	30 af
Net Recharge	917 af

Water Quality

Project impacts on water quality have been mixed. During the Spring of 1991, as described earlier, agricultural runoff filled Recharge Lake and raised atrazine concentrations to alarming levels at first estimated to be at least six times the three parts per billion (3 ppb) maximum contaminant level (MCL) standard for drinking water set by EPA. Atrazine levels in water samples from Recharge Lake actually varied from 93 ppb to .30 ppb from June 1991 through March 1993. Atrazine levels reached 9.3 ppb in one shallow monitoring well adjacent to the reservoir. In March 1993, atrazine was detectable in five of eight monitoring wells and exceeded the MCL (3 ppb) in two wells.[20] Each summer, atrazine levels rise with runoff from cropland while dropping through the winter months.

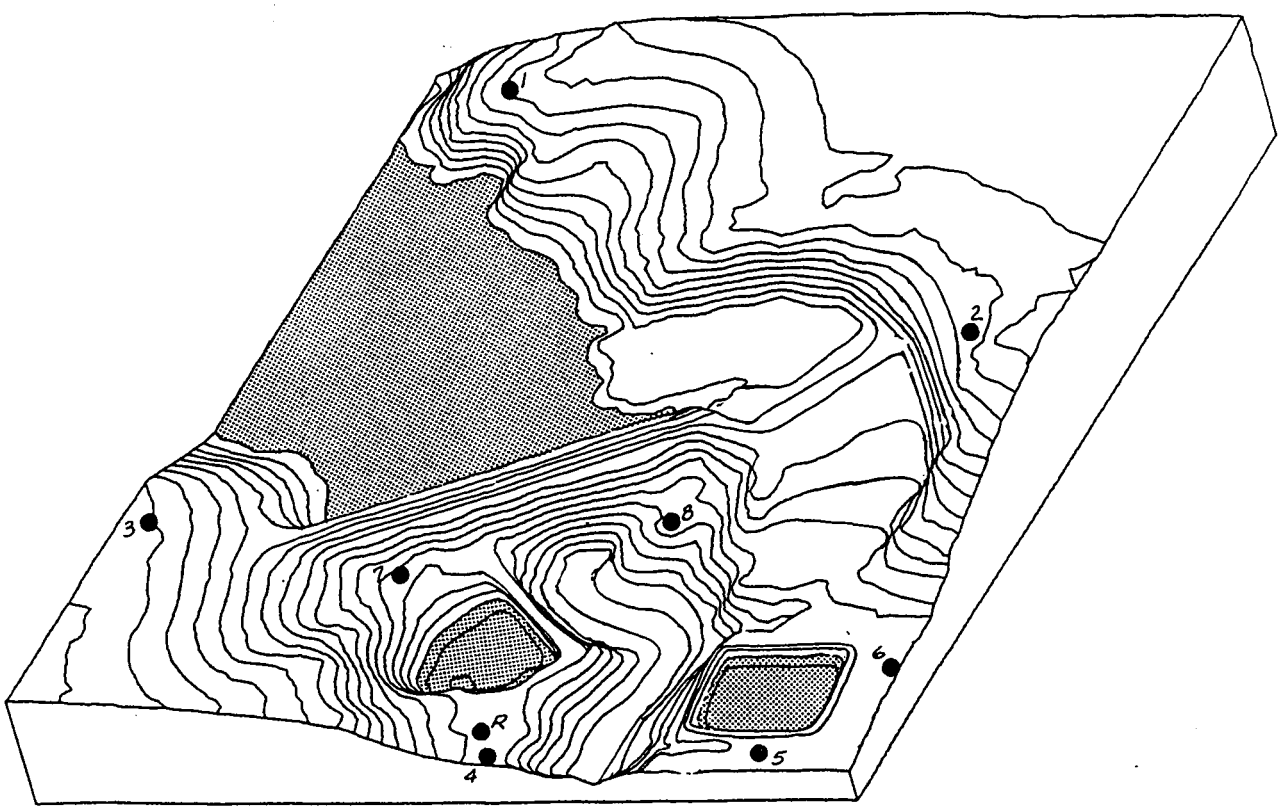
[20] High Plains States Groundwater Demonstration Program, Interim Report, U.S. Department of Interior, Bureau of Reclamation, October 1993, p. 51.

York Project Facilities



Source: Upper Big Blue Natural Resources District

York Project Recharge and Monitoring Well Sites
(Topographical Map)



Source: York Nebraska Ground Water Recharge Demonstration Project Final Report, Drawing 4-1, p. 57.

No atrazine has been detected in the lower aquifer, and no atrazine was found in nearby domestic drinking water wells. However, due to the elevated atrazine levels, operation of the injection well was suspended in 1991. Later, water to be injected was unsuccessfully pretreated using ionized air and ozone to remove atrazine and other pesticides. A direct filtration system using powdered activated-carbon was effective in reducing atrazine levels from 3 ppb to .5 ppb.

However, direct injection never took place as the unconventional treatment techniques could not accomplished the 100% bacteria kill required by the project's Underground Injection Control (UIC) permit, under the Safe Drinking Water Act. Ultraviolet disinfection reduced bacteria from several hundred colonies per 100 milliliters (ml) to zero to three per 100 ml. As the cost of conventional treatment methods would be prohibitive, and the intent of the project was to demonstrate new technologies, the District discontinued direct injection efforts in April 1993.

The York demonstration project was extended for two additional years and federal funding was increased in order to add more monitoring wells to study the fate and transport of atrazine in the ground water aquifer. Moreover, as a result of meetings between the NRD, EPA, Reclamation and the state, a pesticide management plan was developed to protect beneficial uses of ground water. In addition to the placement of more monitoring wells, the plan calls for an increase in the frequency of monitoring, different contingency project operating rules, and provision of an alternative source of drinking water to replace local supplies from domestic wells should atrazine levels ever exceed the 3 ppb MCL. The plan should protect public health and allow the project to proceed.

Hopefully, the work with pesticides and herbicides will provide a better understanding of the potential water quality impacts of similar future recharge projects, as well as any existing natural impoundments.

With respect to nitrate-nitrogen (NO_3-N) pollution, lake surface water levels are usually less than six mg/l. Levels in two monitoring wells improved from six and 12 mg/l NO_3-N to near zero, which is far below background levels. Levels in other monitoring wells declined from 16 mg/l to around four mg/l NO_3-N. Another well's NO_3-N levels have changed very little. The improvements have been attributed largely to recharge through the lakebed, which dwarfs the designed recharge through the spreading basins and injection well.

Of note, the Upper Big Blue NRD maintains an ongoing ground water testing program that monitors nitrates in domestic and irrigation wells. Approximately 400 domestic wells are tested annually and another 400 irrigation wells are tested on a four-year rotation. Individual domestic wells within the District will be sampled and tested at no charge upon a user's request. The District also tests a total of 25 to 30 domestic wells annually for fourteen pesticides commonly used in the area.[21]

[21] Upper Big Blue NRD Programs and Cost-Share Practices, September 1991, p.19.

ECONOMIC EFFICIENCY AND FINANCIAL FEASIBILITY

The Upper Big Blue NRD is providing the required 20 percent non-federal share of the project's costs, which includes District staff time. While the water supply is important, from the District's perspective the information on recharge and its impacts on ground water quality are more important. Recreation features of the project are also important. They were a primary reason for the District sponsoring the project and define their "willingness to pay."

Project Costs and Cost Sharing

The total budget for the project was initially $1.94 million. Development and construction amounted to nearly $1.6 million, and operation and maintenance over the original four-year period of demonstration is expected to be about $200,000. Nearly $1.7 million had been spent on the project by the end of March, 1992. Of that amount, about $1.14 million was for construction. Up-front costs for monitoring wells and associated data collection facilities were over $128,000, and annual data collection and chemical analysis costs (about two-thirds of the total) for three years amount to $38,000 per year. Fish and wildlife and recreation components of the project and associated features total $93,000. Maintenance of recreation facilities is another $2,500 per year.

Initially, the costs for environmental monitoring and compliance were anticipated to be about $240,000. These costs increased due to the unforeseen atrazine problem, and overwhelmed the original project budget. Another $69,000 was the federal government's share of the cost of expanding and extending monitoring and research on potential atrazine contamination of the aquifer. A summary of costs for the project is shown hereafter.[22]

[22] Budget data from Upper Big Blue Natural Resources District, March 31, 1992.

Project Benefits and Beneficiaries

Little information is available to help quantify the value of the water recharged (as an incremental increase in the total water supply), and numerous variables, particularly with respect to water quality impacts, make economic analysis of project impacts problematic. The amount of water recharged by the York project is relatively small, compared to the amount of ground water in storage, and the recharge benefits are similarly small, even on a local basis. Local ground water users may see some direct benefit from reduced pumping lifts (and therefore lower energy costs for irrigation), but such savings are not the primary purpose for this project.

The data gathered and used to analyze the effects of artificial and natural recharge on ground water quality will be valuable in evaluating the potential benefits of future, larger federal and non-federal projects. This is the primary purpose behind the NRD's willingness to pay its share of the project costs, and justification for the federal expenditures. Benefits from the demonstration of the new water treatment process to remove herbicides will also largely accrue when applied to future problems and projects.

Some wildlife habitat and recreation benefits will accrue, but no attempt has been made to account for visitor-days, or gather other information needed to quantify these benefits. There was widespread support for the project within the District, at least in part due to the recreation and wildlife features.

Non-Federal Financing and Cost Recovery

The York Project is a multipurpose project, within a broad array of NRD programs, that provide district-wide benefits. No attempt has

been made to identify and weigh benefits that accrue to specific individuals or landowners. The project is viewed as providing research and development, recreation, and other benefits to the District's members at large. The project was approved by an elected board, and the Upper Big Blue NRD's share of project costs are repaid from general funds.

NRD Revenues and Finances

The District's major source of revenue is a general tax levy on all property within the District. Currently, district landowners are taxed at a rate of 2.75 cents per $100 of assessed value, while state law limits the tax to 4.5 cents per $100 valuation. This finances NRD projects and programs. The NRD utilizes a general fund and sinking funds.[23]

Under Nebraska law, the District may finance projects by issuing tax-exempt general obligation bonds, guaranteed by its taxing authority and general fund revenues, or issuing revenue bonds. As a matter of policy, the District first attempts to use available federal or state funds, in order to leverage local money. NRD funds can be used to provide the required local cost share under a variety of state and federal programs. District funds may be used to encourage and share the cost of both local and many on-farm conservation improvements.

The Upper Big Blue NRD is divided into eight subdistricts. Subdistricts are drawn to even the population served, much like congressional districts. When project benefits are limited to a certain area with easily identifiable beneficiaries, an NRD may also create improvement project areas (IPAs). These IPAs may also be created by petition of the landowners. The District fixes fees by dividing project benefits into units. For revenue producing projects, such as a water supply project, landowners may voluntarily subscribe to a number of benefit units, otherwise units and fees are apportioned among landowners by the District in proportion to anticipated benefits.[24] However, to date, no IPAs have been created in Nebraska.

The construction of dams to impound and store surface waters to supplement, replace, or recharge ground waters is an important NRD activity. Multipurpose dams may also provide recreation and help prevent erosion and/or pollution. Project design, construction and operation are regulated by a number of state and federal statutes. Moreover, state laws protect senior downstream water right holders, and require a permit for water storage for irrigation or any other beneficial use, including water stored underground for recovery later.[25]

Cost Recovery Alternatives

While the Upper Big Blue NRD has determined that the district-wide benefits of the York project warrant general fund financing, it has authority to create an improvement project area, define areas of benefit, and allocate units of benefit. Conceivably, the District's separate authorities to limit water use per acre and levy taxes on real property might also be fashioned as a type of "pumping tax," tailored to recover costs according to actual use. However, any such action would be politically unpopular and is unlikely, given local resistance to a pumping tax. The NRD now sets its authorized levies at one rate over its entire service area, and taxes are collected by the county treasurer.

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[23] Upper Big Blue NRD Programs and Cost-Share Practices, September 1991, p. 7.

[24] Ground Water Recharge Projects in the Western United States: Economic Efficiency, Financial Feasibility and Legal/Institutional Issues, Western States Water Council, October 1990, p. III-33.

[25] Nebraska Statutes 46-241.

York Project Costs Summary

Construction Costs

Dam and Reservoir	$ 572,200
Water Treatment Plant and Recharge Well	164,000
Water Supply and Distribution System	272,000
Spreading Basins	23,900
Meteorologic Stations	5,500
Monitoring Wells	242,000
Recovery Wells	56,500
Wildlife Habitat Mitigation	39,200
Fencing and Access Roads	29,100
Visitor's Center	10,000
Land Purchase	175,000
Total Construction Costs	$ 1,589,400

Operation Costs

Personnel	$ 72,790
Vehicle and Travel	6,600
Fees and Licenses	8,800
Laboratory and Research Fees	24,500
Equipment Operations, Repair and Upgrades	63,500
Electricity	37,000
Total Operation Costs	$ 213,190

Administration Costs

Personnel	$ 11,600
Engineering	176,000
Accounting, Audits and Taxes	3,200
Legal	3,500
Clerical	4,000
Information and Education	1,600
Office	11,000
Federal Administration	273,530
Total Administration Costs	$ 484,430

Total Costs	$ 2,287,020

LEGAL AND INSTITUTIONAL ISSUES

The Upper Big Blue Natural Resources District is one of 23 multipurpose districts created by the Nebraska legislature by statutes consolidating over 150 different conservation organizations.[26] NRDs were formed along the boundaries of major rivers. Political subdivisions of the state, the NRDs are locally controlled by an elected board of directors, which sets management policies to encourage the orderly development and conservation of natural resources.

NRDs are responsible for managing Nebraska's surface and ground waters and other natural resources. NRDs are involved in flood control, preventing soil erosion, ground water conservation and management, protecting water quality, recreation, forest management, and improving wildlife habitat. NRD public information and education programs are also important. In addition to local decisionmaking, the NRDs are responsible for adapting and utilizing state and federal programs to meet local needs and supplement local financial resources. The Nebraska Natural Resources Commission is a state agency that assists the NRDs directly and indirectly through a number of programs, including grants and loans for ground water recharge and other projects.

This has been the most controversial of all demonstration projects built. As described above, the Upper Big Blue and other NRDs are unique local government entities with broad authority over management of Nebraska's natural resources. The York project is only one of many district projects and programs with multiple objectives or purposes. Similarly, the Bureau of Reclamation and Environmental Protection Agency have more broad and different interests. These differences have led to a certain amount of tension with respect to project management decisions, and may lead to further conflict in the future.

The York recharge project, as designed and constructed, would not have been built without federal financial assistance. However, federal funding also triggers federal oversight, some of which have significantly increased the scope and cost of the project. EPA's role in project monitoring and oversight, under a cooperative agreement with the Bureau of Reclamation, has at times been a source of serious concern to the District.

Federal Environmental Regulation

Because of concern about atrazine reaching the aquifer, as described earlier, EPA initially reacted by suggesting that the dam be breached.[27] The District strongly opposed the suggestion, but agreed to extended monitoring. Once completed, the project study will help determine the fate of atrazine in the aquifer and define any potential threats to the environment or public health and welfare. While breaching the dam would have eliminated the threat of atrazine leaching into the aquifer, such action would have been costly and sacrificed other project benefits, in the face of an unknown, but not unusual risk. No atrazine was ever detected in the lower aquifer.

The extensive project monitoring costs can be substantially attributed to participation in the High Plains Program, as they would not have been required otherwise. However, as agreed, 80% of the costs are paid by the federal government. The research results should be useful to the District, the federal government, and others when planning other reservoirs and

[26] Your NRD, pamphlet published by the Upper Big Blue NRD.

[27] An EPA suggestion to the Bureau of Reclamation passed on to the NRD.

artificial recharge projects in intensively managed agricultural watersheds.

A related and expanded issue involves management of agricultural runoff as a source of pollution. Such "non-point source" pollution problems are receiving increased attention at the federal level. At the present, EPA has no direct authority to regulate such sources. Its role with respect to the York project is also limited. However, the atrazine problem and other non-point source pollution raises questions with respect to other small reservoirs and natural impoundments elsewhere that may recharge substantial amounts of water during periods when high levels of atrazine or other pesticides, herbicides and/or fertilizers may be found in agricultural runoff.

The issue of environmental impacts might again be raised in the future. The York project was built under an agreement that precluded the need to prepare a full federal environmental impact statement (EIS) under the National Environmental Policy Act (NEPA). However, continued operation of the project beyond the existing demonstration period will likely lead to a new NEPA review and analysis. Any federal decision to discontinue the project will also likely lead to local objections, and perhaps raise other legal questions and equity issues, given the non-federal investment.

Endangered Species Act

The York recharge project is the largest yet undertaken by a Nebraska NRD, but the Upper Big Blue in the past proposed and supported the much bigger Landmark Project. While no endangered species issues have been raised with respect to the York project, they helped derail the Landmark project and may be a major obstacle to future recharge projects in Nebraska.

The Landmark project would have diverted surface water from the Platte River in wet years for irrigation and ground water recharge. The project was first conceived in 1974 as a series of six dams, one on the Platte River, to divert and store some 300,000 acre-feet of water for distribution through a system of canals to supplement irrigation water supplies.[28] The proposal was scaled back in 1987 for economic reasons and then approved by the Upper Big Blue board of directors. The smaller project would use two reservoirs to store up to 225,000 acre-feet of water to irrigate 67,000 acres of land.

The Nebraska Game and Parks Commission, under the Nebraska Nongame and Endangered Species Act, initially issued a favorable biological opinion for the project stating that the Platte River diversion would not jeopardize threatened or endangered species. However, in 1991, the Nebraska Department of Water Resources (DWR) denied all the NRD's water rights and storage applications, after consultation with the Department of Game and Parks (and 27 days of hearings). DWR Director Mike Jess determined that the benefits of the project to the state would not outweigh the adverse effects, and that the NRD have failed to prove that endangered species habitat requirements would not be jeopardized.

Platte River Water Supply

According to Jess, "The need for the project was well demonstrated. Unfortunately for its sponsors, negative impacts in the Platte Valley and to the state in general were shown to outweigh project benefits." He added that if approved, construction of the project would "...preclude successful operation of the proposed Prairie Bend Project slated for the Kearney to Grand Island area. Prairie Bend was shown to have a superior benefit-to-cost ratio."

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[28] "Landmark Irrigation Project," Upper Big Blue NRD paper.

Prairie Bend is an earlier proposed federal ground water recharge project, not part of the demonstration program, that would also rely on limited Platte River water supplies.[29]

Upper Big Blue NRD Manager, John Turnbull stated at the time the state permits and water rights were denied, "We disputed the issue of jeopardizing the habitats of threatened or endangered species, but did not win the argument." He added, "Those who don't want to see development occur use the endangered species as an issue. The environmental issues are what the whole ruling hinged on." Given the situation on the Platte, however, the state's blessing for any project could prove to be insufficient. It seems clear that any project which proposes the use of Platte River water will face scrutiny under the Endangered Species Act for potential impacts on threatened and endangered species.

Clean Water Act

More germane in the near term to the York Project will be its effects on ground water quality. The unusual stormwater event leading to the high atrazine levels in Recharge Lake was by definition anomalous. Nevertheless, ground water quality is affected by the use of pesticides, fertilizers, and other chemicals. Increased use of agricultural chemicals over the last twenty years has led to increased public concern and an awareness and corresponding federal interest. As yet, the growing federal interest has not culminated in EPA authority to regulate non-point sources of pollution.

Nonetheless, reauthorization of the Clean Water Act is currently before the Congress, and public support may grow for a move from what is now a largely voluntary program that provides incentives to incorporate best management practices toward a regulatory program requiring EPA-approved best management practices and site-specific management plans, especially where it can be shown that non-point source pollution results in the violation of water quality standards. Further, while EPA's jurisdiction is now largely confined to surface water, there is likewise a growing interest in expanding EPA's jurisdiction to include ground water quality. Both of these trends mean that the York Project may well face future regulatory hurdles beyond those imposed by EPA's monitoring requirements under the current federal demonstration program.

As with the federal Endangered Species Act, Nebraska state law granting a permit for the York Project, based in part upon a finding of consistency with the public interest, would not shield the project from such increased federal regulatory scrutiny. The Endangered Species Act has also already shown the potential to inhibit or preclude the exercise of state water rights. Similarly, some have speculated that the Clean Water Act may give rise to "federal regulatory water rights," water rights created by the operation of federal law in amounts necessary to achieve the requirements of the law. Though a theory at this point, it does point to the potential complications that federal laws can have with regard to state approved projects, as a result of the operation of the Supremacy Clause of the Constitution.

State Water Law

Nebraska's general ground water law is based on a combination of the reasonable use and correlative rights doctrines. It provides that "every landowner shall be entitled to a reasonable and beneficial use of the ground water underlying his or her land subject to [statutory requirements]...and the correlative rights of other landowners when the ground

[29] "Landmark Water Project Gets Axe from DWR Director," Nebraska Farmer, Natural Resources Report, February 1, 1992.

water supply is insufficient for all uses."[30] Nebraska law also requires state registration of non-domestic wells, and it includes well spacing restrictions. However, where a local natural resource district, such as the Upper Big Blue, has been formed, it can exercise significantly more control over ground water use within the District. It can adopt rules to allocate water, require measuring devices, require stricter spacing of wells, adopt a system of rotation of use, and if necessary, set up to a one-year pumping moratorium on wells.

The Upper Big Blue Natural Resources District is one of three state approved ground water control areas, formed pursuant to the approval of the State Director of Water Resources, based on the following criteria: "If it shall be determined, following evaluation of relevant hydrologic and water quality data, history of developments, and projection of effects of current and new development, that development and utilization of the ground water supply has caused or is likely to cause within the reasonably foreseeable future the existence of either of the following conditions:

> a. an inadequate ground water supply to meet present or reasonably foreseeable needs for beneficial use of such water supply; or
>
> b. dewatering of an aquifer, resulting in a deterioration of the quality of such ground water sufficient to make such ground water unsuitable for the present purposes for which it is being [used].[31]

Nevertheless, the state remains an important player relative to ground water management and recharge projects. With regard to any application to use water, such as for ground water recharge, the Nebraska Department of Water Resources (DWR) must find that the proposed use of water for recharge will not be detrimental to the public welfare. Further, DWR may condition permits as required for protection of the public interest. This public welfare requirement was, presumably, the basis in law for denying a permit for the Upper Big Blue NRD's proposed Landmark Project.

The regulatory context for the York Project, and other ground water recharge projects, may also be changed by the state legislature. Conjunctive use remains undefined under Nebraska law. However, there is increasing pressure from neighboring states for Nebraska to expressly recognize and impose regulation based on the interrelationship of ground water and surface water.

This approach is about to be tested by the Central Nebraska Public Power and Irrigation District, which is planning to become the first district in the state to assess ground water recharge fees. One of its proposals is for Platte River Valley Irrigators to be charged for pumping wells within an area in which the District holds an incidental ground water recharge right. Upholding this plan, which appears to be authorized in Nebraska's ground water recharge laws, may lead to a greater general recognition of the relationship between surface and ground water laws in Nebraska. As these larger issues and relationships are addressed, they may well impact the context, and in turn the desirability and financial feasibility, of ground water recharge projects in the state.

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[30] Nebraska Revised Statutes, Section 46-656.

[31] Nebraska Revised Statutes, Section 46-658.

CONCLUSIONS

The High Plains Program's water quality monitoring requirements are extensive, even though the York project is predominantly an agricultural water project.

EPA's focus on Safe Drinking Water Act standards to protect human health, and related suggestion to breach the recharge dam, threatened the successful continuing operation of the project.

The York project demonstrates that "passive" or "incidental" recharge from similar projects would not be covered by existing limited federal regulations that protect ground water quality.

Many small to large reservoirs and other impoundments throughout the Midwest and West, where sandy soils may allow substantial ground water recharge, may need to be evaluated for their effects on ground water quality.

The availability of adequate quantities of water of suitable quality remain as perhaps the most serious obstacle to successful ground water recharge projects in Nebraska.

The Platte River and its tributaries are the most likely source of surface water for recharge in the basin.

Any project proposed in the future using Platte River water will have to face the possible impacts on threatened or endangered species and successfully complete the required consultation under the Endangered Species Act.

With respect to economic efficiency, the difficulty in identifying and quantifying all project costs and benefits, and beneficiaries, limit the effectiveness of benefit-cost analyses as a decisionmaking tool for future projects.

In the future, with respect to financial feasibility, the project sponsors' ability and willingness to pay, not arbitrary cost sharing or cost allocation formulas, will be most useful in determining the viability of projects.

Without federal cost sharing, the York project would not have been built, as the local benefits to the District were not perceived as sufficient for the NRD to justify the project's cost.

The York project demonstrates the popularity and salability of recreation and wildlife features, as the additional cost to provide these benefits was modest, compared to the total cost, but enhanced the sponsor's willingness to share project costs.

The NRD's goals and willingness to pay for project costs and benefits were different from those of Reclamation or EPA, and similarly, state and local goals and values may vary.

The successful future construction and operation of recharge projects will depend in large part on the ability of various federal, state and local agencies to find common project purposes.

Nebraska is one of a number of states that explicitly recognizes and regulates ground water recharge.

While Nebraska's state statutes related to ground water recharge seem to recognize the importance of the conjunctive use of surface and ground waters, in general, ground water use remains largely unregulated by the state.

Increasingly more stringent federal non-point source pollution controls and ground water protection proposals may affect future recharge projects.

WASHOE COUNTY, NEVADA

BACKGROUND

The Truckee River is literally the lifeblood on northeast Nevada, specifically the Reno and Sparks areas in Washoe County. Flowing from Lake Tahoe, its waters sustain this arid land where drought is almost a way of life. Water is scarce and precious. Settlers began irrigating the Reno Valley in 1861. Water has always been essential to the continued growth, economic development, and environmental well being of the area.

Early surface water development provided an expanded and more reliable supply to meet growing demands. The Newlands Project was authorized and construction began in 1903. It was one of the first federal projects built by the Bureau of Reclamation. It included a dam controlling the outlet of Lake Tahoe and other impoundments. More federal reservoirs on the Truckee and Carson Rivers were built as part of the Washoe Project in the 1960's and 1970's. However, water remains a limited and precious resource.

Washoe County, through its Department of Public Works, Utility Division, has accepted responsibility for water service in the Reno-Sparks area and is working towards the consolidation of many small public and private water supply systems. Several residential developments throughout the county have inadequate water service, due either to unreliable domestic wells or insolvent small private water companies. The county is in a continuing process of taking control of such small systems and integrating service county-wide. Moreover the state legislature mandated a review of the benefits of the county taking over service from the areas primary private water supplier, Westpac Utilities, a division of Sierra Pacific Power Company.

As residential development spreads and municipal water use grows, ground water has become an increasingly important source of supply. However, it too is limited. North of Reno, growth in the East Lemmon Valley and the Golden Valley has resulted in the mining or overdraft of both aquifers. Since 1970, ground water levels have dropped more than 35 feet in Lemmon Valley and as much as 100 feet in Golden Valley. The average rate of water decline has been about 1.4 and 2.5 feet per year, respectively.

Golden Valley has about 500 homes with domestic wells. There is no municipal water distribution system, and many residents don't want one, due to the cost. As water levels decline, a few homeowners each year redrill and deepen their wells. That done, for the immediate future their problem is solved and they are unlikely to support significant further expenditures for construction of a municipal system. Given such circumstances, artificial recharge may offer greater net benefits than other water management alternatives, and greater local acceptance.

In 1985, Washoe County began evaluating ground water recharge opportunities for Golden Valley. At about the same time, the County acquired a municipal water company in Lemmon Valley, which was experiencing similar ground water supply problems.

There are about 20,000 residents living in East Lemmon Valley and they also depend on ground water for their water supply. Lemmon Valley is partially served by a municipal system, but many homeowners have chosen to drill their own domestic wells, rather than be connected. Therefore, the municipal system serves a patchwork of parcels with water lines

over the valley and both draw on the same limited ground water resources. Pumping tests and a review of historical water levels by the County show that mining is occurring.

The Nevada State Engineer has closed both ground water basins to further appropriations. Even if more pumping were allowed, without some means of future augmentation, finite ground water resources could only provide a short-term solution. Before the state imposed moratorium on new service connections, landowners had been encouraged but not required to hook-up to the municipal system. Ironically, they cannot now be added.

The continuous water level declines in both valleys have led to higher pumping costs, concern over the potential for water quality degradation, and the curtailment of new development. Given the water shortage, federal home loan guarantees have been curtailed, and lenders have refused to make residential loans. Growth projections have been revised, and future population estimates have been reduced for the East Lemmon Valley from 214,000 to 36,270.[32]

In 1986, to address the problems in East Lemmon and Golden Valleys, the County submitted, and the State endorsed, a proposal to participate in the Bureau of Reclamation's federal ground water recharge demonstration program. Reclamation selected the Washoe Project for construction, which began in 1991 and was completed in 1992.

Project Purpose

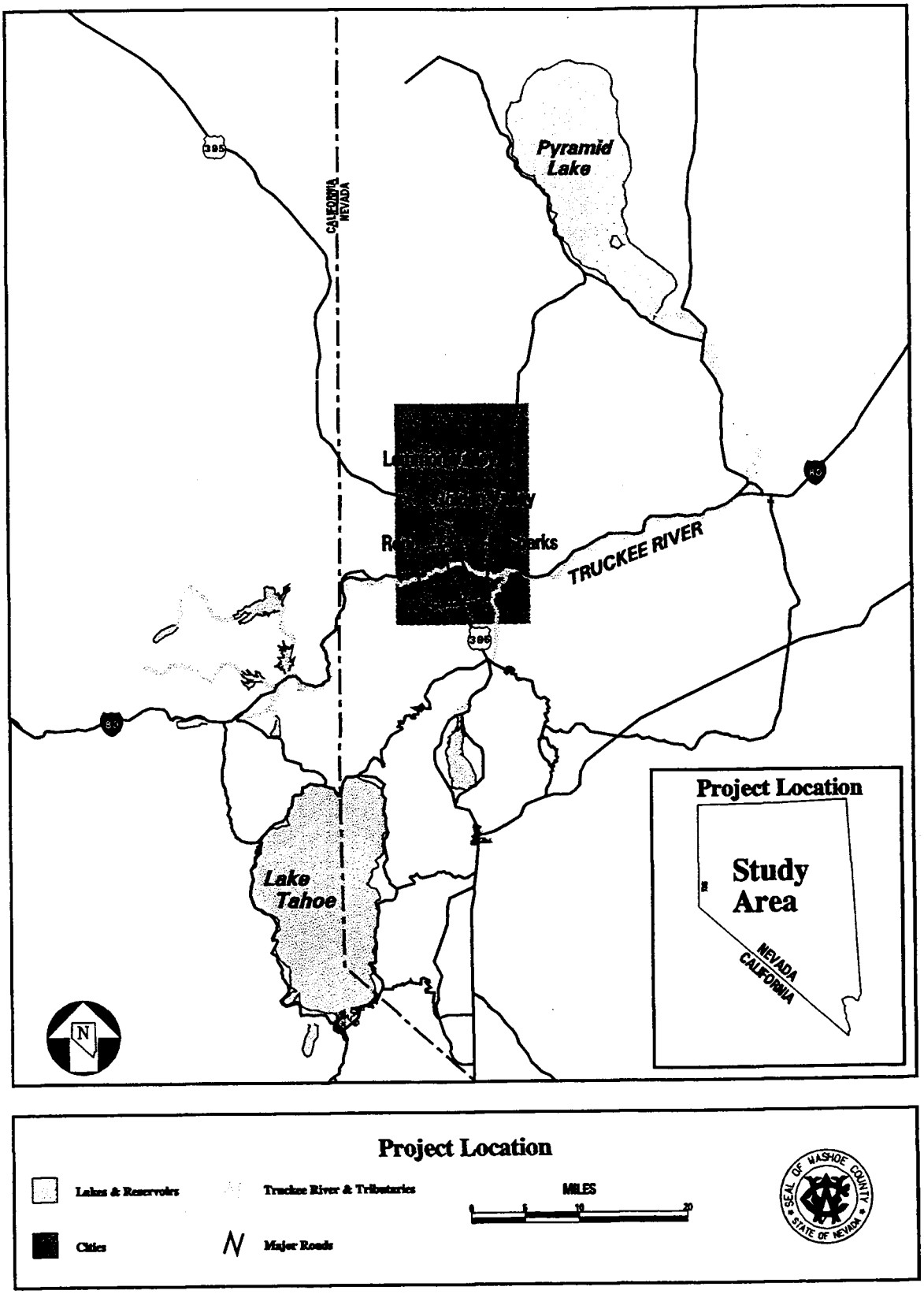
The purpose or goals of the project are to demonstrate the feasibility of restoring water levels in declining aquifers and provide storage for protection against drought by maximizing available water supplies through the conjunctive use of surface and ground water supplies. Ironically, due to an extended drought, the project could not be operated on its initial schedule due to the lack of water for recharge. In response to this project delay, the County requested, and Reclamation extended, their original agreement to allow operations to continue through September 1997.

Western Nevada and Washoe County have suffered through serious periods of drought for the last ten years. Lake Tahoe dropped below its natural rim, at one point, and other sources of surface water storage dried up. Ground water levels dropped more than 20 feet in some parts of the County. Artificial recharge is viewed as an important water management option.

The Washoe County project's injection wells will artificially recharge the aquifer to offset ground water level declines and utilize the available storage to meet future needs. By injecting surface water in the winter and withdrawing it during the summer, the county intends to stabilize and augment existing water supplies. Storage is the key to the long-term stability and reliability of local water supplies, and the project will also demonstrate the potential feasibility of storing vast amounts of water underground for use during droughts in the region.

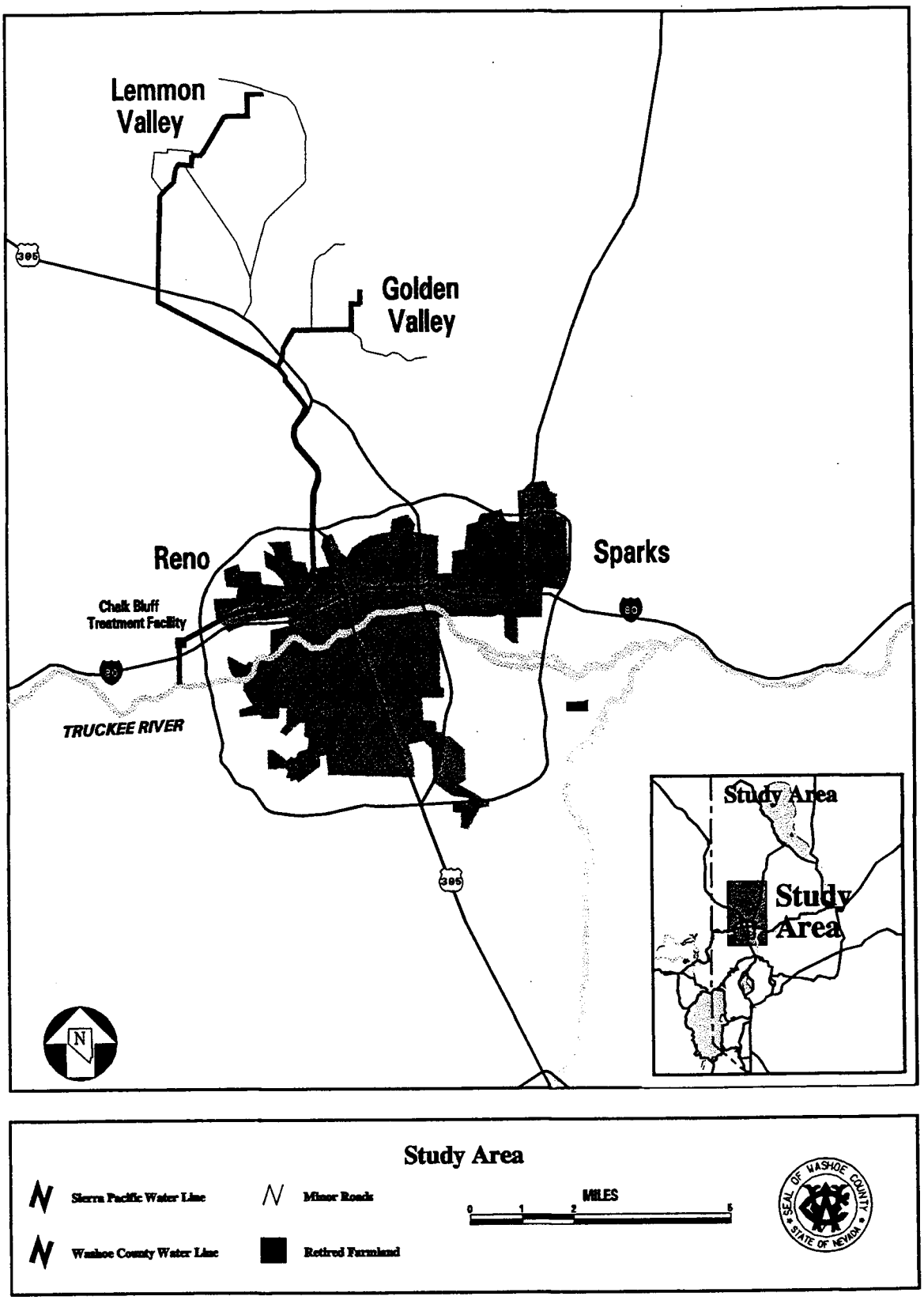
[32] 1974 planning document, The Regional Planning Commission, Reno, Sparks and Washoe County.

Reno Area Map



Washoe County Recharge Demonstration Study - Final Report, August 1996, Figure A

Washoe County Project Study Area



Washoe County Recharge Demonstration Study - Final Report, August 1996, Figure B

Project Description

The Truckee River is the area's primary renewable source of water, and after securing rights to its use, Washoe County reached an agreement with Sierra Pacific for the use of its existing diversion structure, treatment plant, and conveyance facilities to deliver water to the Golden and Lemmon Valleys. Sierra Pacific already supplied water to a small area on the edge of Lemmon Valley. Its Chalk Bluff water treatment plant and conveyance system have excess capacity in winter but not enough capacity to meet peak summer demand.

New construction included extending the existing distribution system, adding a booster pump, and building a 500,000-gallon storage tank needed for system efficiency and -- because of pressure problems -- to ensure consistent system pressurization in order to avoid any possibility of air entrainment problems. One existing production well was retrofitted for injection in East Lemmon Valley, and three new recharge wells were drilled and developed in Golden Valley. Each includes filter houses, filters and all the necessary valves, meters, and electrical equipment. Twelve new dedicated monitoring wells were also drilled, and many other existing domestic wells are also used for monitoring. Withdrawal facilities were already in place, including a production well for 1,200 residences in East Lemmon Valley and individual domestic wells in Golden Valley.

Another existing production well in East Lemmon Valley, connected to Sierra Pacific's system, was shut down during the demonstration period. It could also be retrofitted and used to inject water, if needed. Further Sierra Pacific's pipeline delivering water to the East Lemmon Valley recharge site could in turn take water produced by the project directly back into its water system. Separate facilities for each valley were constructed and as summarized hereafter.

New Construction

Golden Valley

Some 10,000 feet of 4-inch diameter water line
Three 8-inch injection wells, 250 feet deep
Four 2-inch dedicated monitoring wells
Filter house and one carbon filter

Lemmon Valley

Some 10,500 feet of 6-inch diameter water line
One 10-inch injection well, 400 feet deep
Eight 2-inch dedicated monitoring wells
Filter house and two carbon filters

Water Supply and Recharge

Golden Valley is a tributary valley to Lemon Valley, which is a small closed basin. Natural ground water recharge comes from runoff and percolation from Pea Vine Mountain to the West. There are no streams, but once there were perennial springs. These are typical of basin and range hydrogeology with alluvium from erosion of the surrounding bedrock mountains filling the valleys. Most recharge comes from the mountains and virtually none from the playa lake surfaces. During high water years in the early 1980's, the Lemmon Valley playa stood under several feet of water, but subsequent years of drought have left it dry.

The Golden Valley Aquifer appears to be unconfined, with no identifiable confining layers. Estimates of natural recharge are about 120 acre-feet per year (af/yr), with domestic withdrawals and depletions of about 360 af/yr.

Lemmon Valley's alluvium may be divided into two distinct aquifers—a shallow aquifer of poor quality and a deeper confined aquifer of good quality with moderately permeable sand and gravel capable of producing sufficient quantities of water for municipal development.

At present levels of pumping, it will not be able to supply demands without augmentation.

The Truckee River is the area's primary renewable source of water, flowing from Lake Tahoe into Pyramid Lake in western Nevada. The Truckee River is already fully appropriated, and water use is carefully regulated by a water master. Washoe County secured rights to the use of 250 acre-feet of Truckee water per year from two separate sources. First, water appurtenant to a parcel of land acquired by the County for park purposes, but excess to current needs, was dedicated to the project. Second, water for pasture lands owned by the University of Nevada-Reno was leased for five years.

Original recharge goals were never met due to a combination of reasons, including drought, low injection capacities, damage to facilities, mechanical problems and surfacing of recharge waters in Lemmon Valley. The 1991-92 water year was the fifth in six years of below average precipitation (with near average amounts in 1990-91). Diversions from the Truckee River for municipal, industrial and agricultural uses left the reach of the river through east Reno and Sparks dry during the late summer of 1992.[33] Due to the lack of water and related constraints and conditions on the exercise of its water rights, no significant injection occurred in 1992.

Drought again dried up the river in 1994 and limited recharge opportunities, in part in compliance with an agreement with the U.S. Fish and Wildlife Service. In 1995, 200% of average precipitation allowed injection to proceed.

Artificial Injection Volumes
(in acre-feet)

	Golden Valley	Lemmon Valley
1993	26.6	79.5
1994	5.0	15.0
1995	40.6	81.6
1996*	31.4	17.5
	103.6	193.6

* Through July 1, 1996.

The projected total volume injected in 1996 in Golden Valley was 50 acre-feet (af), achieving the original annual goal. However only 40 af were injected in Lemmon Valley, compared to the goal of 200 acre-feet per year, as injection pressures and volumes were sharply reduced when water surfaced from a subsidence fissure near the municipal production well.

Water levels in Lemmon Valley have steadily declined since measurements began in 1992, dropping about seven feet from 1992-1996. More water was extracted than injected during the recharge demonstration period, and water levels continued to decline. However, the proximity of the injection and production wells in Lemmon Valley (300 feet) and pumping of the latter during periods of injection to meet water demands made measurement and analysis of water level changes impractical.

Similarly, water level declines of about three feet annually were recorded in Golden Valley from 1991-1996. However, water levels

[33] Washoe County Recharge Demonstration Study - Final Report, USBR, August 1996, p. 28.

have risen 25 feet or more near the injection wells, with lesser increases out to a distance of some 2,500 feet from the injection sites.

A gravity-fed injection system was planned and used initially in both valleys, but negative pressure caused leaks in rubber seals in above ground connections and fittings, which in turn caused air entrainment problems. In response, pressurization rates ranging from 5.5 pounds per square inch (psi) to 30 psi stopped the negative pressure problems and helped increase injection rates.

The initial recharge demonstration has been successful, and the County hopes to expand the project and inject an additional 350 acre-feet per year in East Lemmon Valley. Up to 600 acre-feet of water should be available in average or better-than-average runoff years from the Truckee River, with additional runoff also available from nearby Pea Vine Mountain.

Water Quality

A water quality assurance/water quality control program was developed in order to determine background levels of contaminants in both the injection water and ground water, compare differences between the two and follow movement of the injected water, and ensure that ground water quality, nor the environment, was adversely effected.

Baseline data were collected in 1991-1993 and showed that the injection and ground water did not contain any contaminants.

Truckee River water quality is excellent and equal to or better than ambient ground water quality. Measurements of total dissolved solids are usually less than 90 parts per million (ppm). The water is filtered and chlorinated at Sierra Pacific's municipal water treatment plant and then piped and pumped to the injection sites where activated carbon filters remove residual chlorine and any suspended solids prior to injection. These filters were found to be easy to maintain and enhanced recharge, proving their worth. The injection wells' specific capacity dropped only slightly with use, and backwashing quickly restored injection rates.

The water in both aquifers is also of high quality, meeting all federal primary drinking water standards and maximum contaminant levels (MCLs) for organic and inorganic compounds, with the exception of a single baseline sample from a domestic well, where naturally occurring radionuclides exceeded the primary MCL for gross alpha. Initial water quality analyses were extensive and included all compounds with established drinking water standards. After the baseline study, Washoe requested, and regulatory agencies approved, a reduction in the number of sampling sites as well as the frequency and breadth of analyses.

Neither aquifer is very susceptible to contamination. In Golden Valley, the aquifer's susceptibility is rated as low-moderate, with depths to water ranging from about 120-160 feet, and some impervious clay material, both protective factors limiting contamination from the surface. The Lemmon Valley aquifer's susceptibility is low, with depths to water use of about 200 feet and an abundance of clay forming a confining layer, above which there is a shallow, water table aquifer.

The baseline data showed that ground water quality was relatively constant during the period prior to initiation of injection. The quality of the water injected varies somewhat as the water delivered by Sierra Pacific is a mixture of Truckee River water and ground water, depending on availability. Most injection water was river water and not ground water.

In Golden Valley, the ground water moves relatively slowly and none of the water injected showed up in any monitoring wells, based on inorganic parameters. In Lemmon Valley, chloroform and other compounds related to chlorination have been detected in monitoring and municipal wells up to 350 feet from the injection well, but as the municipal wells extract more water than is injected, the recharged water has had no significant effect on ground water quality.

The County does not expect recharge to cause deleterious effects on ground water quality, and over time, injection should have a positive impact. Truckee water quality is better than the ambient ground water quality. In addition, artificial recharge may benefit valley homeowners by diluting and decreasing nitrate concentrations at domestic well heads that result from the proliferation of septic systems.

ECONOMIC EFFICIENCY AND FINANCIAL FEASIBILITY

In Golden Valley, economic hardships due to declining ground water levels are likely to continue in the absence of a renewable water supply. Residents will have to continue to redrill and deepen domestic wells, and home sales in the area will continue to be depressed. Moreover, residential and other development in that area will continue to be curtailed. In Golden Valley, water right costs have been about $3,000 per residence. Artificial recharge appears to be the most economic and best available solution for most residents, as the construction of a municipal system would be considerably more expensive.

In Lemmon Valley, the situation is similar. For example, one owner of a 68-acre parcel of land has been unable to subdivide it as the state moratorium limits landowners to one single well.[34] Further, the cost of acquiring an adequate residential water right to the use of 1,800 gallons per day (gpd) has reportedly reached as high as $22,000. At one time, only one such right was available for sale.[35]

Project Costs and Cost Sharing

The original authorized costs were increased to offset increased water costs and the need to drill a new injection well in Golden Valley. The total project costs were $1,915,604, and the federal share was $1,543,080 or 80%; the remaining non-federal share, or Washoe County's share, was $372,524 or 20%.

Project costs have been presented in a number of different ways at different times, and the following figures illustrate the types of costs incurred by project sponsors and not a careful or complete accounting of all project costs. Of note, the costs of purchasing water for recharge are significant recurring costs, as are water quality monitoring and testing costs. No attempt was made to reconcile the cost figures or estimate the value of the anticipated benefits from the project.

Distribution of Project Costs
(through June 1996)

Administration, Operation and Maintenance	$ 420,532
Capital Costs	673,856
Water-Related Costs	380,419
Total	$ 1,474,807

Project Benefits and Beneficiaries

Valley residents and landowners are the most obvious direct beneficiaries of the project, over both the long and short-term, as slowing and reversing the declining water levels will reduce pumping costs and may restore some degree of equilibrium between ground water recharge and withdrawals, thereby raising property values in the area. However, outside of their usual property taxes paid to the County, the landowners have yet to contribute towards the cost of the project.

The County, as the government entity most responsible for meeting the water supply needs of its residents, is also a direct beneficiary and hopes to continue the project if it can secure public support to pay for its future operation.

[34]Personal interview with Dan Dragon, Washoe County Utility Division, January 30-31, 1992.

[35]Telephone conversation with Hugh Ricci, Nevada State Engineer's Office, January 12, 1995.

All of the water users in the County may benefit indirectly from the demonstration of the feasibility of ground water recharge and its potential use as another tool to more efficiently manage the area's limited water resources. The County envisions the possible use of this technology to store vast volumes of water during periods of wet weather for use during dry periods. By ensuring domestic needs and municipal and industrial uses can be met during drought, there will also be more flexibility and greater options available for meeting other important needs, including the needs of Indian tribes and the environment.

Project Financing and Cost Recovery

Payment for the County's share of the demonstration project's costs have come from the County's general fund, which is funded by property taxes. Research and demonstration benefits are perceived as being system-wide. However, with the end of the demonstration project, the County must determine whether or not to continue to finance some recharge-related activities. The extent and duration of any future recharge program will depend on the willingness of landowners to pay for the cost of future project operations, including the acquisition water rights, water conveyance costs, and continuing operation and maintenance of the recharge facilities.

Washoe County intends to continue artificial recharge in Golden Valley, but this will require some financial commitment from residents.

In Lemmon Valley, which has a municipal distribution system, the county will continue to provide "passive" recharge, or in other words, provide alternative surface water supplies when available for municipal use in lieu of ground water pumping. This will allow natural recharge from precipitation to raise water levels. The county may continue to inject water when surface supplies exceed demands, i.e., when winter precipitation is above normal.

The effects of monitoring requirements related to water quality protection on project costs are not yet known. The two monitoring well fields cost $328,000 to construct. Including data collection and analysis, monitoring may account for over half of the project's costs.

Initial water quality analyses were extensive and included all compounds having established drinking water standards. After the baseline study, Washoe requested, and regulatory agencies approved, a reduction in the number of sampling sites, as well as the frequency and breath of analyses. These changes substantially reduced sampling costs from approximately $123,000 per year to $21,000 per year.[36]

[36]Final Project Report, p. 31.

Washoe County Project Costs Summary

Golden Valley

Construction Costs

Monitoring and Injection Wells 4 monitoring wells 4 injection wells Deepening one existing injection well	**$240,000**
Water-line, Booster Pump, Filter System and Filter House	**320,000**
Subtotal	**$560,000**

Operation and Maintenance Costs

Water Purchases (100 acre-feet or 32.6 million gallons/$0.84/gallon)	**$ 27,400**
Monitoring/Water Quality Testing	**10,000**
Other	**15,000**
Subtotal	**$ 52,400**

Lemmon Valley

Construction Costs

Monitoring and Injection Wells 8 monitoring wells One injection well	**$260,000**
Water-line, Filter System and Filter House	**301,000**
Subtotal	**$561,000**

Operation and Maintenance Costs

Water Purchases (500 acre-feet or 163 million gallons/$0.84/gallon)	**$137,000**
Monitoring/Water Quality Testing	**10,000**
Other	**15,000**
Subtotal	**$162,000**

Total Costs	**$1,335,400**

LEGAL AND INSTITUTIONAL ISSUES

According to the County, "Institutional considerations proved to be the most exhaustive component of the project. Proposing to take Truckee River water and deliver it outside the Truckee River Basin for use as recharge required the unquestionable support of many competing interests and regulatory agencies in Nevada."[37] Reclamation's criteria for screening and selecting demonstration projects precluded any project generating significant controversy. As a result, the County identified and contacted all concerned parties in order to discuss and mitigate problems that might generate protests.

The demands placed on the limited water resources in the Truckee-Carson River Basin for many varied uses have created one of the most complex legal and institutional systems for water management anywhere. However, Washoe County's open public participation process and extensive outreach program -- and the fact that the County proposed transferring water to a new use without expanding its existing rights to the use of water -- helped successfully avoid serious opposition to the demonstration project.

The temporary and limited nature of the proposed water use for the demonstration were probably factors in reducing any opposition, which will not be the case if the project is continued or recharge activities are expanded.

State Water Law

Domestic wells and related water rights and water use are permitted and regulated by the state. Washoe County has no control over private domestic wells or undeveloped land, but can require permits for subdivisions and require evidence of water rights. In the Lemmon Valley, the County encouraged, but could not require, landowners to hookup to the available municipal system. Indeed, the primary local public concern relative to the project was that residents would be required to hook-up to a public system. However, the continuing decline in ground water levels caused the state to impose moratoria on both new domestic and municipal wells and new service connections, effectively curtailing new water use and new residential development.

The use of water for the artificial recharge demonstration project required the approval of the state. Traditional state water law regulates the beneficial use and prohibits the waste of water, and requires a right or permit for surface and ground water use or storage. Moreover, in 1987, Nevada enacted a ground water recharge statute and gave the State Engineer specific authority over recharge and recovery projects.[38]

Washoe County secured rights to the use of 250 acre-feet of water per year from the Truckee River to demonstrate the effectiveness of injecting and storing surface water in East Lemon and Golden Valleys -- 200 acre-feet in East Lemmon Valley and 50 acre-feet in Golden Valley. The water was acquired from two separate sources—an existing County right purchased for park purposes and a right leased from the University of Nevada at Reno. These were active irrigation rights, and once transferred to the project, irrigation ceased.

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[37]Final Project Report, p. 8.

[38]NEV. REV. STAT., Section 534.250 to 534.340.

The County leased 159.6 acre-feet per year from the University that had previously been put to beneficial use on pasture lands. The price paid per year for five years was about $244 annually. The remaining water, some 200 acre-feet per year, was provided by the County from its purchase of a ranch and its water rights for park purposes. The water rights in excess of the County's needs for the park were dedicated for use by the recharge demonstration project. Moreover, the transfers were limited to 70% of the historic diversions (about 350 acre-feet) in order to account for return flows.

Under Nevada law in particular and western water law in general, proposed changes in the nature or place of use and point of diversion must be approved by the state (in order to protect other water users from injury as well as ensure the public interest is served by the changes). The County applied for and received approval from the Nevada State Engineer to change the point of diversion for both rights upstream to a place on the river where Sierra Pacific draws water by pipeline for its main Chalk Bluff water treatment plant. The treated water is then conveyed through the existing municipal distribution system, extended by the County, to the recharge site.

The Truckee River is fully appropriated. While rights to its use can be acquired by purchase or exchange, water use is carefully regulated by a water master, and requests for the state to approve new appropriations and new uses or changes in the nature of current uses are carefully scrutinized and routinely raise many concerns and considerable conflict. Changes may be contested or protested by many parties.

Washoe County openly and actively pursued its development plans and sought to define and mitigate problems before they were raised by protest. Among the different parties contacted were the Pyramid Lake Paiute Tribe, the U.S. Fish and Wildlife Service, the Truckee-Carson Irrigation District (TCID), and Sierra Pacific Power Company. Each had its own particular concerns.

The Pyramid Lake Paiute Tribe

The Truckee River flows into Pyramid Lake, a remnant of one of the great prehistoric lakes in the Great Basin. It is a deep lake with no outlet and no other significant source of water other than the Truckee River. It is located entirely within the Paiute Reservation. When diversions for irrigation around the turn of the century reduced the flow of the Truckee River, lake levels began to drop dramatically. This, in turn, threatened natural spawning for native fish, including the cui-ui sucker, which is an important part of the Paiute's diet, heritage, and culture.

The demonstration project's use of prior rights to water for irrigation, that were discontinued and retired temporarily due to land fallowing, and the County's limiting its exports to 70% of the total right in order to account for the possible loss of any return flows, satisfied the tribe's concern that there be no increase in existing depletions. As a result, no significant opposition arose from the tribe over the use of these water rights for recharge.

Sierra Pacific Power Company

As Sierra Pacific was an integral partner in the success of the project, diverting and delivering the water for recharge, its support was critical. Its main concern was generating any controversy that might upset ongoing negotiations between the many parties regarding the distribution of Truckee River water. The County solicited and received letters of support at Sierra Pacific's request, and

a delivery agreement was reached. However, this also required development and approval of a new rate structure to allow Sierra Pacific to deliver water on an interruptible basis. This involved an extensive procedural process to get the approval of Nevada's Public Service Commission.

Truckee-Carson Irrigation District

Another important party was the Truckee-Carson Irrigation District (TCID) in Fernly and Fallon, Nevada. The Truckee is its main source of water and it is interested in any changes in diversions upstream. However, after meeting with TCID's attorney, the County received the support of TCID's staff and board.

Federal Environmental Laws

Endangered Species Act

The cui-ui is listed and protected as endangered under the Endangered Species Act. Historic diversions and reduced flows have led to the formation of a delta at the terminus of the Truckee at Pyramid Lake, which has also made spawning more difficult. The U. S. Fish and Wildlife Service (FWS) wanted to protect spawning seasonal flows, and the County agreed to limit the exercise of its rights during periods of low flows and during the fish spawning season.

As the peak fisheries needs are from late January through June, and the peak municipal and domestic demand period is from July through September, injection was generally timed and limited to the period from October through January. However, the County was able to extend its recharge activities outside of these limits, given the reduced injection rates and amounts, based on streamflow forecasts by the Natural Resources Conservation Service.

The revised agreement prevented the County from injecting water from September through March when Truckee River flows were projected below 80% of normal. Injection was allowed from September through March when projected streamflows were 80%-120% of normal, and through June when greater than 120% of normal.

This agreement and drought conditions, affected project operations and required the extension of the demonstration period to better prove the feasibility of recharge opportunities.

Safe Drinking Water Act

The Environmental Protection Agency and Bureau of Reclamation reached an agreement presented in an EPA memo, known as the Mlay/Cook memo, that outlines various conditions that all demonstration project sponsors had to comply with to protect water quality and meet attainment goals. This required concentrations of any constituents at the point of injection to meet National Primary Drinking Water Standards or recommended Health Advisory Levels not exceed natural concentrations found in the receiving aquifers.

EPA required extensive and expensive monitoring requirements to ensure these conditions were met but allowed for reduced or modified monitoring parameters if pre-project sampling and the first year of sampling showed water quality conditions were relatively stable and/or predictable.

An Underground Injection Control (UIC) permit under the federal Safe Drinking Water Act was also required and issued by the Nevada Division of Environmental Protection.

CONCLUSIONS

In addition to demonstrating the technical and physical feasibility of ground water recharge in isolated desert basins, the Washoe Project illustrates the importance of legal and institutional considerations.

Potential opposition to the proposed project was minimized by the extensive and open public participation process and discussions with interested parties or stakeholders.

The potential benefits of using recharge opportunities to store vast amounts of water during periods of abundance for later use during drought could prove critical to the continued growth and prosperity of the Reno-Sparks area.

Growing demands for water for various uses will continue to serve as a catalyst for change and new management innovations.

Ground water recharge will become more important as an accepted management practice as demands and the cost of developing water or purchasing and transferring rights from existing to new uses continue to rise.

The economic and financial feasibility of further ground water recharge activities in the area have yet to be carefully considered and presented in comparison to other water management alternatives.

Cost recovery for continuing and expanding artificial recharge in the project area will depend on ground water users' perceived benefits from the demonstration project and their willingness to pay for this service.

Ground water recharge opportunities may serve to maximize efficient use of existing resources and facilitate settlement of differences among competing uses and water users by providing more storage and greater flexibility in the timing of recharge and recovery activities.

Ground water recharge may be the means of meeting growing municipal and industrial demands while at the same time protecting environmental and other uses.

Recharge may serve as a means to facilitate water transfers between different uses.

Water quality related monitoring and testing requirements are a significant project cost, that may be reduced in the future following experience gained from the demonstration project.

The cost of gathering initial baseline data and monitoring early project operations will continue to be a major expense.

Recharge of high quality surface waters offers the opportunity to actually improve the quality of ground water.

Economic hardships are likely to continue to arise at a local level as scarce water resource supplies are stressed by growth.

Limited availability of water resources will more and more often lead to the curtailment of new development.

Protection of endangered species remains a critical consideration for any development.

Indian trust responsibilities and water rights may also influence the future use of ground water recharge technology.

Blaine Gypsum, Oklahoma

BACKGROUND

The Oklahoma Water Resources Board (OWRB) and the Southwest Water and Soil Conservation District sponsored the Blaine Gypsum Project near Hollis, Oklahoma. Since 1968, the District has used crudely designed and constructed wells to recharge the heavily pumped Blaine Gypsum Aquifer using only gravity and stormwater from local streams. The aquifer is a source of agricultural irrigation water, but it is not used as a domestic or municipal supply, due to high total dissolved solids (TDS) levels, averaging 2,800 or more.

The Blaine Aquifer is a gypsum and dolomite formation with karst features such as caves, caverns, cavities, sinkholes, solution channels and fractures that sometimes swallow surface streams and supply local springs. The study area covers some 373 square miles in southwestern Oklahoma, defined by the Sandy Creek drainage. Taking advantage of recharge opportunities, the District has in the past drilled some 70 wells and constructed four diversions to channel untreated stream runoff to recharge the aquifer.[39] Many wells have collapsed over the years, and been replaced by new wells.

The OWRB, a state agency, was responsible for the construction of the recharge demonstration project, and operating and maintaining the facilities, as well as monitoring, data analysis and interpretation. The District secured needed permits, land and easements, assisted with project maintenance, and served as a liaison with local farmers.

[39]Blaine Gypsum Groundwater Recharge Demonstration Project Final Report, USBR, July 1997, p. S2.

Project Purpose

Artificial recharge has allowed the District to supplement its finite water supply and helped sustain agricultural production and the local economy, which is the primary purpose for the demonstration project. The federal program and Board's sponsorship helped the District expand on its past experiences, gain a greater understanding of the aquifer, and improve the effectiveness of their artificial recharge efforts.

Project Description

The project is an extension of the District's existing recharge program, and consists of five recharge wells, each surrounded by three to seven monitoring wells. One site, near Hollis, includes a small impoundment of up to 25 acre-feet, draining some 369 acres. It also provides some flood protection to the town. At each site, an inlet structure diverts surface runoff and the water flows by gravity into the recharge well. (See the area map and diagram of a well.)

OWRB and the District worked together to improve upon existing well designs and incorporate new features to prevent dissolution in the shallow zones and subsequent collapse. This included pressure cement grouting of the 12-inch diameter wells, which range from depths of 155 to 270 feet.[40] Operation and maintenance consists of cleaning debris screens and controlling brush and weeds around the inlet structures, as well as burrowing animals around the well and inlet pipes.

[40]Ibid. p. S3.

Water Supply and Recharge

Surplus runoff following rainfall is the source of water for the project. Average annual rainfall is 23 inches. Without enhancement, water levels have been observed to immediately rise after rain. The project has allowed the OWRB to monitor the quantity of water recharged and the response of the aquifer. This has included measuring rainfall, stream discharges, recharge flow rates, and ground water levels. Baseline monitoring of water levels in existing wells began in 1990. Recharge began in 1993, and data was recorded through June 1997.

Typical of karst aquifers, ground water changes were dramatic and flashy. Water levels in some monitoring wells rose as much as 25 feet in an hour, and one dye tracing test found the velocity of ground water movement to be as high as two miles in a day, with an average of one mile per day. Regionally, ground water movement is estimated to be nine feet per day.

The watersheds contributing to each well vary in size from 250 to 14,000 acres, with the total project drainage area covering over 23,000 acres. Total average annual runoff is estimated to be 1,245 acre-feet. Only 2% to 36% of the calculated runoff was captured by the instream inlet structures, compared to almost 100% at the Conservation Dam Site (R01). The increase in the efficiency of recharge was dramatic with the small impoundment.

The exact amount of water recharged could not be determined as flows were indirectly estimated using pressure transducers that measure water depth, or head, and not flow rates. Moreover, recharge volumes were estimated for rainfall events when measurements were missing or incomplete.

Overall, an estimated 1,056 acre-feet (af) of water was recharged, ranging from a high of 726 af in 1995 to a low of 72 af in 1994. The estimated volume of water recharged by the project, compared to other sources of recharge, are as follows.

Total Volume of Water Recharged
(in acre-feet)

Recorded Flow Measurements	746 af
Unmeasured Precipitation*	310 af
Total Enhanced Recharge	1,056 af
Measured Precipitation	558 af
Tailwater	188 af
Total Other Recharge	746 af

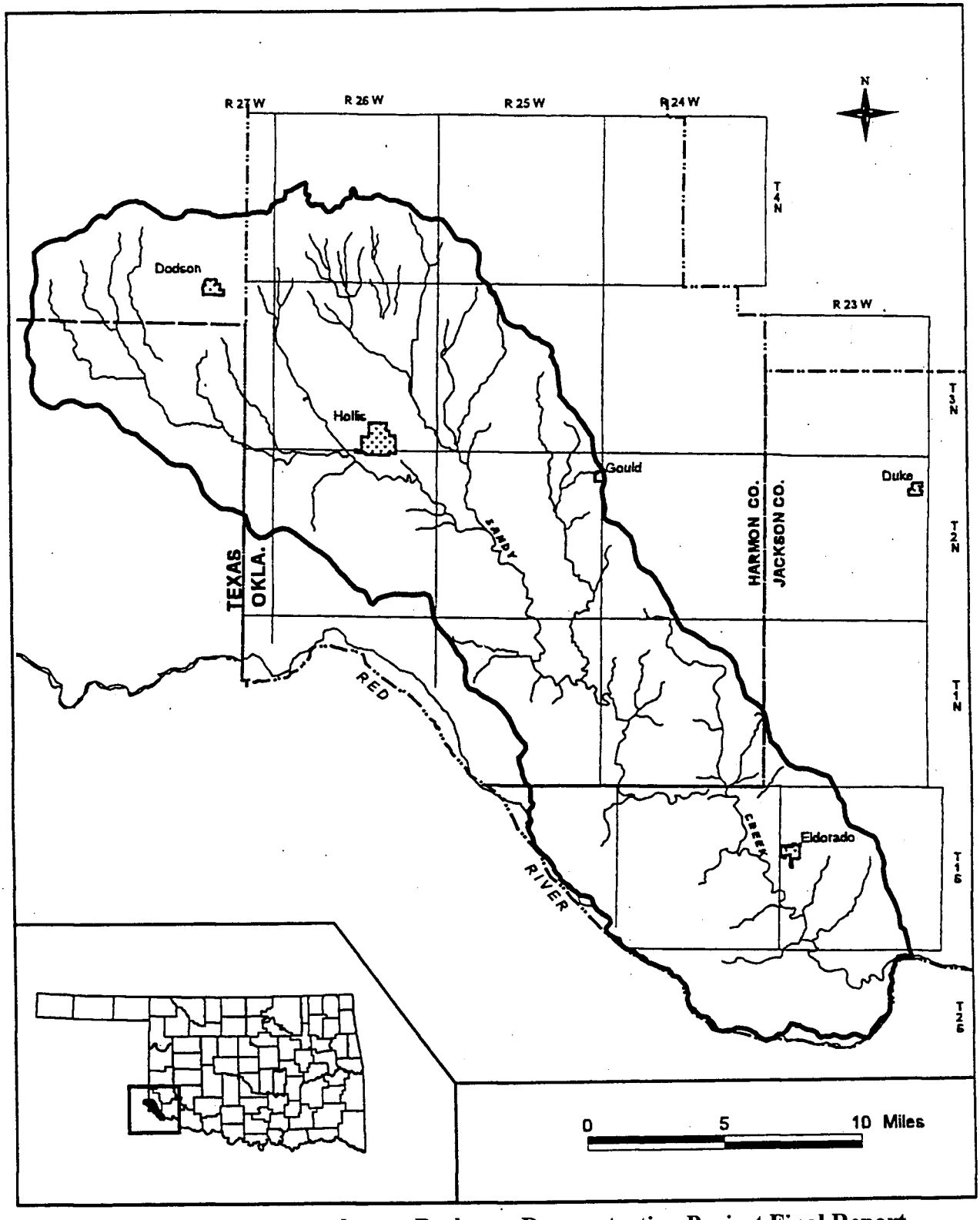
*estimated amount entering wells

Of note, from 1994 to 1996, the average annual recharge per well for the five wells was 70 af (compared to average annual pumping per well of 142 af for some 350 local wells). Variations in the amount of runoff captured by the wells without an impoundment varied with well capacity, the volume of runoff, spatial variation of rainfall, and aquifer storage capacity.

Water Quality

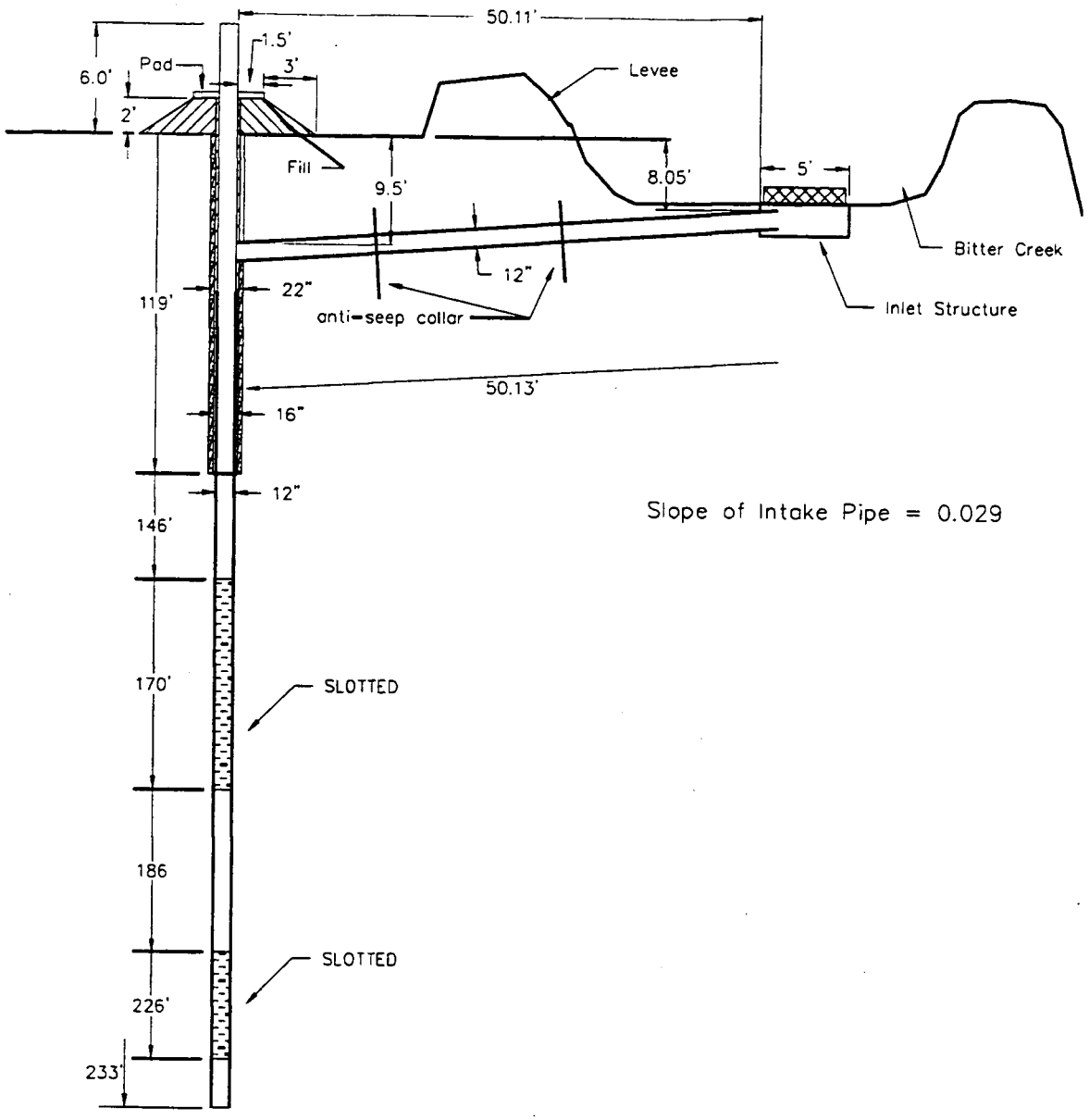
Both surface water and ground water quality in the area are poor. Sandy Creek, a tributary of the Red River, has high total dissolved solids (TDS), sulfate and chloride. It is not suitable for use as a drinking water supply without extensive and expensive treatment. Ambient ground water quality is even poorer. The Blaine Gypsum Aquifer is highly mineralized and not used as a drinking

Project Area Map Near Hollis, Oklahoma



Blaine Gypsum Groundwater Recharge Demonstration Project Final Report
Oklahoma Water Resources Board and U.S. Bureau of Reclamation, July 1997, p. S-11

Blaine Gypsum Project Recharge Well Diagram



Blaine Gypsum Groundwater Recharge Demonstration Project Final Report
Oklahoma Water Resources Board and U.S. Bureau of Reclamation, July 1997, p. S-12

water supply, but is defined by the Environmental Protection Agency (EPA) as a potential source of drinking water.

The rain water recharged is low in dissolved solids and actually improves ground water quality over the short-term, as measured by samples taken within seven days of a recharge event. TDS concentrations decreased as much as 1,000 mg/l. However, the dilution is only temporary as gypsum, dissolved by the water, adds calcium and sulfate to the ground waters. A decrease in nitrate also occurred at all five sites, but was only statistically significant at two.[41]

Increases in a few water quality parameters were observed at some sites, including calcium, phosphorus, potassium and total suspended solids (TSS), but may reflect short-term changes and not necessarily long term trends. High levels of trace metals, exceeding EPA's maximum contaminant levels (MCLs) for drinking water, were found in both ground water and the injectate, but only in samples with high TSS, indicating the metals were bound to the soil and were not mobile in water.[42] Low levels of pesticides and herbicides were found, primarily trifluralin and pendimethalin, which are used for pre-emergent grass and weed control, but they were below regulatory levels and did not persist over time. Similarly, a few ground water and injectate samples detected some volatile organic compounds (VOCs) such as toluene, xylene, 1,2,4-trimethylbenzene, chloroform and 1,1,1-tricholoroethane), but at concentrations well below EPA's established MCLs.

Of note, dilution and passing the initial stream surge after rainfall events (prior to recharge) helps avoid water quality problems.

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[41]Ibid. pp. S-7.

[42]Ibid.

ECONOMIC EFFICIENCY AND FINANCIAL FEASIBILITY

The Southwest Water and Soil Conservation District includes both furrow and center-pivot irrigation systems. Ninety percent of the irrigated acreage is cotton. To avoid nematode problems, cotton is rotated with other crops, including winter wheat, alfalfa, milo, maize, and sorghum, and peanuts. Land values vary considerably. Farmland in the top 10% is valued at $850 to $900 per acre, and $700 to $500 for the next 30% of the land. Farms generally range in size from 1,200 to 1,500 acres. Lending institutions' policy discounts the value of the land, excluding the value added by irrigation, as the ground water supply is not considered to be dependable.

Project Costs and Cost Sharing

The projected project cost authorized under the original cooperative agreement was $1,991,615 and the sponsor's share was 20%. Project operations were extended two years, and the budget was increased by $148,606 which was equally shared by Reclamation and the sponsor. The total project cost was therefore $2,140,221 excluding related federal administrative costs. The monitoring costs totaled $679,720 or 32% of the total project cost. This assumes there was essentially no cost for the water supply.

Given these figures, an estimated 20-year project life, and average annual recharge of 353 acre-feet (1,056 af over three years), the approximate cost per acre-foot recharged is $303.15 [=$2,140,221/20/353], plus operation and maintenance costs of $0.75 per acre-foot [calculated from an average of $53.00/well/year times 5 wells = $265/353 af = $0.75]. The total estimated cost of water per acre-foot is therefore $303.90 per acre-foot, excluding recovery costs.

This is an exorbitantly high amount for irrigation water! However, the state regulates Class V injection wells under authority of the Safe Drinking Water Act, and none of the monitoring undertaken as a necessary part of the demonstration project would be required for similar projects in the future (injecting runoff into a non-potable source of supply, such as the Blaine Gypsum Aquifer). This alone would cut the cost of water by $198.46 per acre-foot per year! Other administrative oversight costs by state and federal agencies would also be reduced. Taking only those costs related to test drilling, construction of the recharge wells and conservation dam, and the land purchased for the later, the annual costs per acre-foot, including annual operation and maintenance costs would total about $41 per acre-foot, a much more reasonable expense that may be cost effective for agriculture. Recovery costs are excluded.

Minimized Recharge Costs

Test Drilling	$ 60,269
Well Construction	120,713
Recharge Dam	46,680
Related Land Purchases	56,961
Total Capital Costs	$284,623

(Costs per Acre-Foot per Year)

Capital Costs (20yrs/353 af/yr)	$ 40.31
Operation and Maintenance	0.75
Total Minimized Annual Cost	$ 41.06

The Conservation Dam Site (R01) was the most expensive, due to the cost of land and additional construction, but it also recharged the most water. The site takes up only five acres,

and given the increase in the efficiency of capturing and recharging runoff, the sponsor suggests this is a "small investment considering the returns."[43] Again, the cost of the land is a major consideration.

Project Benefits and Beneficiaries

The minimized annual cost of $41.06 per acre-foot is consistent with the OWRB and the District's estimate of the average cost of recharge of $0.13 per thousand gallons. They also estimated the value of the water at $0.53 per thousand gallons or $172.69 per acre-foot, based on the value of the water injected to irrigate cotton.

In 1995, cotton sold for $0.735 per pound. Average cotton production was about 291 pounds per acre, for a total value of $214 per acre. Long-term average water use to irrigate cotton is about 1.25 acre-feet per year. Using an average amount of recharge per well of about 70 acre-feet per year, that is enough to irrigate 56 acres of cotton. The value of the cotton would be $11,980.00 or $0.53 per 1,000 gallons of water. This simplified benefit to cost ratio -- estimated to be greater than four to one -- ignores other production costs, including the cost to recover the water.[44]

The primary beneficiaries of the project are the local landowners and farmers, but the secondary benefits ripple throughout the local economy. The Southwest Water and Soil Conservation District represents about 135 landowners, with about 355 wells. Without augmentation, irrigation opportunities would be more limited, and the project demonstrated the economic feasibility of using recharge to offset seasonal and long-term aquifer water level declines. Recharge has also helped keep agricultural land values from declining.

Sustaining agricultural production is important to the local economy. There are also indirect state and federal benefits related to maintaining a stable local economy as well as demonstrating the use of similar technology elsewhere. A 1950-57 drought seriously depleted ground water reserves, and recharge efforts have led to the highest static water levels since 1952.

There may be some water quality related benefits with regard to the migration of poorer quality ground waters. During droughts of the 1950s and 1960s, farmers reported that the water quality in some wells deteriorated, most likely from induced infiltration of salt water from underlying strata, but water quality has not been a problem since the droughts as water levels have risen and the aquifer has not been as heavily stressed. In times of drought, recharge activities could help prevent a recurrence of such a problem.

In addition to the water supply benefits, construction of the Conservation Dam and small impoundment created a small measure of flood protection to a vulnerable part of town in Hollis.

Further, there are some environmental benefits as recharged water is later discharged downstream and once ephemeral streams are flowing on a perennial basis for the first time in 25-30 years.

Project Financing and Cost Recovery

[43]Ibid. pp. S-6

[44]Ibid. pp. 7-7.

For the most part, the demonstration project was financed by federal and state general fund money, without much thought given cost recovery. However, the efforts of the conservation district provide an innovative example of one way to tailor cost recovery measures to promote economic efficiency, using the beneficiary pays principle.

Simple, but effective, recharge activities were initially undertaken as a cooperative effort by local farmers. Irrigation water production wells in the area are primarily powered by natural gas, and farmers agreed to a three percent surcharge on their gas bills to fund district operations, including ground water recharge. District revenues are $12,000 to $20,000 per year, depending on the amount of rainfall and the subsequent need to pump water. This has been sufficient for the construction of about one recharge well per year.

Northern National-PEOPLES Gas Service collects the surcharge for the District, and as the primary power supplier, benefits from the stabilizing effect of the recharge program on the local economy. In essence, the surcharge acts as an excise tax on the use of the ground water resource, as those that pump the most, use the most natural gas and pay the most, thus financing most of the cost of the recharge program and other district operations.[45]

Natural gas is still much less expensive than other fuel options though there are a few pumps powered by electricity or diesel fuel. Agricultural use rates are less than domestic rates or other commercial-industrial rates.

In addition to the five demonstration program project wells, there are about 45 other recharge wells operating in the area. Assuming that their performance is similarly as effective as the project wells, together the existing average annual recharge would total about 3,500 acre-feet, or just over 20% of the average annual amount of water pumped, which is about 17,000 acre-feet. Nearly 200 new wells would be required in order for recharge to equal withdrawals. Whether or not it would be physically practical as well as financially feasible to construct a sufficient number of recharge wells to totally offset pumping would require extensive study.

[45]Site visit and conversation with Paul Horton, landowner and past president of the conservation district, June 8, 1992.

LEGAL AND INSTITUTIONAL ISSUES

The Blaine Gypsum Project has been very successful in part due to the lack of serious legal and institutional barriers. At least in part, this is due to the success of past efforts, and the particular circumstances surrounding this project. For example, the unique geology and hydrology of the area make it possible to recharge significant amounts of water without harm to other water users or the environment. The quality of water in both the aquifer and downstream surface streams limits its potential use for potable purposes, and consequently the need for expensive monitoring or other protection measures. The ephemeral nature of streams in the recharge area also limits possible conflicts with fish and wildlife needs. Lastly, the project benefited from the existence of an established local authority with public support.

Local Conservation District

The existence of the Southwest Soil and Water Conservation District and its past history of successful cooperative landowner activities helped facilitate the initiation, operation and completion of the project. The District will continue to maintain and operate the facilities at the conclusion of the demonstration program. This is one obvious measure of the success of the project. However, without the institutional structure the District provides for cooperative action, past, present and future successes could and probably would have been limited.

The District was originally organized as a special service district to control cut and wash erosion. Its 130-140 members include the vast majority of local landowners and tenant-operators. It is governed by a five member elected board, which includes well respected local landowners and farmers. The common interests of its members and their close family, community and other relationships help facilitate cooperation. Economic interests and a conservation ethic among farmers also promote cooperative endeavors towards sustainable resource management and use.

State Water Law

Stream water use permits are issued by the state of Oklahoma. The District has long held drainage rights to the use of streams and years ago applied for and received permits to use stream water for artificial recharge. In order to store water, the applicant must also hold ground water rights covering the area where the water is injected and stored. The individual landowners within the District hold such rights to the use of ground water for irrigation.

Oklahoma ground water law may be considered somewhere between a correlative rights doctrine and the absolute ownership doctrine. The law states, "The owner of the land owns water standing thereon, or flowing over or under its surface but not forming a definite stream." However, this is not an unqualified right as the "use of ground water is to be controlled, governed and managed according to the provisions of the Oklahoma Ground Water Law."[46] The state may condition and reasonably restrict production.

The Oklahoma Water Resources Board issues use permits, and applicants must own or lease the lands overlying the ground water basin and demonstrate that the intended use is beneficial and waste will not occur.

[46]OKLA. STAT. tit. 60, sec. 60.

Ground water is allocated according to the number of acres the applicant owns overlying the basin, with the landowner taking a proportionate share of the water, based on a 20-year minimum aquifer life (i.e, after 20 years half the overlying landowners wells would not be able to withdraw their proportionate share). However, when hydrologic surveys for ground water basins are unavailable, temporary permits generally allow for the use of up to two acre-feet per surface acre.

Legally, surface and ground water are separate, but the state recognizes recharge as a beneficial use. Surface water use is permitted for artificial recharge, and a separate permit allows the withdrawal of the amount "believed to be reasonably recharged." The applicant must demonstrate the ability to recharge the amount proposed for withdrawal. The state's authority under existing statutes and regulations has been sufficient for the operation of the demonstration project. Further, no need has been expressed for more comprehensive ground water recharge legislation.

Federal Environmental Laws

As already mentioned the state has been delegated regulatory authority under the federal Safe Drinking Water Act and its Underground Injection Control Program. Artificial recharge injection wells are covered as Class V wells, and project wells were registered with the Oklahoma Department of Environmental Quality. However, monitoring of the water quality of the injectate is not required by the state, and following the demonstration project, which has had no significant effect on water quality (either ground water or surface water), there is no reason to believe that extensive monitoring requirements need to be imposed on similar projects in the future.

The U.S. Fish and Wildlife Service provided suggestions included in a fish and wildlife plan that adequately addressed different aspects of the project and any environmental impacts. However, it was determined that the project was not likely to affect any species listed as endangered or threatened or proposed for listing.

Other federal regulatory activities included a cultural resources ground survey to comply with the National Historic Preservation Act, and no significant historic or cultural resources were found.

In closing out the project, the Bureau of Reclamation concluded there have been no long-term environmental effects, in compliance with the National Environmental Policy Act (NEPA).

CONCLUSIONS

The Blaine Gypsum Project successfully demonstrated the feasibility of artificial recharge for agricultural purposes, specifically the use of gravity flow wells to offset seasonal water level declines in an area characterized by karst geologic features.

The availability of surplus runoff and use of relatively simple technology with minimal maintenance requirements reduced the costs of the project.

However, water quality monitoring costs related to the demonstration program were expensive and in the future should be unnecessary, given similar circumstances.

The construction and use of small impoundments can dramatically increase the capture of runoff and the effectiveness of recharge. The cost of land required by such impoundments will be an important factor.

The project was successful in part due to the support of the state as the sponsoring entity and the experience of the conservation district with earlier recharge activities.

There were no significant concerns raised by the project regarding water quality or the environment. Indeed there were some benefits.

The continuing operation of the project, following the completion of the demonstration program, is evidence of its success and the lack of significant opposition.

Past, present and future project operations will serve to stabilize and restore static water levels and the agricultural base of the local economy.

The use of a surcharge on the use of natural gas as a surrogate for taxing water withdrawals, and its acceptance by water users, proves to be an effective tool for promoting efficient resource use. Its use as a means for partially capturing the value added by indirect benefits to local economy might be explored (i.e., a variable general surcharge imposed according to the category of use, including domestic use).

However, the success of the gas surcharge can be traced to its public acceptance, and in turn, landowners' clear perception that they directly benefit from the use of the money raised for recharge and similar purposes.

Again, willingness to pay is the primary measure of the economic and financial feasibility of the project, in the absence of data and detailed economic analysis.

The value-added relationships between water use and crop production, and its impact on land values and the local economy, might be more carefully delineated.

The cooperative private cost recovery mechanism, using the natural gas supplier, is unique, and its possible use elsewhere might be seriously considered.

In this instance, the existing water laws of the state were sufficient for adaptation and use to adequately regulate recharge and recovery activities without new statutory authority.

With public and private support, and no significant opposition, the project has been a win-win solution to a significant common problem that was well defined and lent itself to positive cooperative action.

SOUTHEAST SALT LAKE COUNTY, UTAH

BACKGROUND

Surface water spreading for artificial ground water recharge was tested in the northeast part of the Salt Lake Valley near the mouth of Parleys Canyon as early as 1936, and a series of test wells for injection were drilled in the Olympus Cove area in 1974. In 1983, the Salt Lake County Water Conservancy District (District) contracted for a geotechnical and engineering study for a new dam and reservoir in Dry Creek Canyon. The study found that there was no shallow impermeable stratum to allow a conventional surface reservoir to adequately retain water, but suggested a small dam and spreading reservoir for artificial recharge would be feasible.[47]

Following enactment of the High Plains States Groundwater Recharge Demonstration Program Act of 1983, the District began more seriously studying recharge opportunities. In 1986, the District submitted an injection well project proposal, which was accepted. Construction was completed and injection activities began in 1992, making it one of the first program projects successfully operated. It demonstrates the feasibility of artificial recharge of a principal aquifer by injecting imported surface water treated to state and federal drinking water standards. Once recovered, the water is delivered through an existing system for municipal use in Salt Lake County, which has a population of some 500,000.

Project Description and Purpose

Peak demands during the summer months and limited surface water delivery capacity in the southeast area of Salt Lake County served by the District have led to increasing ground water use and seasonally declining water levels. Moreover, many local wells reach their production capacity early in the summer. In order to avoid shortages, the project utilizes excess winter capacity in the existing municipal water conveyance, treatment and distribution systems to recharge water for recovery later to meet peak summer demands. Located in Sandy City, the project includes two injection well sites near 2200 East, 9400 South and 2300 East, 9800 South, in a developed residential area with some light commercial use.

Water Supply and Recharge

Snowmelt runoff from the Wasatch Mountains to the east feeds local streams and an alluvial aquifer through fractures deep in the bedrock. The unconsolidated aquifer is composed of sand, gravel and cobblestones bearing near pristine water at a depth of 500-600 feet. Untreated surface water from the Provo River is conveyed to the valley by means of the Salt Lake aqueduct, a pipeline 69-inches in diameter and 34 miles long. During the hot dry summer months the aqueduct reaches its current capacity of about 170 cubic feet per second (cfs), while during the winter months it carries only about 40-50 cfs. Water is stored on

[47] Richard P. Bay, "Summary of Southeast Salt Lake County Artificial Groundwater Recharge Demonstration Project," Salt Lake County Water Conservancy District, September 1992, pp. 1-5.

the Provo River behind Reclamation's Deer Creek dam and reservoir and the recently completed Jordanelle dam, which is part of the Central Utah Project. The project utilizes releases from Deer Creek reservoir to maintain instream flows for fisheries below the dam. The water is diverted before it can be degraded in Utah Lake.

Raw water is taken directly from the aqueduct at a turnout at the 9800 South site. It is treated using a rapid mix chemical feed station and in-line filtration process that lacks flocculation and sedimentation basins, but relies on aggregation of particles in the 16-20 inch feeder pipeline. Following filtration, the water is disinfected by means of ultraviolet light, which leaves no chemical residuals in the water, and is then injected. The site includes separate injection (I-1) and recovery wells (R-1), an adjacent washwater decant basin, and an up gradient monitoring well (M-1). The recovery well also serves as a monitoring well.

Water from the existing municipal system is injected at the 9400 South site following full conventional treatment at the District's Little Cottonwood plant, including chemical additions, flocculation, sedimentation and filtration, before disinfection using chorine. The treated water is delivered to the 9400 South site. It is injected and recovered from the same well (I/R-2). There are two nearby monitoring wells (M-2 and M-3). One is down gradient (in the landscaped parking median of a local grocery store and strip mall). The drawings on the following pages illustrate the nature and location of these facilities.

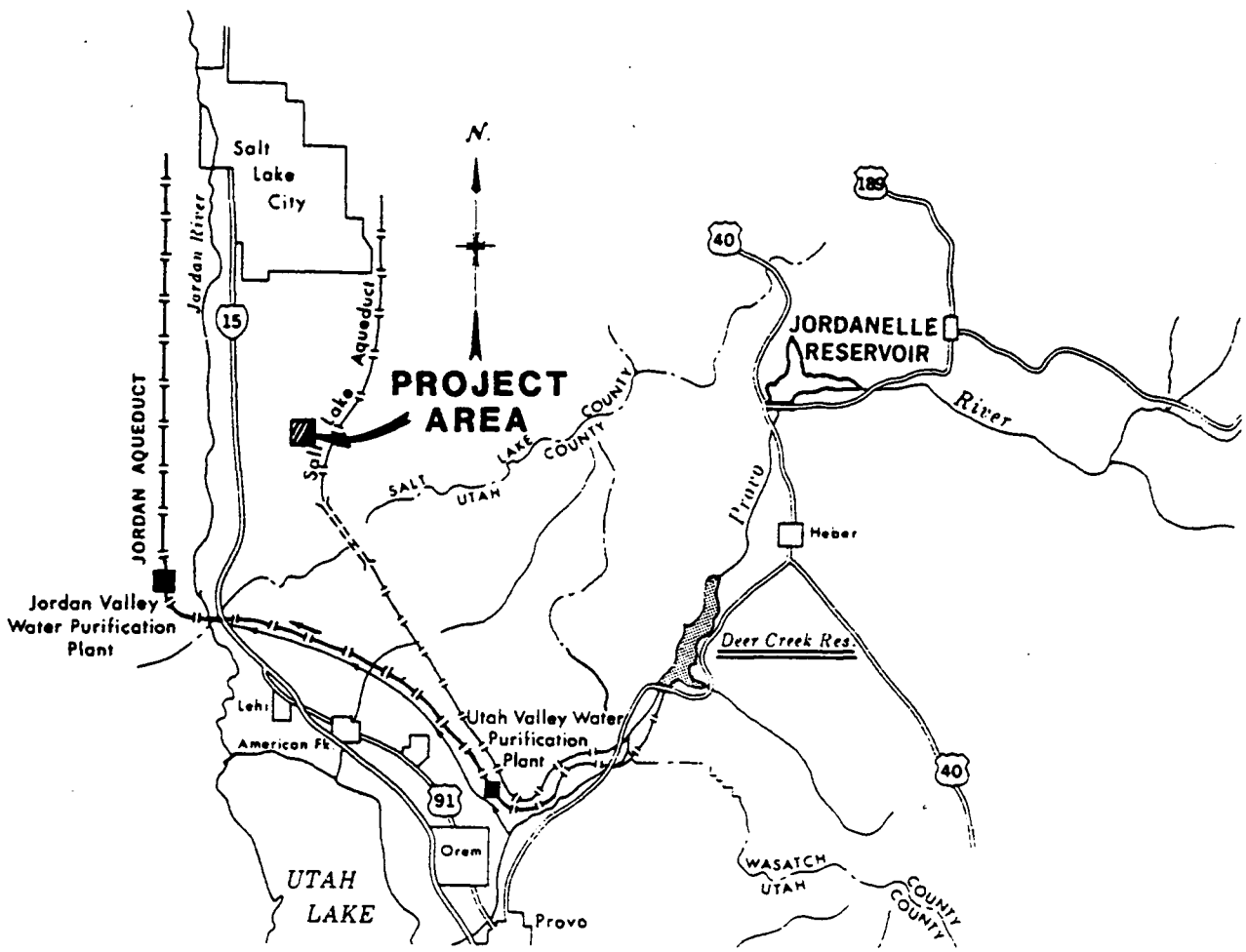
The original development plan called for the injection of 1,430 acre-feet (af) of water per year, with each well injecting 715 af or 900 gallons per minute (gpm) for 180 days. The total for the three-year test period would be 4,290 af. Somewhat more water would be recovered, taking advantage of the District's rights to native ground water. Each well would recover 2,000 gpm for 90 days (from July through September), for a total of 1,588 af per year and 4,764 af over three years.

The District did not start injecting water until January 1992, so less water was recharged than expected for a normal seasonal cycle. Through May 1992, well I-1 injected 374 af and well I/R-2 262 af, for a total of 636 af. Injection rates reached 1,100 gpm. However, the maximum optimal rates were shown to be 900 gpm at well I-1 and 950-1,000 gpm at well I/R-2. Ground water mound buildups occur at both sites, but given the high transmissivity of the aquifer, the mounds quickly collapse (within ten minutes) once recharge stops. Mounding of ground water raised water levels 18-19 feet at M-2, and due to a pressure effect or chain reaction, the buildup was detectable for a radius of greater than one mile.[48] At well I-1, the mound collapses daily, during self-backwashing of the pressure filters, every 35-45 minutes.

Rapid well plugging occurred at well I-1 during the first two weeks of injection, but then mound buildup stabilized. Early rapid plugging also occurred during the first injection cycle at well I/R-2, where fully-treated water is continually injected. A head loss of 30-40 feet was observed in each injection well. The head loss was not restored by stopping injection to allow the built-up mounds to collapse. At the end of the injection season, tubing from each well was removed and cleaned. Pump surging was also necessary for well redevelopment, as swab surging was relatively ineffective.

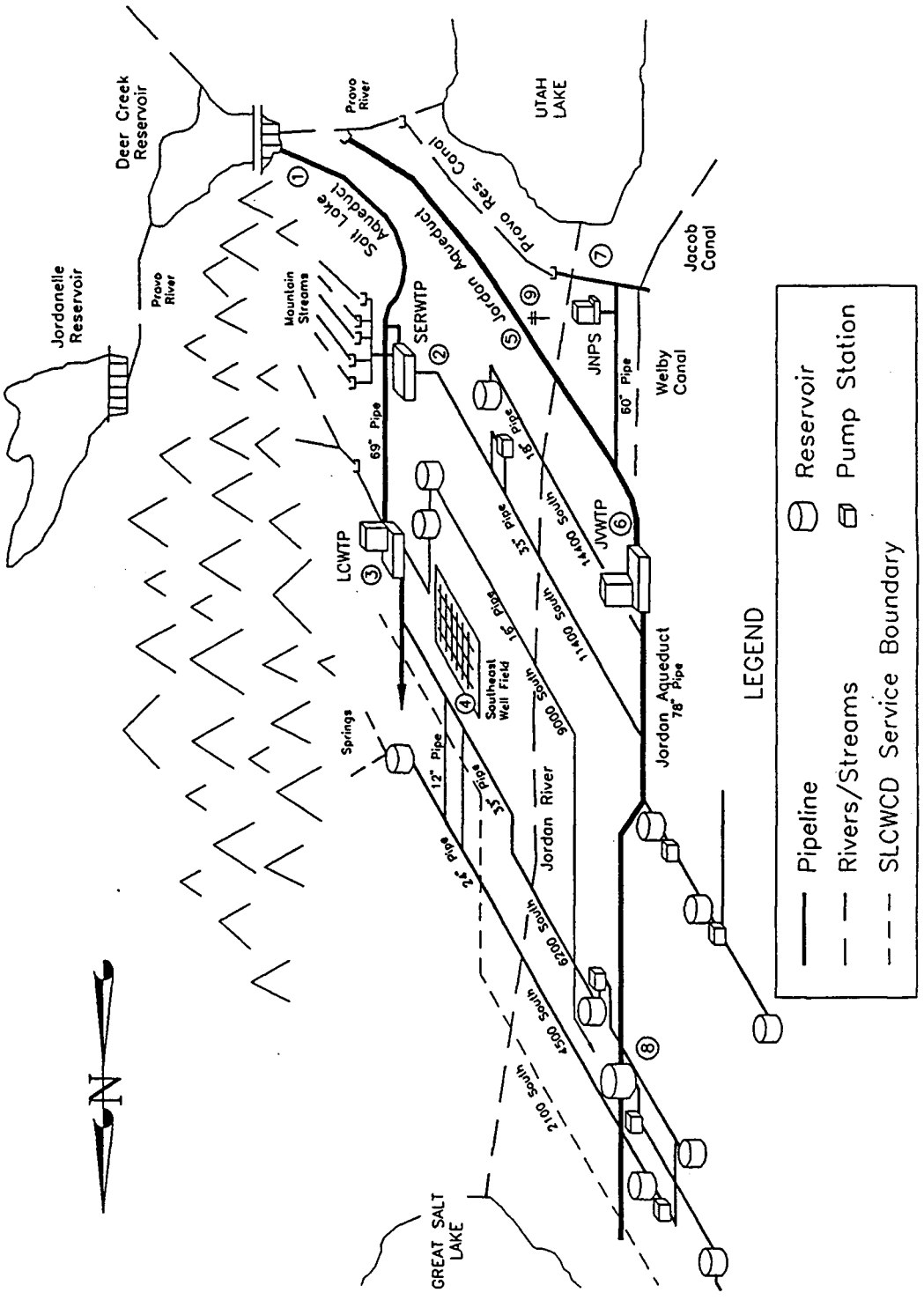
[48] Ibid, pp. 12-13.

Central Utah Project Facilities



Southeast Salt Lake County Artificial Groundwater Recharge Demonstration Project Final Report, Salt Lake Co. Water Conservancy Dist., February 1996, Fig. 1.1.5F, p. 1-11

Southeast Salt Lake County
Project Facilities



Southeast Salt Lake County Artificial Groundwater Recharge Demonstration Project Final Report, Salt Lake Co. Water Conservancy District, February 1996, Figure S-2, p. S-5

Water Quality

Given the nearly pristine nature of the water in the aquifer, and its importance as a source of drinking water, protecting water quality is imperative. It is also necessary for the successful operation of the recharge wells. Initial hydrogeological and geochemical modeling concluded that the surface water and native ground water were generally compatible, both are calcium carbonate. However, the recharge water included high aluminum concentrations and the ground water was relatively high in iron, raising concern that any siderite in the aquifer alluvium might lead to precipitation of the iron and some plugging. Further testing suggested the risk was marginal.

Initially, the District considered constant monitoring of the project injectate water, but found no practical on-line and real-time monitoring system available. The District has adopted a conventional grab sampling approach with an extensive and comprehensive quality assurance and quality control (QA/QC) plan that carefully specifies field sampling procedures and techniques to ensure analytical precision.[49]

The monitoring wells include dedicated sample pumps. Water samples are drawn semi-weekly, bi-weekly, monthly and quarterly from the treated surface water, native ground water and co-mingled ground water. An extensive list of possible contaminants is analyzed, including radionuclides, volatile organics (VOCs), synthetic organics, inorganics, and bacteriological and physical parameters. The QA/QC plan meets or exceeds all state and federal requirements.

The Utah Department of Health's Division of Water Quality regulates and oversees project operations through an Underground Injection Control (UIC) permit, required by the federal Safe Drinking Water Act. The state also requires that the injected water meet Utah Ground Water Quality Standards, presented on the next page. The standards are generally identical to current drinking water standards for the ground water analytes included. The standards do not include a bacteriological category, but the District has adopted an extensive testing program for total coliform bacteria and heterotrophic plate count bacteria.

The Utah Department of Health's Division of Drinking Water monitors water recovered for municipal use to ensure it meets state and federal drinking water standards. The District's extensive QA/QC plan meets or exceeds all state and federal requirements. The recovery wells do include on-line instrumentation to monitor temperature, pH and conductivity.[50]

Of note, analysis of plugging debris at injection well I-1 revealed high levels of dissolved inorganic constituents that are byproducts of conventional water treatment. This included aluminum from the aluminum sulfate used as a primary coagulant and manganese from the potassium permanganate used as an oxidant in the treatment process. High iron concentrations appear to be the result of naturally occurring iron in the aquifer alluvium.

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[49] "Southeast Salt Lake County Artificial Groundwater Recharge Demonstration Project Summary," Salt Lake County Water Conservancy District, July 14, 1992; and Bay, pp. 9, and 14-16.

[50] Bay, pp. 10-11.

Ground Water Quality Standards
Utah Department of Environmental Quality

Parameter	Concentration (mg/l unless noted otherwise)
Physical Characteristics	
Color (units)	15.0
Corrosivity (characteristic)	noncorrosive
Odor (threshold number)	3.0
pH (units)	6.5 - 8.5
Inorganic Chemicals	
Fluoride	2.4
Foaming Agents	0.5
Nitrate (as N)	10.5
Metals	
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Copper	1.0
Lead	0.05
Mercury	0.002
Selenium	0.01
Silver	0.05
Zinc	5.0
Organic Chemicals	
Pesticides 2, 4-D	0.1
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2, 4, 5 - TP Silvex	0.01
Volatile Organic Chemicals	
Trichloroethylene	0.005
Carbon Tetrachloride	0.005
Vinyl Chloride	0.002
1, 2, - Dichloroethane	0.005
Benzene	0.005
1, 1, - Dichloroethylene	0.007
1, 1, 1, - Trichloroethane	0.200
para - Dichlorobenzene	0.075
Other Organic Chemicals	
Trihalomethanes	0.1
Radionuclides	
Combined Radium 226 Radium 228	5pCi/l
Gross alpha particle activity, including radium 226 but excluding Radon and Uranium	15pCi/l
Beta Particle and photon radioactivity (man-made)	4 Millirem

ECONOMIC EFFICIENCY AND FINANCIAL FEASIBILITY

The Bureau of Reclamation and Salt Lake County Water Conservancy District are equally sharing project costs. The total cost of the project is a little less than $3.1 million, which includes preliminary investigations, pilot testing, facilities construction, and operations for three years. Capital costs total $2,315,800 and operation, maintenance and repair costs $699,400.[51] Unit water supply costs have been calculated for each site taking into account the cost of the raw water supply, treatment, recovery and injection well redevelopment. The unit costs are presented below.

Water Supply Unit Costs
(per acre foot)

	9400 South	9800 South
Raw Water		
pumping	$ 25	$ 25
aqueduct conveyance	12	12
capitol recovery	25	25
Treatment		
operation & maintenance	15	40
capital recovery	87	--
Recovery Pumping		
operation & maintenance	65	65
capital recovery	84	84
Injection Well Redevelopment	30	0
	$343/af	$251/af

The raw water supply cost for the two sites are the same and include pumping, conveyance and capital recovery costs. Capital recovery costs were calculated over a twenty-year period at a seven percent interest rate. Recovery pumping costs are also the same. There are major differences in the operation and maintenance costs of treatment. The most significant difference is attributable to the capital cost savings at the 9400 South site due to the use of excess winter capacity at the District's Little Cottonwood water treatment plant. Another important difference is the cost of injection well redevelopment at the 9800 South site.

Compared to the District's current average unit water supply costs, project unit costs are very high at $251 to $343 dollars per acre foot. At this time, aquifer storage and recovery would not be a cost effective water supply alternative for meeting base demands. However, the project was designed as an important source of supply for meeting peak demands.

When compared to the cost of developing a new water supply, as illustrated on the next table, the recharge project is clearly a cost effective and reasonable alternative. The Provo River construction estimates are actual construction costs for the District's Jordan Aqueduct (1984-1985) and Jordan Valley Water Treatment Plant (1972-1988), which serve the west side of the Salt Lake Valley. The construction costs for the Bear River facilities are 1991 estimates.

The District may develop more recharge and recovery wells.[52]

[51] Bay, p. 20.

[52] Bay, pp. 20-21.

Southeast Salt Lake County Project
Peak Supply Unit Costs

Ground Water Recharge Project	
Total Capital Costs	$2,315,800
Project Capacity (two wells @ 2,000 gpm)	8.9 cfs
Unit Cost	$260,000/cfs
Provo River Aqueduct/Treatment Facilities	
Jordan Aqueduct Construction	$ 64 million
Jordan Valley Water Treatment Plant	37 million
	$101 million
System Capacity	270 cfs
Unit Cost	$374,074/cfs
Bear River Pipeline/Treatment Plant	
Pipeline Construction	$118 million
Treatment Plant	37 million
	$155 million
System Capacity	163 cfs
Unit Cost	$950,920/cfs

Financing, Cost Sharing and Cost Recovery

The Salt Lake County Water Conservancy District is funded by water sales and property tax levies. About 80% of its revenue comes from water sales, and the remaining 20% comes from taxes. The District's property tax levy is 4 mils, 50% of which is allocated for operation and maintenance expenses. The District's capital construction fund is also financed from the proceeds of two revenue bonds issued in 1987 and 1991.

With respect to cost sharing and cost recovery alternatives, the recharge project is considered an integral part of the District's overall water supply system. There has been no attempt to measure any specific incremental local benefit or to try to recover project costs from possible beneficiaries. The District does have authority to set variable rates, based on the cost of service, which would include water storage, pumping and distribution costs. Moreover, the District may establish differential rates that include hourly and daily peak use charges. However, to date, such authority has not been used with this project.

Of note, the potential "zone of benefit," or area affected by the District's recharge activities, extend beyond the District's boundaries as responsibility for water service in the area is also shared with Sandy City's municipal utility and the White City Water Company, a private utility. Given the unconfined nature of the aquifer recharged, water lost outside the project's boundaries may be captured by adjacent wells. Different utilities' wells are intermingled throughout a patchwork service area. As a result, the potential exists for other water purveyors, with wells in the area, to benefit from the project without sharing the costs.

Sandy City, with wells adjacent to the project area, would be the most likely to intercept any escaping water. Sandy City and other water utilities may also benefit from elevated water levels and any related reduction in pumping costs.[53] Initially, Sandy City was to be a cosponsor of the project, but it ultimately declined the invitation.

Of note, the state now credits and allows the District to recover 80% of the water recharged, but the District hopes to be able to demonstrate that recovery of 100% of the water recharged is possible.

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[53] Personal interview of Richard Bay, Salt Lake County Water Conservancy District, March 1, 1993.

LEGAL AND INSTITUTIONAL ISSUES

As mentioned above, responsibility for water service in southeast Salt Lake County is fractured and falls upon different public and private agencies. While this has had little impact on the current demonstration project, it may very well be an important obstacle to the future expansion and use of ground water recharge as a general water supply alternative for the area.

Local Government

Differences between the District and Sandy City over rate increases, among other things, led the city to withdraw from membership in the District. Sandy City now relies on surplus water supplies that it purchases as a member of the Metropolitan Water District of Salt Lake City, utilizing its own 800 af water storage right and 25 mgd share of the capacity of the District's Little Cottonwood water treatment plant. However, surplus Salt Lake City water may only be available through 2001, after which it will be needed to meet Salt Lake's growing demands. Greater cooperation and collaboration between water management agencies may be necessary to meet future water supply needs.

Planning and Zoning Ordinances

Of particular interest, landscaping of project facilities became an issue of some significance. The recharge, recovery and monitoring wells and related buildings are all located in developed and developing residential areas, with some light commercial use. Indeed, one monitoring well (M-3) is located in the landscaped parking median of a nearby grocery store and strip mall on 9400 South. The 9800 South site is the largest and covers a number of acres. Initially, the county planning commission wanted the entire area planted in bluegrass. Ultimately, the District agreed to plant trees around the perimeter of the site, and plant other grasses to cover much of the site. In addition to aesthetics, dust and pests (grasshoppers) were of concern.

State Water Law

The Utah State Engineer and the Division of Water Rights, within the Department of Natural Resources, regulate water use. When the District began preliminary work on the recharge project, the state of Utah had no direct statutory authorization for such activities. State law now recognizes and regulates recharge and recovery activities, but initially the District and the state had to work out an arrangement under the state's general water laws.

First, the District made separate applications for the underground storage of its existing surface water rights and for the extraction of native ground water. The latter was in the form of a required application to change the point of diversion for the District's substantial existing, but largely undeveloped, ground water rights, which carry an early priority date. The ground water use rights were approved by the Utah State Engineer, but the temporary change application for a new point of rediversion to allow the District to recharge and store its existing surface water rights was protested by Sandy City, due to water quality concerns. The change application was withdrawn, but later Sandy's concerns were resolved and the change application was renewed and granted.

In 1991, recognizing the value of this emerging technology, the Utah State Legislature passed the Ground Water Recharge

and Recovery Act.[54] The law requires separate recharge and recovery permits, and establishes filing fees. First, an applicant for a recharge permit must have a valid water right for the water proposed to be recharged, or enter into an agreement to use water proposed to be recharged by someone with a valid water right. Evidence of compliance with all applicable water quality permits is also required. Evidence of the applicant's financial and technical capabilities is required, as well as a study demonstrating hydrologic impact and feasibility, the percentage of anticipated recoverable water, and that the project will not cause unreasonable harm to land or impair any existing water rights within the area of hydrologic impact. The state engineer may require other information, and in issuing the recharge permit may attach any conditions deemed appropriate. Recharge projects must be completed within five years or the permit will lapse, unless extended with the approval of the state engineer.

Recovery permits may be filed along with recharge permits by the same applicant, or with the consent of the owner of the recharge permit. The required information includes the purpose for which the stored water will be recovered. The state engineer shall issue the permit if the proposed recovery of stored water will not impair any existing water right, the point of diversion (or withdrawal) is within the area of the hydrologic impact of the project, and the applicant has complied with other applicable requirements and conditions. The construction of any new well to recover stored water must comply with existing rules. Recovery projects must be completed within two years or the permit will lapse.

[54]Utah Code Annotated, Section 73-3b-101, et seq.

The state engineer is to establish a storage account for each project. Permit holders must monitor project operations and file reports as required regarding the quantity of water stored and recovered, and the quality of the recharged water, receiving aquifer and recovered water. Moreover, an annual fee is assessed by the state engineer, which is to reflect the division's costs of administering and monitoring recharge and recovery projects. The state engineer may unilaterally modify a permit if necessary to protect existing water rights or the water quality of the aquifer. Ground water recharge and recovery permits may be assigned with the approval of the state engineer. Permit requirements and conditions are enforced by civil penalties of up to $10,000 per day, and possible suspension or revocation.

In 1991 and 1992, the state approved recharge and recovery permits for the District. The state engineer does not yet allow multi-year "banking" of water. Rather, water recharged must be recovered within the same year, with the recharging agency showing what percentage of the recharged water was recovered. The District conservatively estimated recovery of 80% of the surface water recharged, which the permit allows. The District hopes to be able to submit proof that an even greater amount is recoverable. Again, the District also holds rights to withdraw native ground water, so any water withdrawn in excess of 80% of that recharged is debited against that other right. Actually, the commingling or mixing of surface and ground water makes these waters indistinguishable when recovered.

No other recharge or recovery permits have been sought or granted by the state. However, there are a number of areas where artificial ground water storage and recovery may be feasible. Further, the District is considering the possibility of expanding its recharge activities.

Federal Environmental Laws

To date, the District has not found state or federal environmental statutes and regulation to be a burden, but there are potential obstacles to future development and expansion. The U.S. Environmental Protection Agency and Department of Interior's Fish and Wildlife Service carefully considered possible project impacts on the environment (as part of the initial screening process by which projects were selected for the demonstration program). To date, no serious concerns have arisen over adverse environmental impacts. In fact, the project's utilization of water in the winter helps maintain minimum flows in the Provo River for fish habitat as water is released from storage upstream. Further, by displacing peak demands, the project may help reduce pressures to increase spring and summer diversions, thus also protecting fish.

Endangered Species Act

To date, there appear to have been no adverse impacts on listed endangered or threatened species, nor are any likely due to the construction and operation of the project. However, this issue may need to be revisited in the future, as part of a regular environmental (NEPA) review, should the District choose to continue to operate the project beyond the present demonstration period.

Expanded recharge activities and increasing diversions from the Provo River would have an effect on flows into Utah Lake and might affect the endangered June sucker. Studies are now underway to help determine the needs of this endangered fish and the extent of the effect of continuing and increasing water diversions.

Provo River water use is governed by a complex array of rights, exchanges, and agreements involving a number of different water districts and water projects. Further ESA consultation may be required for future operation of the Central Utah Project, and might possibly also affect operation of the Deer Creek dam and reservoir. Both are Reclamation projects that store Provo River water.

Safe Drinking Water Act

Utah regulates all injection wells in the state under authority of the federal Safe Drinking Water Act and the Utah Water Pollution Control Act and Utah Administrative Code.[55] Within the Department of Environmental Quality, the Division of Water Quality, regulates ground water recharge wells as Class V injection wells. When the permit was issued for the project, responsibility lay with the former Bureau of Water Pollution Control, then within the Department of Health. The Class V permit authorizes the use of two injection wells and outlines a method for approval of other wells within the permit area. As the aquifer recharge supplies a significant portion of the urbanized part of Salt Lake County, the state and the District have adopted a conservative approach to permitting the injection of water. Only fully treated water (treated with an approved coagulant/oxidant and then filtered, as previously described) may be injected. All additives to the injection stream must meet all Utah Public Drinking Water Regulations,[56] and recharged water may not cause a violation of Ground Water Quality Standards,[57] or otherwise

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[55]Utah Code Annotated (UCA), Title 26, Chapter 11 and Utah Administrative Code (UAC) R448-7.

[56]UAC R449-108-5.

[57]UAC R448-6-2.

adversely affect the public health. Limits on project operation and injection also cover pressure in order to ensure sampling integrity. The Class V injection well permit issued on June 5, 1990, expires and must be renewed prior to June 4, 1995.

CONCLUSIONS

The conjunctive use of the District's surface and ground water rights, using artificial recharge and recovery, is a practical and cost effective alternative to meet peak summer water demands.

The Southeast Salt Lake County Project demonstrates the effective conjunctive use of ground water and surface water from existing federal facilities -- both the Deer Creek Project and the larger Central Utah Project.

The Provo River, the surface water source of supply for the demonstration project, is governed by a very complex array of water rights, exchanges, agreements and laws prescribing its uses.

Again, securing an adequate surface water source for ground water recharge is an important limiting factor in the successful use of available technology.

Existing state water laws may be adapted to accommodate ground water recharge projects, or a state may choose to enact new authorities to address the unique concerns surrounding recharge.

The project served as a catalyst for changing Utah water law to specifically address the unique circumstances surrounding ground water recharge activities, smoothing the way for future projects.

The District may be able to cost effectively expand recharge activities, enhancing the efficiency of its water supply system.

Responsibility for water management in the area served by the project is fractured, and expansion of conjunctive use and artificial recharge projects will necessarily require increased cooperation and collaboration among a number of local agencies.

The Endangered Species Act and other federal regulatory requirements continue to be important constraints, creating substantial uncertainty with respect to the future development and use of western water resources and utilization of recharge opportunities.

Aquifer storage and recovery projects may be compatible with developed residential urban areas, but local planning and zoning requirements are significant issues and increase costs.

HIGHLINE WELL FIELD, SEATTLE, WASHINGTON

BACKGROUND

The Highline Well Field project is located in the City of Seattle, just north of the Seattle-Tacoma international airport, and west of I-5. The Seattle Water Department (SWD) is the project sponsor. While most of the city is served by an extensive surface water supply and distribution system, the Highline area receives supplemental seasonal service from a number of ground water wells. Summer peaking demands cause ground water level declines of as much as 30 feet, and growing demands could lead to future peaking requirements that are beyond the present capacity of the water distribution system. Moreover, the most recent westwide drought strained Seattle's water supplies and resulted in outside water use restrictions across the city. Recharge activities were suspended in 1992 for a time as joint production-recharge wells had to be pumped to meet peak summer demands.[58]

The Highline aquifer system consists of shallow, intermediate and deep zones within a thick sequence of unconsolidated glacial and interglacial deposits. The intermediate zone has the highest transmissivity, and is the primary source of ground water for the well field. Its boundaries are the Duwamish River valley on the east, and Puget Sound on the west, with confining aquitards on the north and south of fine-grained sediments with low-permeability. Natural recharge to the deep and intermediate aquifers amount to about 2-5 inches per year from precipitation and infiltration from some small lakes. Given an estimated recharge area of about 15 square miles, preliminary calculations indicate the deep and intermediate aquifers are capable of producing 6.5-13 million gallons of water per day (mgd) over a four-month period of time without permanently lowering water levels.[59] However, greater use would lead to mining of the resource. Of note, to date no salt water intrusion problems have been experienced.

Project Purpose and Description

The Seattle Water Department's Highline well field project is an aquifer storage and recovery (ASR) project. The goal is to mitigate ground water level declines during the summer months and develop a ground water supply capable of meeting a peak demand of 12 mgd for up to four months per year. The objective is to supplement existing municipal surface water supplies with local ground water supplies and thus extend the life of the present distribution system and avoid the need for any costly expansion. The Highline well field provides only a relatively small amount of the city's total water supply, but as a peaking and emergency supply, it is very important.

Water Supply and Recharge

The Cedar River is the principal surface water source for the City of Seattle and the project, with some additional water from the

[58] Personal interview with Bob Schwartz, Seattle Water Department, and Kenneth Trotman, CH2M Hill, June 12, 1992.

[59] Highline Well Field Initial Evaluation, Seattle Water Department and CH2M Hill, Vol. 1, September 1990, p. vii.

South Fork of the Tolt River. Both watersheds originate in the Snoqualmie National Forest on the Cascade Range, including the Wenatchee Mountains and Alpine Lakes Wilderness Area, north of Mount Rainer. The Tolt River watershed covers approximately 20 square miles. The Cedar River watershed covers about 140 square miles, and provides about two-thirds of the drinking water for the greater Seattle area's 1.2 million people. The city owns about 80% of the watershed, which is a natural area closed to unauthorized public access to protect water quality. "You're either escorted into the watershed, or you're escorted out!"[60]

The municipal delivery system is primarily gravity fed. The Cedar River originates with Meadow Mountain at an elevation of 5447 feet above sea level and water is diverted some 30 miles downstream at Lansburg, at an elevation of 538 feet. The water is screened, chlorinated, fluoridated and piped to storage reservoir for distribution to Seattle Water's direct service retail customers as well as suburban water utilities.

The Highline project uses surface water from the existing distribution system and a well field developed in 1984. Water is supplied from the existing 60-48 inch Cedar River pipeline #4 (CRPL-4). It runs west from just south of the intersection of I-5 and state road 518 to 24 Avenue S, then north. Adjacent to the pipeline is the Riverton Heights Reservoir (steel tank) and well facility, the Metro test well, Glacier High School well, and further north to the Boulevard Park School well facility. The map on the next page illustrates the location of these sites. The project was developed in phases, first with the construction and successful testing of the Metro site, followed by a successful pilot recharge program at the Boulevard Park production well site.[61] Further testing at the Riverton Heights site was unnecessary.

Full-scale recharge was planned for the spring of 1992, but again, it was delayed due to the drought and regional water supply shortages. However, full-scale operations at the Boulevard Park and Riverton Heights sites occurred from January to May 1993, with both wells recharging about 1.44 mgd. The total amount recharged was about 400 million gallons, and recovery began on July 1, with the normal pumping season to meet peak summer demands. Construction of a fourth well is expected to increase well field management efficiency and raise potential production 1-1.5 mgd.

Water Quality

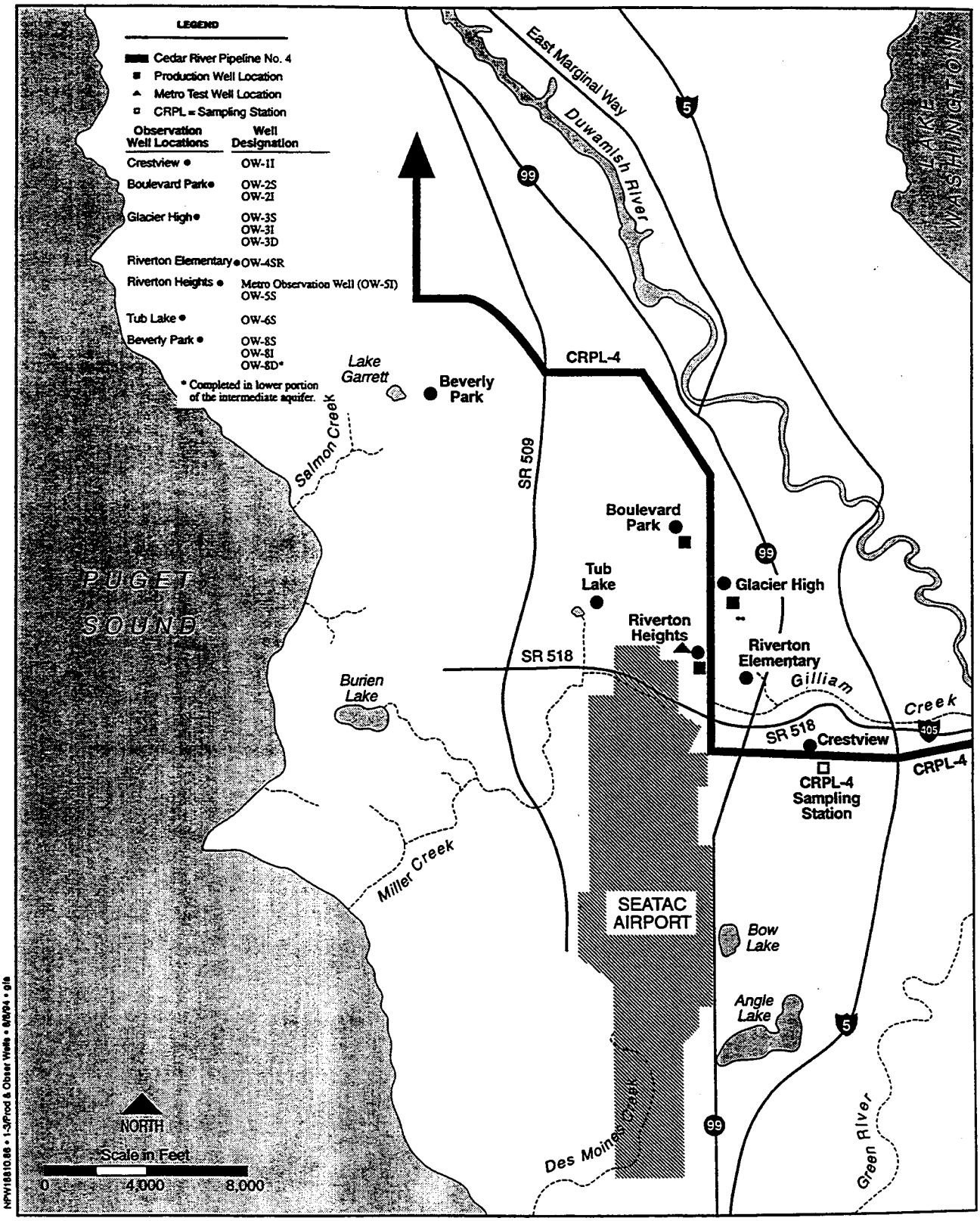
Water quality is an important concern - both with respect to successful operation of the wells for recharge and the subsequent recovery and use of the water for municipal and industrial purposes. Recharge well clogging was a minor problem. Filtration testing indicated that the most important variables related to the well clogging included the level of suspended solids in the source water, the rate of injection, the effective surface area of injection, the hydraulic conductivity of the aquifer, and the temperature of the source water. Other potential sources of clogging that were not found to be significant contributing factors included air entrainment, clay mineral swelling, chemical precipitation of iron and manganese, and bacterial slime.

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[60] The Cedar River Watershed, Seattle Water Department, pamphlet, 1992.

[61] Highline Well Field Pilot Test Results, Executive Summary, Seattle Water Department/CH2M Hill, January 1992

Seattle's Highline Well Field Production and Observation Wells



Highline Well Field Pilot Test Results, CH2MHill, January 1992, Figure 3-1, p. 3-2.

Clogging at the Metro well test site appears to have been the result of algal or diatom blooms in one of the city's surface water reservoirs, Lake Young, and the concentration of fine-grained solids filtered by the aquifer in the immediate vicinity of the well screen. Clogging occurred during full-scale recharge at both the Boulevard Park and Riverton Heights sites. The wells were back-flushed every two weeks, but it was difficult to determine how effective this was. However, ground water mounds at both sites continued to build. Water produced by back-flushing was diverted to a sedimentation pond and later discharged to a storm drain.

Water quality was monitored during full-scale recharge and enough information was gathered on geochemical and other reactions to evaluate overall water quality trends that might affect the blending of recovered water and treated drinking water in the distribution system. Data collection focused on subsurface bacterial growth, radon concentrations (due to elevated natural background levels), and disinfection by-products. Information was also collected on alkalinity, hardness (river water is much softer), pH and chlorine. The analytical parameter groups are presented in the table on the next page, followed by a diagram of the conceptual recharge water envelope.

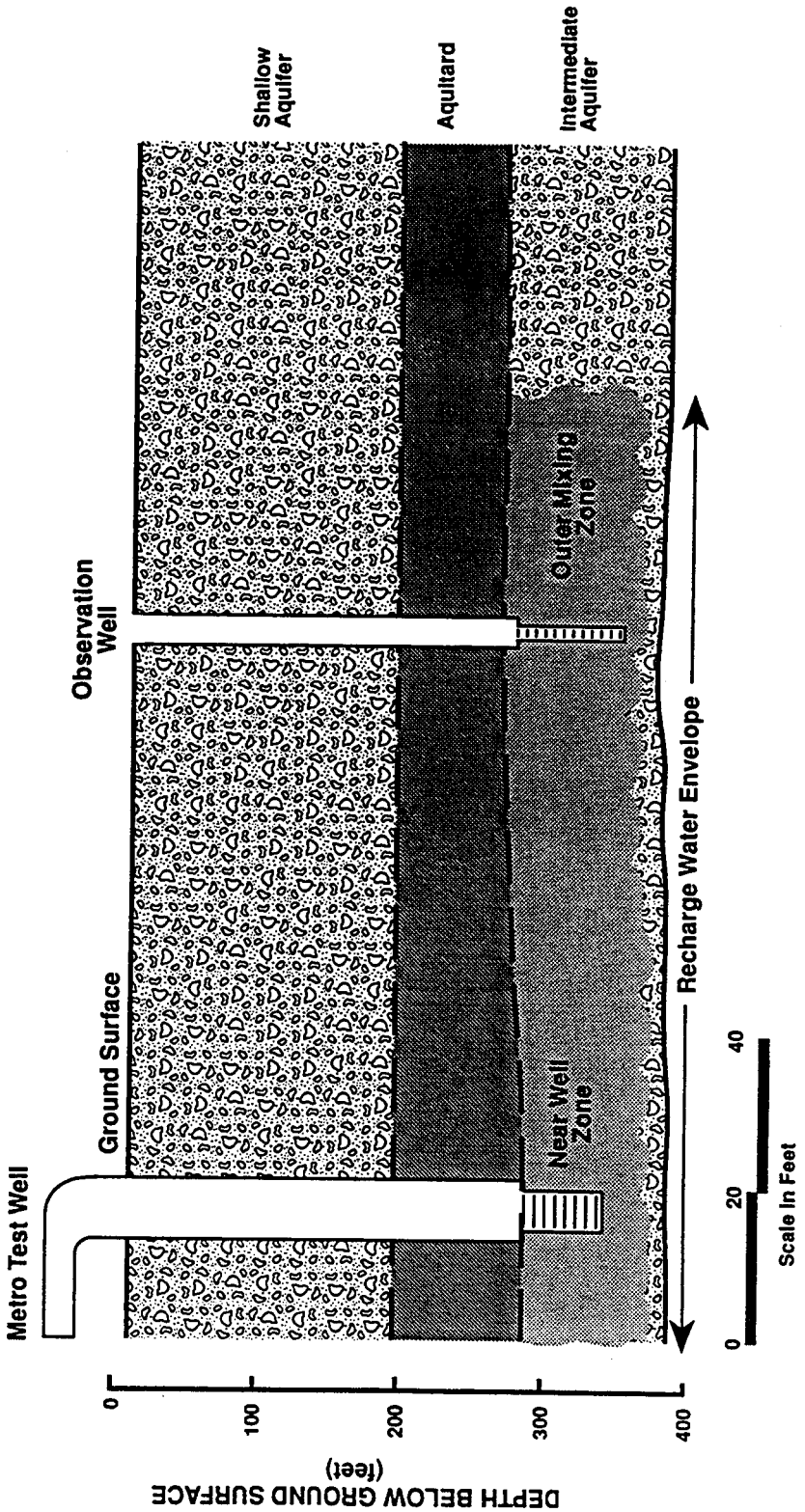
All water quality standards have been met in both the recharged water (or injectate) and in the aquifer. Seattle must protect the quality of its water and the integrity of its distribution system, but the water department is also concerned with the costs imposed on the project by EPA's "elaborate quality" assurance/quality control (QA/QC) requirements. The table on the next page illustrates the breadth and scope of the monitoring requirements, which include geochemical, bacteriological, solids and drinking water analytical parameters.

Also of note, in the future, wellhead protection concerns may need to be addressed. The SeaTac airport area has been incorporated, and Boeing has constructed a maintenance building adjacent to the Riverton Heights well field. Seattle was not consulted and essentially has little or no control over land use outside its boundaries but adjacent to its wellfield. As ground water recharge projects become more common, cooperative intergovernmental efforts to protect wellhead and recharge areas between jurisdictions will become even more important.

Highline Well Field Water Quality Monitoring Parameters

Table Analytical Parameter Groups For Water Quality Monitoring			
Geochemical	**Bacteriological**	**Solids**	**Drinking Water**
Calcium	Ammonia	Total dissolved solids	Fluoride
Magnesium	Nitrite	Total suspended solids	Hardness
Sodium	Nitrate	Total volatile solids	Color
Silicon	Dissolved ortho-phosphate	Turbidity	Chlorine demand
Alkalinity	Dissolved organic carbon	Total phytoplankton	Radon-222
Chloride	Total organic carbon	Total zooplankton	Disinfection by-products
Bromide	Cyanide		Trichloroacetic and
Sulfate	Tannin-lignin		Dichloracetic acid
Sulfides	HP count		Chloral hydrate
Oxygen (dissolved)	Coliform (total)		Bromate
Oxygen (% saturation)	Coliform (fecal)		Chlorine
Aluminum			Chloramines
Antimony			Chlorine dioxide
Arsenic			Chlorate
Barium			Chlorite
Beryllium			Chloroform
Cadmium			Chlorodibromomethane
Chromium			Bromoform
Color			Bromodichloromethane
Copper			
Iron			
Lead			
Manganese			
Mercury			
Molybdenum			
Nickel			
pH			
Potassium			
Selenium			
Silver			
Specific conductance			
Thallium			
Total organic halides			
UV absorbance			
Vanadium			
Zinc			

Highline Well Field Conceptual Recharge Water Envelope



Highline Well Field Pilot Test Results, CH2MHill, January 1992, Figure 4-1, p. 4-2.

ECONOMIC EFFICIENCY AND FINANCIAL FEASIBILITY

The Seattle Water Department's (SWD) final project report includes an economic evaluation prepared to provide information to help evaluate future potential projects.[62] It presents development, construction and operation costs for the Highline well field with and without the aquifer storage and recovery (ASR) component. Future project costs may vary depending on labor and material costs, competitive market conditions, final project scope, implementation schedule and other variables. Of note, the report also points out that research, monitoring and testing requirements were more stringent, and engineering and hydrogeological investigative costs were somewhat higher than usual for an ASR project, as the project was built under the federal demonstration program.

Project Benefits

The Highline project is a single-purpose water supply project, with no other significant benefits that are apparent. The actual value of the additional peaking water supply provided by the project has not been determined, but could be estimated based on the alternative cost of expanding the distribution system in order to meet peak demands. Moreover, there will be some energy savings related to reduced pumping lifts. As with other program projects, economic efficiency has largely been assumed given the project sponsor's willingness to pay the required cost share.

Project Costs and Cost Sharing

The total cost of developing the Highline Well Field and recharge project has been about $5.2 million. The total cost of the recharge portion of the project is about $2,320,000 and the City of Seattle's required 20% share of that cost is $464,000. Seattle and wholesale water purveyors are the direct beneficiaries of the additional water supply provided by the project.

Since 1984, the Seattle Water Department has invested more than $2.9 million, including its share of the demonstration program costs, into developing the Highline well field. Operation and maintenance (O&M) costs vary, but range from $60,000 to $100,000 annually. In 1992, no recharge took place as well field production was needed to meet emergency drought demands. In 1993, no water was pumped from the well field as it was not needed.

The project report's economic evaluation categorizes components under engineering and hydrogeological investigative, capital, annual, replacement and other costs. First, investigative costs include planning, conceptual design, predesign and final design, and studies of hydrogeologic conditions (ground water supplies and water quality). Capital costs refer to construction costs and include site development, facilities construction, well installation, and all labor, materials, and equipment associated with the well field and ASR system. Other related costs include contingency, sales tax, engineering, legal, administrative and financing costs.

Total capital costs include construction and other costs. Historical construction costs were available from the Seattle Water Department.

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[62] Highline Well Field Final Report, U.S. Bureau of Reclamation Recharge Demonstration Program, Part 4 Economic Evaluation, CH2M Hill Northwest, Inc., May 1994, p. 4-1.

Initially, other costs were estimated, based on industry standards: 30% contingencies; 8% sales tax; 25% engineering; and 6% legal, administrative and financing costs. To obtain the total project costs, the actual construction costs were adjusted by a factor of 1.85 to account for unknown costs.

Annual well field facilities costs are estimated over a 50-year project life and are categorized under operation and maintenance (O&M) costs and well field monitoring costs. Annual O&M costs for 1992 and 1993 represent costs with and without ASR. In 1992, due to the drought, SWD operated the well field at near full pumping capacity for the first time, without any ASR activity. From June 5 to June 30, and August 17 through December 21, the well field produced 1,038 million gallons of water. In 1993, from January 13 through May 24, well field operations included full-scale multi-well recharge and recovery testing and simulated operational conditions. A total of 380 million gallons of water were processed.

Monitoring costs with and without the ASR component were developed based on testing parameters and testing frequency as outlined in the project's operations and maintenance manual.[63] Monitoring costs included planning, reporting, sample collection, laboratory analysis and miscellaneous expenses (travel, equipment and shipping costs). Labor estimates ranged from $30-$50 per hour for sample collection, planning and reporting, while SWD provided laboratory analysis costs typical for privately-owned laboratories.

Replacement costs were estimated assuming a 50-year life expectancy for well field facilities, except for pumps, electrical and instrumentation equipment, which were assumed to be replaced after 25 years.

Other costs that were not included in the economic evaluation and estimates included costs incurred: (1) as part of a well head protection program; (2) incorporating ASR activities as part of the existing well field O&M manual; (3) the final project report; and (4) well field modeling and well abandonment. These additional activities either would have been incurred with or without incorporating ASR activities, or might not be required for a typical ASR project.

The present worth of the Highline facilities was calculated using 1994 costs and a three percent discount rate recommended by the SWD financial office. For comparison, total project costs were estimated with and without the ASR component. Next, a unit cost of water was calculated as the sum of the capital cost, the present worth of equipment replacement costs, and all annual costs over the life of the project, divided by the "levelized well field yield."

Unit Cost of Water

The levelized well field yield was determined based on the maximum annual well field production capacity of 5.6 million gallons per day (mgd) without ASR and 10 mgd with ASR, assuming operation over a 3-month (summer peak demand) period. The value of the water was discounted at 3% over the life of the project, and the unit cost of water was then calculated as the ratio of the present worth of the project cost to the levelized well field yield. Assuming maximum full-time production over three months, the unit cost of water ranges from

[63] Highline Well Field ASR Operations and Maintenance Manual, Seattle Water Department, March 1994.

54 cents per 1,000 gallons with ASR operations, to 82 cents without. While the with ASR cost of water appears favorable, if the well field is operated at less than full capacity, the unit cost of the water tends to increase significantly.

Different production scenarios were evaluated with and without ASR, including full-time well field operation at maximum production capacity for 3 months, the same scenario with a 50% increase in O&M costs, full-time operation at 50% and 65% production capacity, and half-time operation (1.5 months) at 50% capacity. Sensitivity analysis revealed that the unit cost of water was affected more by changes in well field production than by changes in annual costs. A 50% reduction in production resulted in a two-fold increase in the unit cost, while a 75% production cut back resulted in a four-fold unit cost increase. Changes in annual operating costs would have relatively minor effects on unit costs.

The unit cost of water was also found to be sensitive to the discount rate and assumptions with respect to equipment life expectancy and the life of the project. Moreover, the use of levelized well field yield produced a cost twice that calculated using the arithmetic sum of water supplies over the life of the project (non-levelized yield). The tables in the appendix attached to this case study present project costs and the results of the sensitivity analysis.

Project Financing and Cost Recovery

The Seattle Water Department is an independent municipal utility, and its operations are financed entirely from revenues from water sales. However, no attempt has been made to define different zones of benefit within the city, nor tailor water rates accordingly.

At present, the city has no plans to further expand its recharge activities. Seattle's future demands will be met through construction of Pipeline #5, a major intertie with Tacoma's water system, which will bring water from the Green River to Seattle.

LEGAL AND INSTITUTIONAL ISSUES

No serious legal and institutional issues have been raised so far. No objections were raised in the process of acquiring various state and federal environmental permits or approvals. However, the expansion of recharge activities might in the future raise a number of potential issues. As mentioned above, ground water quality protection is an important consideration and interjurisdictional cooperation related to the protection of the well field may be a concern.

State Water Rights

Water for the project is drawn from the Cedar River under a temporary state permit allowing the use of up ten cubic feet per second (cfs). There are some conditions, to protect river flows, but none have yet limited diversions. As the Cedar River's usual flow is around 370 cfs, there is little impact from the project.

Federal and State Environmental Regulation

All recharge projects are subject to the federal underground injection control (UIC) program, under the Safe Drinking Water Act. EPA has delegated UIC operation and enforcement authority to the state of Washington, which indicated SWD did not need a permit, though SWD did file an Injection Well Notification Form. The latter also sufficed in place of a state waste discharge permit.

A federal permit under Section 404 of the federal Clean Water Act (CWA) was not required.

SWD has implemented a monitoring and quality assurance program, as required under agreement with EPA. Relations with EPA have generally been good, as has cooperation with USGS and other federal agencies.

SWD also prepared and submitted a State Environmental Protection Act report.

In addition, SWD contacted the Office of the State Archeologist, which responded saying that no known sites would be affected by the project.

Endangered Species Act

Several northwest salmon stocks have been listed as either threatened or endangered, and fish and wildlife concerns may become a major constraint to expanding the use of surface waters for recharge in the future. Seattle's average annual diversions amount to about 27% of the water yield of the Cedar River, and seasonal flows are especially critical to support sockeye salmon and steelhead trout that spawn in the river below the Landsburg diversion. However, the U.S. Fish and Wildlife Service agreed that a fish and wildlife plan was not required for the demonstration project.

CONCLUSIONS

Seattle's Highline Well Field Project demonstrates the potential for integrating recharge opportunities with existing water supply systems.

There appears to have been no serious technical, legal or institutional problems.

SWD has been able to comply with the sometimes "elaborate" EPA monitoring requirements without serious difficulties, perhaps in part due to the city's familiarity with Safe Drinking Water Act testing requirements.

The City's initial investment in the well field later provided the infrastructure and information needed to help make the recharge project feasible.

The project demonstrates that greater system efficiency and flexibility may be achieved through the conjunctive use of surface and ground water resources using artificial recharge.

The project fulfills a very limited, but important need, for an emergency and seasonal peaking water supply.

The need for such flexibility has been demonstrated by the extreme water supply conditions faced by Seattle in past years, with flooding in 1990, drought in 1992, and ample water supplies again in 1993.

The sensitivity of unit costs to production levels further demonstrates the need to carefully evaluate potential project costs and benefits on a case-by-case basis.

Without federal funding, it is unlikely that the Seattle Water Department would have undertaken this recharge project.

Development of ground water resources is only a recent initiative for the City of Seattle, and SWD has no plan for future recharge or conjunctive use projects.

Highline Well Field Project Costs Appendix

Table 4.1
Estimated Analytical Coast for Water Quality Monitoring of the Highline Well Field [a]

Phase	Location	Parameters	Number of Samples	Unit Cost ($)	Total Cost ($)
With out ASR [b]					
Production	Five monitoring wells RH #1 and BP	Indicator inorganic and organic compounds Complete inorganic and organic compounds	10 2	$500 $1,000	$5,000 $2,000
Subtotal					$7,000
With ASR [c]					
Recharge	CRPL #4	Conventionals, bacteria, algae Silica, total organic carbon, dissolved oxygen	1-5/week 1/week	$0 $0	$0 $0
Recharge Surge	RH #1 and BP	Turbidity, bacteria Giardia/cryptosporidium	100 20	$50 $400	$5,000 $8,000
Storage	RH #1 and BP	Residual chlorine	20	$5	$100
Recovery	5 monitoring wells RH #1 and BP RH #1 and BP	Indicator inorganic and organic compounds Complete inorganic and organic compounds Primary inorganic and organic compounds	10 2 2	$500 $1,000 $800	$5,000 $2,000 $1,600
Subtotal					$21,700

a Cost estimates include quality assurance/quality control.
b Assume an annual 3-month production period.
c Assume same schedule as routine surface water monitoring program (as conducted by SWED), no net increase in charges.
RH #1 Riverton Heights No. 1 production well
BP Boulevard Park production well.
CRPL #4 Cedar River Pipeline No. 4

Table 4.2
Highline Well Field: Full- Time Operation (3 months)
Maximum Well Production Capacity

	ASR Pilot Facility		Full Scale w/o ASR Component		ASR Component		Full Scale w/ASR Component	
Cost Component	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000
Engineering and Investigative Costs		$546		$633		$323		$1,502
Capitol Costs	$143	$180	$5,789	$9,262	$39	$42	$5,971	$9,484
Subtotal Cost	$143	$726	$5,789	$9,895	$39	$365	$5,971	$10,986
Cost Component	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000
Operation & Maintenance [a]	–	–	$12	$314	–	–	$26	$674
Monitoring Costs [a]	–	–	$10	$268	–	–	$31	$800
Subtotal Cost	–	–	$23	$581	–	–	$57	$1,474
Cost Component	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000
Equipment Replacement [b]	–	–	$246	$117	–	–	$246	$117
Total Present Worth $1,000 [c]				$10,594				$12,578
Water Production	Annual (1,000 gal)	Present Worth ($1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)
1.0 mgd, 3 mos./yr (w/ASR)	–	–	–	–	–	–	900,000	23,156,820
5.6 mgd, 3 mos/yr (w/o ASR)	–	–	504,000	12,967,819	–	–	–	–
Unit Cost of Water ($/1,000 per gal) [d]				$0.82				$0.54

a Project Life - 50 years.
b Equipment Replacement in 25 years.
c Project Discount Rate - 3%.
d Unit Cost of Water - (PW Project Cost) (PW Water Produced).

Table 4.3
Highline Well Field: Full-Time Operation (3 months)
Maximum Well Production Capacity, O & M Costs Increased 50 Percent

	ASR Pilot Facility		Full Scale w/o ASR Component		ASR Component		Full Scale w/ASR Component	
Cost Component	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000
Engineering and Investigative Costs		$546	$0	$633	$0	$323	$0	$1,502
Capitol Costs	$143	$180	$5,789	$9,262	$39	$42	$5,971	$9,484
Subtotal Cost	$143	$726	$5,789	$9,895	$39	$365	$5,971	$10,986
Cost Component	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000
Operation & Maintenance a	–	–	$37	$942	–	–	$26	$2,025
Monitoring Costs a	–	–	$10	$268	–	–	$31	$800
Subtotal Cost	–	–	$47	$1,209	–	–	$57	$2,825
Cost Component	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000
Equipment Replacement b	–	–	$246	$117	–	–	$246	$117
Total Present Worth $1,000 c				$11,222				$13,929
Water Production	Annual (1,000 gal)	Present Worth ($1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)
10.0 mgd, 3 mos./yr (w/ASR)	–	–			–	–	900,000	23,156,820
5.6 mgd, 3 mos/yr (w/o ASR)	–	–	504,000	12,967,819	–	–	–	–
Unit Cost of Water ($/1,000 per gal) d				$0.87				$0.60

a Project Life - 50 years.
b Equipment Replacement in 25 years.
c Project Discount Rate - 3%.
d Unit Cost of Water - (PW Project Cost) (PW Water Produced).

Table 4.4
Highline Well Field: Full-Time Operation (3 months)
Maximum Well Production at 50 Percent Capacity

	ASR Pilot Facility		Full Scale w/o ASR Component		ASR Component		Full Scale w/ASR Component	
Cost Component	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000
Engineering and Investigative Costs	$0	$546	$0	$633	$0	$323	$0	$1,502
Capitol Costs	$143	$180	$5,789	$9,262	$39	$42	$5,971	$9,484
Subtotal Cost	$143	$726	$5,789	$9,895	$39	$365	$5,971	$10,986
Cost Component	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000
Operation & Maintenance a	–	–	$12	$314	–	–	$26	$674
Monitoring Costs a	–	–	$10	$268	–	–	$31	$800
Subtotal Cost	–	–	$23	$581	–	–	$57	$1,474
Cost Component	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000
Equipment Replacement b	–	–	$246	$117	–	–	$246	$117
Total Present Worth $1,000 c				$11,594				$12,578
Water Production	Annual (1,000 gal)	Present Worth ($1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)
10.0 mgd, 3 mos./yr (w/ASR)	–	–			–	–	450,000	11,578,410
5.6 mgd, 3 mos/yr (w/o ASR)	–	–	252,000	6,483,910	–	–	–	–
Unit Cost of Water ($/1,000 per gal) d				$1.63				$1.09

a Project Life - 50 years.
b Equipment Replacement in 25 years.
c Project Discount Rate - 3%.
d Unit Cost of Water - (PW Project Cost) (PW Water Produced).

Table 4.5
Highline Well Field: Half-Time Operation (1.5 months)
Well Production at 50 Percent Capacity

	ASR Pilot Facility		Full Scale w/o ASR Component		ASR Component		Full Scale w/ASR Component	
Cost Component	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000
Engineering and Investigative Costs	$0	$546	$0	$633	$0	$323	$0	$1,502
Capitol Costs	$143	$180	$5,789	$9,262	$39	$42	$5,971	$9,484
Subtotal Cost	$143	$726	$5,789	$9,895	$39	$365	$5,971	$10,986
Cost Component	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000
Operation & Maintenance a	–	–	$6	$157	–	–	$13	$377
Monitoring Costs a	–	–	$10	$268	–	–	$31	$800
Subtotal Cost	–	–	$17	$425	–	–	$44	$1,137
Cost Component	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000
Equipment Replacement b	–	–	$246	$117	–	–	$246	$117
Total Present Worth $1,000 c				$10,437				$12,241
Water Production	Annual (1,000 gal)	Present Worth ($1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)
10.0 mgd, 3 mos./yr (w/ASR)	–	–	–	–	–	–	225,000	5,789,205
5.6 mgd, 3 mos/yr (w/o ASR)	–	–	126,000	3,241,955	–	–	–	–
Unit Cost of Water ($/1,000 per gal) d				$3.22				$2.11

a Project Life - 50 years.
b Equipment Replacement in 25 years.
c Project Discount Rate - 3%.
d Unit Cost of Water - (PW Project Cost) (PW Water Produced).

Table 4.6
Highline Well Field: Full-Time Operation (3 months)
Well Production at 50 Percent Capacity

	ASR Pilot Facility		Full Scale w/o ASR Component		ASR Component		Full Scale w/ASR Component	
Cost Component	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000	Est. Const. Cost $1,000	Est. Project Cost $1,000
Engineering and Investigative Costs	$0	$546	$0	$633	$0	$323	$0	$1,502
Capitol Costs	$143	$180	$5,789	$9,262	$39	$42	$5,971	$9,484
Subtotal Cost	$143	$726	$5,789	$9,895	$39	$365	$5,971	$10,986
Cost Component	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000	Annual Cost $1,000	Present Worth $1,000
Operation & Maintenance a	–	–	$24	$625	–	–	$26	$679
Monitoring Costs a	–	–	$10	$268	–	–	$31	$800
Subtotal Cost	–	–	$35	$895	–	–	$58	$1,474
Cost Component	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000	Replacement Cost $1,000	Present Worth $1,000
Equipment Replacement b	–	–	$246	$117	–	–	$246	$117
Total Present Worth $1,000 c				$10,908				$12,583
Water Production	Annual (1,000 gal)	Present Worth ($1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)	Annual (1,000 gal)	Present Worth (1,000 gal)
10.0 mgd, 3 mos./yr (w/ASR)	–	–	–	–	–	–	594,000	15,283,501
5.6 mgd, 3 mos/yr (w/o ASR)	–	–	333,000	568,023	–	–	–	–
Unit Cost of Water ($/1,000 per gal) d				$1.27				$0.82

a Project Life - 50 years.
b Equipment Replacement in 25 years.
c Project Discount Rate - 3%.
d Unit Cost of Water - (PW Project Cost) (PW Water Produced).

GRANITE REEF PROJECT - PHOENIX, ARIZONA

BACKGROUND

Long before Arizona became a state, the inhabitants of the area were struggling to balance water supplies with demands. The Hohokam civilization, known to the Pima Indians as "the people who are gone," established a system that was irrigating thousands of acres across the Gila River valley and other areas by 900 A.D., and by 1300 A.D., cities and towns dotted the land.[64] Much later, European settlers recognized and set about improving on the Hohokam irrigation system. Later still, large dams were built to control the rivers and stream and conserve and store water from season to season, mitigating the effects of floods and droughts. The availability of water determined the extent and pattern of growth then and now.

Given Arizona's mostly ephemeral streams, early inhabitants and settlers also turned to developing the area's ground water resources. Conjunctive use of the state's surface and ground waters is essential to effective management of these critical resources. Over the past decade there have been many challenges and changes in the management of water in Arizona, focusing mostly on measures to reduce ground water use in order to achieve a balance between recharge and yield and arrest declining water tables. A number of artificial recharge projects have also been initiated in the Phoenix area in order to augment local water supplies and place recently available water from the federal Central Arizona Project (CAP) to maximum beneficial use. Artificial recharge is an important element in the City of Phoenix's Water Resources Plan and will help provide long-term water supply for the rapidly growing Phoenix metropolitan area.[65]

Much of the metropolitan area is served by the Salt River Project (SRP), one of the oldest and most successful federal reclamation projects. Theodore Roosevelt Dam, which was completed in 1911, is the key storage feature and one of six multipurpose dams. Granite Reef Diversion Dam was built about 50 miles downstream at an outcrop of bedrock or "reef," just below the confluence of the Salt and Verde Rivers. Completed in 1908, it diverts water into canals running north and south that deliver water to thousands of acres of land. The SRP delivers more water than any other utility in the state, and it is one of the largest public power utilities in the country.[66] SRP water and power provided a dependable resource base for economic growth.

The Salt River Valley Water Users' Association was formed in 1903 as the entity responsible for repayment of the Salt River Project's reimbursable costs. In 1917, the

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[64]Rich Johnson, The Central Arizona Project: 1918-1968, University of Arizona Press, Tucson, 1977, p.1.

[65]Phoenix Water Resources Plan, City of Phoenix, Water and Wastewater Department, Water Conservation and Resources Division, 1990.

[66]A Valley Reborn: The Story of the Salt River Project, Salt River Project, p.1.

Association assumed operational responsibility for and control of the project. Soon thereafter it began acquiring greater hydroelectric generating capacity, which increased revenues from power sales and provided power for pumping ground water to supplement surface water supplies. The Association issued general obligation bonds for the construction of additional surface water storage capacity.

In 1925 and 1927 respectively, Mormon Flat and Horse Mesa Dams were completed. Stewart Mountain Dam was completed in 1930. The Association contracted with the Bureau of Reclamation for construction of Bartlett Dam on the Verde River, agreeing to pay 80% of the cost. It was completed in 1939. The last of the six major dams, Horseshoe Dam, was built on the Verde River between 1944 and 1946 by the Phelps Dodge Copper Corporation, which financed the project in exchange for Salt River Project water from the Black River for use in its mining operations at Morenci. In 1948, due to drought, SRP began a ground water development program to help landowners supplement their surface water supplies. Also of note, in 1955, the Association repaid its obligation to the federal government for construction of Roosevelt Dam.

Today the Salt River Project is a not-for-profit corporation managed by landowners within its service area. However, the nature of the project has changed over the years as urban growth has displaced farmlands. The project's service area covers a total of 262,935 irrigable acres, but only about half that amount has ever actually been irrigated, with water reaching 136,701 acres in 1969.[67] Urban growth has brought subdivisions where there were once farms, and lawns have replaced crops. By the year 2000, around 80% of the SRP service area will be urbanized and no substantial amount of irrigated agricultural land is expected to remain in production after 2034.[68]

In response to rapid urbanization, in 1952 the SRP and City of Phoenix entered into a contract for the delivery of water. The City pays SRP the annual assessments on urban lands that are no longer irrigated, and SRP in turn delivers to the City water to which the urban lands are entitled. The City, acting for SRP, receives, treats and delivers the water to users. SRP has entered similar domestic water supply contracts with Chandler, Gilbert, Glendale, Mesa, Peoria, Scottsdale and Tempe. These contracts provide these cities with stable surface and ground water supplies at the same rate paid by agricultural users for irrigation water.[69]

Project Purpose

The Granite Reef Underground Storage Project (GRUSP) is an integral part of future water management plans for the Phoenix metropolitan area. It is a joint venture involving SRP, and the cities of Chandler, Gilbert, Glendale, Mesa, Phoenix, Scottsdale and Tempe.[70] Chandler, Mesa and Phoenix are SRP's major partners. GRUSP is a recharge,

[67] Project Data (book), U.S. Bureau of Reclamation, 1981, p. 1088.

[68] A Valley Reborn, p. 12.

[69] Ibid.

[70] Information based on interviews with employees of the Salt River Project (John Sullivan, Larry Bedome), City of Phoenix (William L. Chase, Jr.), and Arizona Department of Water Resources (Greg Bushner), February 16, 1993.

storage and recovery project, and it is primarily designed: (1) to guarantee future water supplies; and (2) make beneficial use of available federal CAP supplies that substantially exceed current demands. The project may also help ameliorate significant water quality and subsidence problems caused by ground water mining and overdraft. It also will help meet peak demands and provide drought relief.

It is also significant that given the current availability of unused Central Arizona Project water and Arizona's unique ground water law, substantial amounts of water from the federal project may be recharged. This not only allows for greater overall efficiency in the management of Arizona's Colorado River entitlement, but other surface and ground water resources. Moreover, it demonstrates the potential benefits of more closely integrating the development and use of state appropriated ground waters and surface waters delivered by federal projects.

It is also significant to note the potential use of ground water recharge and storage programs as an alternative to facilitate the development and use of interstate water transfer agreements, particularly among the states within the lower Colorado River Basin.

Project Description

The project is located east of Phoenix within the bed of the Salt River, an ephemeral stream, a few miles downstream from Granite Reef Diversion Dam and directly upstream of Gilbert Road. SRP is leasing 350 acres of land from the Salt River Pima Indian Community for in-channel recharge activities. The site was selected due to its proximity to existing water delivery and recovery facilities, geohydrologic feasibility, the quality of the available recharge and receiving waters, minimal anticipated effects on agricultural lands or urban and industrial development, and an absence of sensitive environmental areas.[71] These screening criteria are similar to those used to select Reclamation's own demonstration projects.

The project includes construction of four recharge basins within the bed of the Salt River. The four recharge basins cover 217 acres. GRUSP will take advantage of existing facilities, including SRP's Granite Reef Dam and upstream storage system, the CAP aqueduct, SRP's Arizona and South Canals, and production wells along the South Canal. Construction also includes a CAP/SRP interconnection to allow CAP water to be conveyed through SRP's Arizona and South canals, with a third component to deliver CAP water to the recharge facility. Construction of the conveyance facilities and ground water recharge basins began early in 1993, and was completed during the summer of 1994. A map of the project is on the next page.

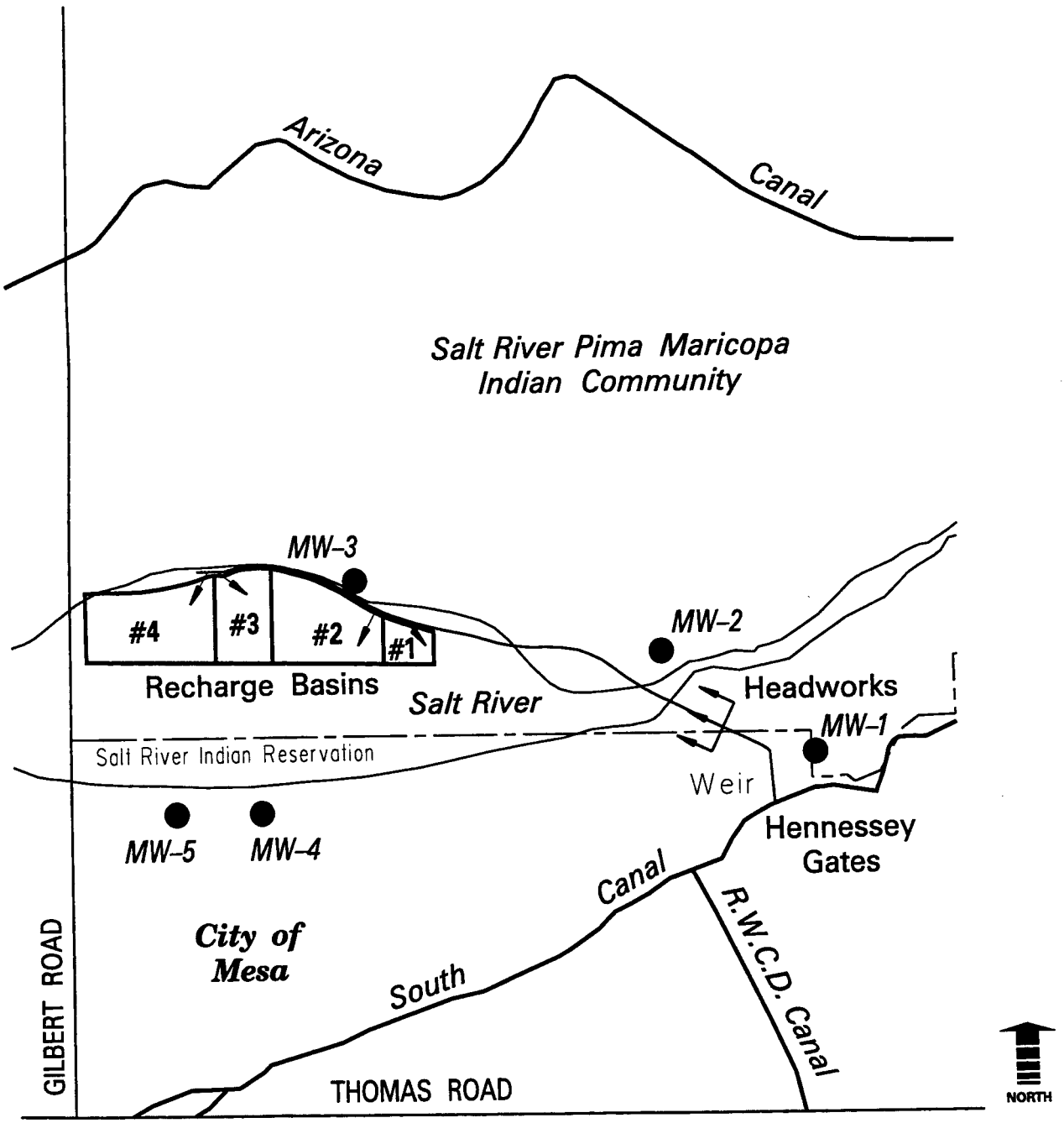
A detailed geophysical and hydrogeologic study and tectonic analysis indicate that a sufficiently suitable basin lies under the site. The following diagrams show the geologic setting and hydrostratigraphy of the project, and the estimated transmissivity and storativity (T and S) for the different geologic units.[72]

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[71] "Granite Reef Underground Storage and Recovery Project," SRP, a paper by Mario R. Lluria, Gary G. Small and Robert B. Mack.

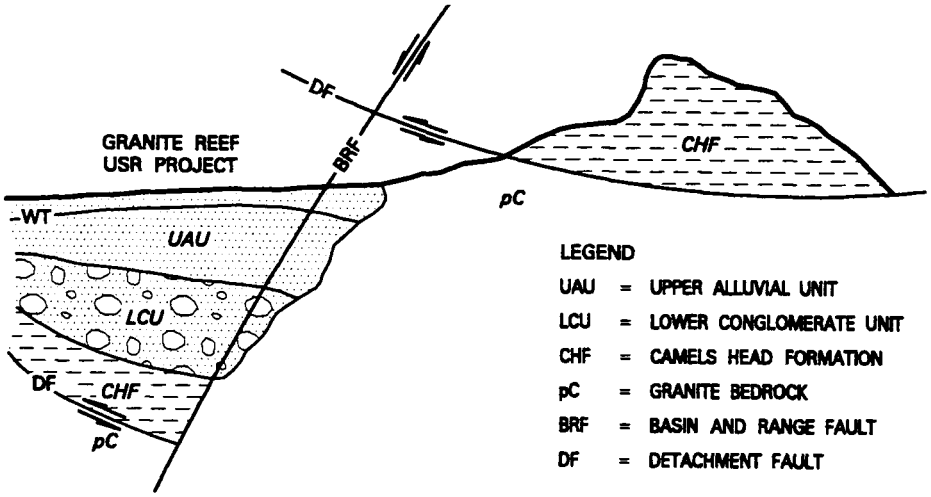
[72] Ibid., pp. 4-5.

Granite Reef Project Area Map

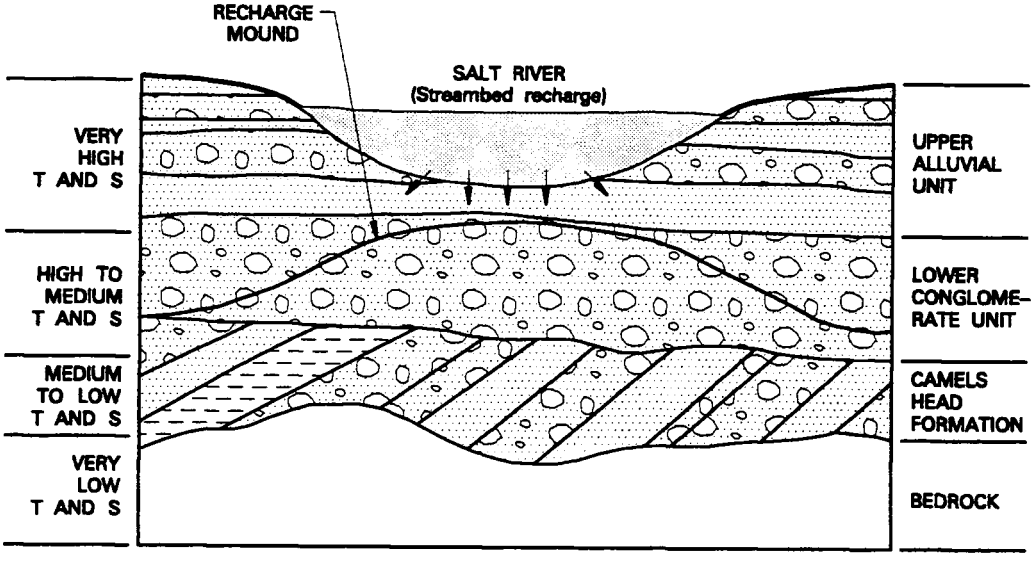


Granite Reef Undergrouind Storage and Recovery Project Location Plan, SRP Corporate Engineering, Fig. 1

West East



Geologic Setting of Granite Reef Underground Storage and Recovery Project



Cross Section Showing Hydrostratigraphy of the Granite Reef Project (with transmissivity ranges)

"Granite Reef Underground Storage and Recovery Project," Mario Lluria, et al., Figures 3-4, p. 4-5

Water Supply and Recharge

The project will make it possible for Phoenix and other cities to more fully use their annual deliveries of surface water from various sources. As part of recent safety-of-dams work, Roosevelt Dam was raised, creating additional storage space which was paid for by cities in the Phoenix area. This will provide additional surface water that will be available at times for recharge through GRUSP. However, by far the largest potential source of water for recharge is the federal Central Arizona Project (CAP), and putting this water to use is a high priority. At present, much of Arizona's allocation of Colorado River water continues to go unused, due to a lack of demand. CAP water may be available for artificial recharge for perhaps the next 40 years, after which water demands are expected to more closely match available surface supplies. Thereafter, CAP water could continue to be used for recharging aquifers during wet periods, and for conjunctive use with surface supplies when demands are high.

The project is designed and permitted to allow the infiltration or percolation of up to 200,000 acre-feet annually, but at its current stage of construction, it can recharge about 90,000 acre-feet of water annually. By the end of 1998, approximately 260,000 acre-feet of water will have been recharged. The lack of available water, and not design capacity, has been the limiting factor. Phase II plans include the expansion of the size of the existing recharge basins. However, infiltration rates have been higher than expected with virtually no clogging. Therefore, the designed recharge capacity may be achieved without the need to expand the size of the percolation ponds. The aquifer's total storage capacity, which was once thought to be virtually unlimited (given the maximum annual recharge rate), will be better known following the completion of DWR modeling studies.

SRP and the cities own shares of GRUSP, and recharge rights are shared proportionally. SRP also serves as the operating agent, and the project participants pay a recharge fee to cover the cost of construction and operation and maintenance. Under state law, described later, each entity is credited for the amount of water it stores in the project. The state credits towards storage 100% of the water diverted at a weir and headworks on SRP's South Canal, minus a percentage calculated to account for evaporation from the recharge basins. The recharge site is a little over a mile from diversion works, and the water is conveyed mostly by means of an unlined channel traversing the usually dry riverbed.

Ironically, in early 1995, flows in the Salt River reached 80,000 cubic feet per second (cfs), destroying GRUSP conveyance works in the riverbed. The project was designed to pass natural riverflows of up to 10,000 cfs. SRP also breached the recharge basin dikes to minimize damage to the remaining berms. As a result, while surplus waters flow downriver, the percolation ponds stand empty. Estimates to repair the damage are around $150,000.

Of note, the 50,000 acre-feet of water recharged to date was stored under an agreement with the Central Arizona Water Conservancy District, which in essence leased space and GRUSP facilities to recharge CAP water (held in a special account). In the future, other waters, including rights leased from Indian tribes, might be available for recharge. Again, it is the availability of water that is the most important constraint on the total amount of water that might be recharged.

Water Quality

Water quality has not been a major issue. The quality of the water available for recharge is good, and there is little development within the watershed upstream. Some concerns were raised, but later dismissed, over the operation of a nearby landfill. Five monitoring wells will be used on both sides of the Salt River to evaluate water quality impacts of GRUSP on the aquifer. Monitoring costs are a significant portion of project construction costs. The Arizona Department of Environmental Quality is responsible for aquifer protection, in cooperation with the Department of Water Resources.

While not an issue in this instance, water quality concerns are of particular importance to the metropolitan area as the City of Phoenix and other communities have lost substantial well production capacity due to ground water contamination. Project water will be one alternative source of supply, which may help replace some of the lost production.

ECONOMIC EFFICIENCY AND FINANCIAL FEASIBILITY

Economies of scale make GRUSP water relatively inexpensive to develop. As a result, the project is expected to become an important and cost-effective water supply alternative, providing long-term storage and facilitating conjunctive use of surface water and ground water. Moreover, under state law promoting the replenishment of depleted ground water resources, under certain circumstances, project participants may in the future find recharge and recovery less expensive than using natural ground water supplies, given state fees levied on withdrawals.

Project Costs and Cost Sharing

Estimated expenditures for GRUSP construction total about $2.2 million, with another $500,000 plus for operation and maintenance (O&M) for a total cost of $2.7 million.[73] Project design and engineering, plus various studies and the monitoring wells account for some $1 million of the construction costs. Actual O&M costs have been less than expected, but given the recent flood damages, have been near estimated levels.

SRP and the cities share project costs, and revenues, in proportion to their ownership and entitlements under an intergovernmental agreement. SRP's share of the project is 30%. SRP is entitled to the use of 30% of the project's capacity, pays 30% of the project's costs, and receives 30% of the project's revenues. Chandler, Mesa and Phoenix are the other major partners.

To the extent that SRP and the cities participating are not utilizing their allocation of the project's capacity at any given time, the other partners may -- or the surplus capacity may be leased to another entity.

Participating agencies or contractors pay a recharge fee, and bear any additional cost for the water to be recharged. Participants also pay their own recovery costs.

SRP has its own water rights and surface water storage and distribution system, so there are no additional water supply costs. However, others may have significant costs associated with securing a supply of water for recharge. For example, the cost of CAP water for recharge (or any other purpose) is around $50 per acre-foot.

Unit Recharge Costs

The unit cost is $11.80 for each acre-foot recharged annually -- assuming 50,000 acre-feet of water are recharged annually, and that annual O&M costs are $500,000 per year, and straight-line depreciation of the $2.7 million project over 30 years. For 100,000 acre-feet recharged annually, the unit cost drops to $5.90 and at the design capacity of 200,000 acre-feet the cost is only $2.95.

In calculating the actual water supply costs, the cost of the water recharged and the cost of recovery and conveyance would have to be added to this amount. However, in this instance, the municipal water supply project costs would appear to compare very favorably with other alternatives.

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[73] Updated estimates provided by Larry Bedome, Salt River Project, telephone conversation on March 6, 1995.

Economies of scale and site-specific conditions contribute to GRUSP's success and relatively inexpensive cost. Tucson's Pima Road injection well project, by comparison, involves up-front construction and other costs of $4.5 million to recharge 14,000 acre-feet of water per year. GRUSP's construction, operation and maintenance will be less.

Project Benefits and Beneficiaries

In addition to the usual water supply benefits from the project, the cities gain from the increased flexibility the project affords in operating their respective systems. The cities may directly benefit in proportion to their participation, but some project benefits may not be general or evenly distributed across all participants. For example, lower pumping lifts for production wells in GRUSP's impact area have not been estimated, but may add to the benefits of the project.

Because the water recharged is surface water, cooperating municipalities expect to withdraw it and avoid paying the State's ground water replenishment tax (described later), which is currently $100-$150 per acre-foot, or the estimated cost of replacement water.

Financing and Cost Recovery

The original construction costs were financed by the respective partners. A recharge fee of $5 per acre-foot of water is assessed for using GRUSP facilities, and is paid by both the participating entities and any outside contractors. Revenues are shared by the project's partners proportionately.

In 1994, the Central Arizona Water Conservancy District (CAWCD) took advantage of the availability of GRUSP's unused capacity and a state demonstration program to recharge 50,000 acre-feet of CAP water. The state provided $4 million towards the purchase and recharge of CAP water by the CAWCD. The $250,000 of revenue from recharge fees generated by the CAWCD's use of the project were allocated proportionately among the GRUSP participants, and may help repay project costs financed up-front by SRP and the cities.

These costs were financed from SRP's and the cities' general funds. SRP levies and collects general assessments on landowners within the project. The cities' share of GRUSP's costs were financed with revenues from water sales. As an alternative water supply project, the incidence of project benefits are assumed to be general, and no attempt has been made by participants to try to determine any special zone(s) of benefit, or to tailor cost recovery requirements to particular benefits.

LEGAL AND INSTITUTIONAL ISSUES

Arizona's ground water laws and the Law of the River in the Colorado River Basin have developed and changed over the years, along with new and growing demands. A unique legal and institutional framework has also arisen, through trial and error, that seems to now provide an adequate foundation for the most efficient management of Arizona's water resources. Ground water recharge has become an integral part of water management rippling through Arizona's legal and institutional waterscape.

State Water Law

Unlike most western states, ground water law in Arizona has followed the doctrine of absolute ownership, which allows a landowner the right to use whatever water can be captured by a well and pump, subject only to limits on waste, and usual beneficial use requirements. However, in 1980, then Governor Bruce Babbitt signed the Arizona Ground Water Management Act, which he was instrumental in helping get enacted into law.[74] The new law provided a basis for controlling ground water use, and began a serious conservation effort. However, many subsequent legislative actions have also shaped ground water management.

Ground Water Management Act

Arizona's Ground Water Management Act was a historic measure that for the first time authorized comprehensive regulation of the state's ground water resources. It was enacted after a painful political struggle, and represented the state's serious commitment to conservation as a means of reducing the use of and dependence on dwindling ground water resources. The primary objectives of the Act are to: (1) provide a secure long-term water supply; (2) control severe overdraft or mining of ground water; and (3) provide a means of allocating ground water to most effectively meet the state's changing water needs.[75]

The new law created the Arizona Department of Water Resources (DWR), with comprehensive authority to regulate both surface and ground water use. Its predecessor, the Arizona Water Commission, became a board advising the new department's director. The new law also established four active management areas (AMAs) and three irrigation non-expansion areas (INAs) within which ground water use is now tightly controlled. The four AMAs surround the metropolitan cities of Phoenix, Tucson, and Prescott, as well as Pinal County.

In 1990, over 80% of Arizona's population resided within AMAs, which accounted for about 70% of the state's water use.[76] However, types of ground water use vary widely. Agriculture accounts for 60% of the use in the Phoenix AMA, 33.2% in the Tucson AMA, 37.6% in the Prescott AMA, and 97% in the Pinal AMA.[77] Development of new irrigated

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[74] S.B. 1001 was approved by the Governor on June 12, 1980.

[75] "Conservation Requirements for the Second Management Period: 1990-2000," Arizona DWR, p. 2.

[76] Ibid, p. 4.

[77] Ibid, pp. 4-5.

acreage is prohibited within the AMAs and three designated INAs, which are Joseph City, Douglas, and Harquahala.

Each AMA has a director and a ground water users advisory council, appointed by the governor, which provides ongoing review and input on management plans and programs. The Phoenix, Tucson and Prescott AMAs have a management goal of achieving safe yield no latter than 2025. The Pinal AMA goal is to preserve water supplies for future municipal and industrial uses, while extending the life of the agricultural economy for as long as is economically feasible. Management plans for reaching these goals are developed within each of the AMAs, approved by DWR, implemented and then reviewed and revised.

The law required five progressively more stringent plans, four ten-year plans from 1980-2020, and a final five-year plan for 2020-2025. Water conservation, including mandatory water use restrictions for all sectors -- municipal, agricultural and industrial uses -- is the key feature of AMA management plans. However, proposals to augment an AMA's water supply are also included in the plans.

Within the AMAs, ground water users must have legal authority, in the form of a water right or permit, to withdraw water -- with the exception of "exempt wells," pumping less than 35 gallons per minute (gpm). All wells in the state must be registered, and those in AMAs that pump more than 35 gpm must be metered. Users are grouped into several categories based on their type of water use and associated type of water right. Within AMAs and INAs, users must report their annual ground water withdrawals to the state and pay a withdrawal or use fee of up to $5/acre-foot.

The law also requires that developers obtain a certificate from DWR. They must have a 100-year "assured water supply," before new subdivisions can be approved. While this was intended as a conservation measure, the mandatory requirement has increased demand and led to a rush to "lock up" available water resources and water rights, often through purchasing agricultural water and transferring it to municipal uses.

A Decade of Change

Over the past decade, there have been numerous amendments to the 1980 Ground Water Code and related management plans, as well as other legislative, administrative and judicial changes that have had an effect on ground water recharge.

In 1989, in the "Tumbling T Ranches" case, Arizona Public Service Company v. Long, the state supreme court redefined the nature of sewage effluent and allowed it to be sold.

In 1990, the state legislature enacted bills creating a water conservation assistance program (H.B. 2042), establishing the Tucson AMA Water Augmentation Authority (S.B. 1556), and also providing for the indirect storage and recovery of artificially recharged ground waters (S.B. 1253).

The Groundwater Transportation Act (S.B. 1055) and the Groundwater Replenishment Districts Act (H.B. 2499) were enacted in 1991. The latter was amended in April 1993 (S.B. 1425), and again in April 1994 (S.B. 2547).

In 1996, the Arizona Water Banking Authority was created to facilitate maximum beneficial use of the state's entitlement to water from the Colorado River.

Each of these important legislative and other changes are summarized hereafter.

A New Definition of Effluent

In 1989, in Arizona Public Service Company v. Long, Arizona's Supreme Court determined that sewage effluent, while a product of surface and ground waters, was neither, but rather it was something distinct under Arizona water law.[78] Once discharged, it again becomes surface water or ground water, a public resource subject to appropriation. However, until discharged it is not. Further, municipalities do not own sewage effluent, but they have the right to put it to beneficial use. The court stated that the legislature had the right to control the use of sewage effluent, but had not. Therefore, in this case, the court found that cities were free to contract to sell and deliver sewage effluent to utilities for treatment and use as cooling water for the Palo Verde Nuclear Generating Station.

The state legislature explicitly affirmed the court's decision in 1991 by amending Arizona water law and recognizing effluent as distinct from either surface or ground water, passing S.B. 1254. Effluent was defined as "...water that has been collected in a sanitary sewer for subsequent treatment in a facility that is regulated pursuant to [state law]. Such water remains effluent until it acquires the characteristics of groundwater or surface water." The decision encourages cities to use effluent for recharge or irrigation, rather than discharge it and lose the use of this resource.[79]

Ground Water Replenishment Districts

In 1991, the legislature passed the Groundwater Replenishment Districts Act to allow for the establishment of a ground water replenishment district (GRD) for the Phoenix AMA (H.B. 2499).[80] While Phoenix and other cities supported H.B. 2499, they did not take the steps required to allow formation of a GRD. With minor exceptions, all municipal and industrial ground water users would have been required to be GRD members, and would have been assessed a replenishment tax for the withdrawal of each acre-foot of overdrafted ground water.

The intent was for the districts to use the fees to obtain supplemental water to recharge or replenish the aquifers in the Phoenix AMA, and encourage the maximum utilization of Central Arizona Project (CAP) and other surface water supplies, as well as treated sewage effluent. As long as the new districts met certain obligations, new developments within the AMA would be considered (until 2001) to have the 100-year assured water supply required by the 1980 Groundwater Management Act. Therefore, developers gained the most from the new law. The cities, with their full CAP water allocations providing the required assured water supply, didn't act to form the GRD in an attempt to restrict urban sprawl and limit development outside city limits.

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[78] Arizona Public Service Company v. Long; A Tumbling T Ranches v. Phoenix; and Arizona Public Service Co. v. A Tumbling T Ranches, Supreme Court No. CV-86-0634-T, April 17, 1989.

[79] S.B. 1254, May 13, 1991; ARS 45-101, 402, 467-68, 576, and 1901.

[80] H.B. 2499

In April 1993, with political support from developers, the state legislature revisited the issue and passed S.B. 1425, which while recognizing the Tucson Water Augmentation Authority, established a GRD encompassing the Phoenix, Pinal and Tucson AMAs, with the Central Arizona Water Conservation District (CAWCD) as the operating entity responsible for replenishment programs and activities.[81]

Under the new law, the CAWCD will furnish member lands with the required assured water supply, thereby avoiding potential limits on developments in the AMAs. Moreover, any "municipal providers" within the three AMAs may also secure an assured water supply designation by enrolling their service areas. New assured water supply rules were released. Providers may lose their assured water supply designation if certain conditions are not continually met, including the annual payment of a replenishment tax.

Under S.B. 1425, the District has a cumulative replenishment obligation, based on the amount of ground water being mined within its jurisdiction. Each parcel of member land (for which the county assessor has issued a separate tax number) and municipal providers' service areas enrolled in the District share proportionally in this replenishment obligation, and are subject to a related assessment or tax. The obligation is discharged through the District's operation of "aquifer replenishment projects," or "indirect ground water storage and recovery projects," that reduce ground water use, or participation in a number of authorized "state demonstration projects," through which the District accrues "stored water credits."

The District must recharge Central Arizona Project (CAP) water -- or water from any other lawfully available source -- which excludes ground water withdrawn from within an AMA, but might include water leased from Indian tribes or other waters. The legislation is intended in part to promote wise management of water and to "protect the general economy and welfare of this state and its citizens," by storing CAP water for "future needs or use for replenishment purposes," or use during a "serious water shortage due to a substantial reduction...or a prolonged interruption of deliveries of Central Arizona Project water."[82]

The Central Arizona Water Conservation District (CAWCD) is also responsible for repayment of the local share of the CAP costs.

The Department of Water Resources issues permits to a ground water replenishment district to add water to an aquifer, and annually accounts for stored water credits and replenishment obligation debits.

A replenishment district must also annually calculate the costs and expenses attributed to replenishment obligations and levy an assessment against parcels of land within the district or a replenishment tax against all municipal providers' service areas. According to the law, the annual replenishment tax is levied "for the privilege of withdrawing groundwater in the district.... The tax shall be levied at a rate...sufficient to...pay the water acquisition costs...to offset the debit balances of all members' replenishment accounts...."[83]

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[81] H.B. 2499 was signed by the governor on April 21, 1993.

[82] ARS 45-831, declaring the public policy of the state.

[83] ARS 48-4470, 4472, and 4501.

Assessments and taxes received on behalf of the district are to be used to establish and maintain "reserve accounts" necessary to perform replenishment obligations,[84] establish a revolving fund "for the purpose of defraying the costs and expenses of the district,"[85] or are to be deposited in a "special fund established by the State Treasurer to be expended at the discretion of the district"[86] to effectuate the provisions of the law, with any monies not immediately required deposited in a "water acquisition fund" and invested by the State Treasurer.[87]

Explicit replenishment covenants attach to enrolled member lands, and annual replenishment assessments are a lien against the title.[88] Assessments are transmitted by the counties to the State Treasurer for deposit in the special fund for authorized replenishment purposes. Delinquent assessments and taxes are also subject to interest charges (12%), and eventually possible court-ordered civil penalties of up to $1,000 per day.[89]

Ground Water Transfer Restrictions

S.B. 1055 was passed in conjunction with H.B. 2499, the first bill authorizing creation of a ground water replenishment district. The bill (S.B. 1055) restricted the transfer of ground water from rural basins to AMAs, and between the Pinal and Phoenix AMAs. It also included provisions for in-lieu tax payments by municipalities for remote properties, and levied a ground water transportation fee of $3 to $30 per acre-foot for exports of one to five million acre-feet of water. This fee is to be paid directly to the county from which the ground water is withdrawn.

Underground Water Storage Program

In 1994, the state legislature made a number of changes to state law to clarify state policy and programs and further encourage ground water recharge and conservation. A primary goal is to promote the use of renewable water supplies, such as effluent, surface water and CAP water by promoting underground water storage, savings and replenishment. Waters that cannot be directly put to use immediately are stored underground for use later in times of drought or other shortages.

The legislative changes also promote more effective and efficient water use by allowing water to be stored in one place underground and then allowing the "storer" to recover a like amount elsewhere.[90] The intent is to allow water to be "transported" without the need to construct expensive canals and/or pipelines. The new law (S.B. 2547) also made changes in terminology, deleting references to "aquifer replenishment" and "indirect ground water" projects.

Under the new law and program, the Department of Water Resources requires three types of permits to store, save or replenish water: (1) a storage facility permit; (2) a water

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[84] ARS 48-3772.A.5

[85] ARS 48-3773.B

[86] ARS 48-3773.3

[87] ARS 48-4501.D

[88] ARS 48-3779

[89] ARS 48-3783

[90] ARS 45-801.1

storage permit; and (3) a recovery well permit.[91] In other words, the state permits construction and management of underground water storage facilities, then permits the recharge and storage of water, followed by a separate permit for a well to recover the stored waters. All three permits may be applied for and processed simultaneously by a person, water district, conservation district or replenishment district.

Storage facilities may be "constructed," such as an injection well or percolation pond, or "managed" using natural features such as a dry river bed. Storage facilities are also defined to include "groundwater savings facilities," which allow a "recipient" to receive and use a renewable water supply in lieu of pumping non-renewable ground water, thus effecting "groundwater savings." The burden of proof is on the recipient to demonstrate a gallon-for-gallon savings, in return for ground water storage credits.

Accounting for stored ground water is a significant component of the program. Before issuing a storage permit, DWR must determine a project is practical and financially feasible, and that nearby landowners and water rights will not be harmed. This is particularly problematic for a managed storage facility using an ephemeral stream or riverbed. While most Arizona streams are usually dry, any natural flows must be divided from artificial flows, in order to account for storage credits.

DWR must define a project's area of impact, which is also used to determine where and how much stored water may be recovered or credited towards replenishment. Replenishment districts are obligated by law to replace any ground water pumped by its members that is in excess of that allowed under the state's assured/adequate water supply program.

All facilities and recovery wells must have DWR-approved water measuring devices, and the storage, savings and replenishment of ground water and recovery of stored water is carefully regulated. DWR accounts for water by the type of water stored, the entity storing or replenishing the water, when and where the water is recovered, and how much is recoverable. Usually, the state allows recovery or credit for 90-100% of the water recharged. However, some water may be determined to be irrecoverable, either physically, economically, or legally. In addition, the law allows stored and replenished waters to be assigned or transferred, with some limits.

DWR publishes a quarterly report on recharge activities, which includes current permit applications, and summarizing the status of projects in a table that presents the project name, permit number, recipient, type of permit, and amount of water requested. DWR also periodically publishes a summary of recharge and storage accounts.

Over a four-year period, ending in January 1995, total recharge for all projects totaled 274,798.3 acre-feet (af) of water. Over that period of time, some 9,827.5 af was recovered.

Water Banking Authority

In 1996, the Arizona legislature adopted a 20-year state sponsored recharge program and organized the Arizona Water Banking Authority with the Department of Water Resources

[91] ARS 45-811.01, 45-812.01, 45-831.01, and 45-834.01.

providing staff support. Praised by Governor Fife Symington as "innovative legislation," it enables Arizona to maximize the benefit of its Colorado River water. Arizona is entitled to 2.8 million af per year, but has the most junior priority in the Lower Colorado River Basin. Moreover, Arizona's unused entitlement now flows downstream to southern California. The recharge program is designed to store that portion of Arizona's entitlement that is surplus to its current needs for use during future shortages, as well as to help meet the state's ground water management goals by replenishing depleted ground water aquifers with CAP water. An ad valorem tax revenue base finances Authority operations.

Of note, the Authority is currently studying recharge opportunities in the Tucson Active Management Area. The first deliveries of CAP water for municipal use caused a number of complaints from customers due to water quality related problems. Unacceptable turbidity, taste and odor problems were largely attributed to corrosion of older cast iron and galvanized steel pipes caused by pH and other chemical differences in the CAP water, compared to native ground water. Further, total dissolved solids (TDS) in the CAP supply is significantly higher, about 700 milligrams per liter (mg/l), compared to 200-500 mg/l for ground water. A local referendum now prohibits the direct use of CAP water, without extensive and expensive treatment. Direct use of CAP water has therefore been indefinitely delayed.

Artificial recharge may provide a means to use CAP supplies indirectly. However, there are a number of limiting factors, including the potential degradation of ambient ground water quality, and the availability of adequate or suitable recharge sites. Some of the concerns are due to a lack of hydrogeologic and other technical data, which can be costly and time consuming to compile, as well as regulatory disincentives, such as impact assessment and mitigation requirements under the Endangered Species Act and other federal environmental and cultural protection statutes. At present, suitable recharge sites are not adequate to meet the potential needs, and the Authority and Tucson AMA are studying sites based on proximity to source water, recovery considerations, currently contaminated ground water areas, particularly along major stream channels, and other factors.

Of particular interest, the law allows the Authority to use Arizona's aquifers and underground storage facilities to bank water on behalf of other states. California or Nevada might pay up-front for the use of the bank to store Colorado River water from Arizona's unused entitlement and thereby create a "water savings account" for use during periods of drought. Arizona would draw its entitlement from the "account" in dry years and allow the other states to take more than their allotted share of water from the Colorado River. Similarly, Arizona communities along the Colorado River could acquire stored water credits through the bank in central Arizona and, as needed, exchange those credits for the right to divert water directly from the Colorado.

The Arizona Water Bank may also help facilitate the resolution of other problems, such as the settlement of Indian water rights claims.

Over the years, an active state role in the management and conjunctive use of ground water resources has necessarily evolved, and ground water recharge has become an increasingly important activity in achieving state management goals. It is also a promising management alternative for resolving regional interstate water supply problems.

CONCLUSIONS

The Granite Reef Underground Storage Project (GRUSP) is unique but demonstrates that recharge opportunities can significantly increase efficient and effective management of both surface and ground waters.

GRUSP demonstrates the feasibility of recharging large amounts of water and represents a significant regional resource.

GRUSP also demonstrates it is possible for numerous governmental entities at the local, state, tribal and federal levels to cooperate in the development, operation, and regulation of a large-scale recharge project.

It is an important example of integrating the use of waters from a federal Reclamation project, the Central Arizona Project, with development and use of local surface and ground water resources.

GRUSP is also an example of successfully integrating artificial recharge and recovery activities with a federal project at little or no cost to the federal government.

Further, GRUSP demonstrates the economic and financial flexibility of ground water recharge as a new and significant water supply alternative for efficiently meeting base demands.

Given economies of scale, GRUSP water is orders of magnitude cheaper to develop than ground water recharge projects in the federal High Plains Program or other Arizona projects.

Ground water recharge is an integral part of state/local water supply planning in Arizona that promises to help mitigate the effects of past mining and also bank water for future needs.

Arizona ground water law recognizes, encourages and accounts for artificial recharge using a complex array of laws, institutional entities, accounts and financial mechanisms.

Arizona's ground water and ground water recharge law has developed, through trial and error, and continues to evolve.

Arizona carefully accounts for all water uses and encourages the maximum beneficial conjunctive use of all available resources -- surface water, ground water and effluent -- using artificial ground water recharge.

State fees related to ground water recharge and management serve to support augmentation activities as well as encourage conservation and wise use.

Over the years, an active state role in the management and conjunctive use of ground water resources has necessarily emerged, and ground water recharge has become an increasingly important activity in achieving state management goals.

Artificial recharge, storage and recovery projects and programs are also a promising management alternative for resolving regional interstate water supply problems and tribal water right claims.

KERN COUNTY, CALIFORNIA

BACKGROUND

There are dozens of successful artificial ground water recharge projects in California in various stages of development. In some arid areas, recharge has been going on for decades. Kern County and Bakersfield receive about five to eight inches of precipitation each year. Irrigated agriculture is very important to the economy of the county, which produces cotton, alfalfa, grain and permanent crops such as almonds. Given the fluctuating nature of local surface water supplies, ground water provides an important supply safety buffer, but long-term over use, in excess of natural recharge, led to mining which threatened the stability that this buffer provided. Ground water pumping has also caused land subsidence, threatening roads and water distribution facilities.

Ground water overdrafting or mining has been a concern in Kern County since the end of World War II, but it reached a peak during the 1976-77 drought. Ground water levels around Bakersfield dropped 80-100 feet as some 5-6 million acre-feet of water was withdrawn from the aquifers. The drought of 1987-1992 also increased demands on ground water and led to more overdrafting. The California Department of Water Resources (DWR) estimates that in the Tulare Lake Basin, which includes Kern County on the south and Fresno, Kings and Tulare counties to the north, the sustainable annual yield is 2.5 million af per year. In 1995, DWR estimated the annual over-draft in the basin totaled 820,000 acre-feet.

Agriculture is the major use of water throughout the San Joaquin Valley. Urban growth (and the resulting loss of agricultural land), rising pumping costs and conservation efforts have reduced agricultural water use, but the demands on ground water still exceed natural recharge. Most of the long-term over-draft problem is the result of irrigation, though municipal and industrial uses are growing

Over the years, many ongoing ground water recharge projects and programs were developed around Bakersfield. Significant volumes of water are now being recharged using spreading basins and local and imported waters. In addition to local surface water supplies from the Kern River, water is purchased and imported from the California State Water Project (SWP) and federal Central Valley Project (CVP). Many different municipal and agricultural water agencies are involved, and some of their activities will be described briefly hereafter. These examples illustrate the effective mixing or integration of different water supply sources and their conjunctive use, which provide a substantial degree of flexibility and greater margin of safety in meeting present and future water needs. Conjunctive use of surface and ground water supplies to meet the demands of urban and agricultural water users has become a common practice.[92]

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[92]Interviews: Bakersfield Water Department (Gene Bogart), Kern Co.Water Agency (Kane Totzke), and California DWR (Philip Wendt, Carl Hague, Dan Otis, Stephen Cowdin, and John R. Fielden), April 5, 1993.

Kern County provides many examples of the challenges and opportunities related to large scale ground water recharge. Some of the lessons involve environmental protection and endangered species concerns. It also provides important examples of successful cost sharing and cost recovery mechanisms, with sufficient information gathered over a long period of time to allow evaluation of the costs and benefits of recharge, compared to other alternatives.

BAKERSFIELD

Bakersfield lies near the southern end of California's San Joaquin Valley in Kern County. Historically, land and water were critically important to early pioneers. Two prominent settlers were Henry Miller and James B. Hagen. Miller built up his cattle business based on riparian pasture along the Kern River as high flows averaged about 40,000 acre-feet per year. James B. Hagen settled upstream and began the Kern County Land Company. He appropriated water and began draining and irrigating land under the Desert Lands Act and Swamp and Overflow Lands Act. Downstream, the riparian lands on the west side of the valley began drying up. A number of court battles over riparian and appropriative uses finally led to the California State Supreme Court. The conflict was finally settled by a contract known as the Miller-Hagen Agreement. Almost a century later, conflicts over water and land use continue.

Over time, the City of Bakersfield acquired rights to withdraw up to 90,000 acre-feet/year of water from the Kern River or about 25% of the natural flow. In 1967, Tenneco, a private company, bought the assets of the Kern County Land Company and began rebuilding pioneer works and a system of 90 water wells. The City first sued Tenneco and then settled a dispute over its water rights by purchasing the company's rights in 1976 for $17.9 million. About the same time, the City also entered into 35-year contracts with four water districts to acquire surplus water.

Project Purpose and Description

Bakersfield's population and municipal and industrial water needs are growing rapidly. Much of the land west of Bakersfield is ideal for artificial recharge, with coarse soils and gentle sloping gradients. In order to ensure its future water supplies by utilizing available storage underground, the City acquired some 4,000 acres in and along the Kern River bed and, in 1978, began developing a recharge project on the land.

In 1983, a spreading agreement was reached with Kern County, and in 1984, construction began on the City of Bakersfield's so-called "2800-acre project." This project originally included in-river settling works and eight off-channel basins. A total of thirteen off-channel spreading basins have now been built covering 1,350 acres. The City allows water districts and other entities to use its facilities to recharge and store water. Spreading is permitted through contractual agreements. Other contractors participating in the 2800-acre project include the Buena Vista Water Storage District, Kern County Water Authority (KCWA), and the Olcese Water District.

Other surrounding recharge and recovery facilities in the Kern Fan Area include the Berrenda Mesa Project, Pioneer Project and the Kern Water Bank (described later). These and other projects in the Kern Fan Area involve a number of different water supply entities, using

various water sources, to recharge a significant amount of water, as illustrated hereafter.

Water Supply and Recharge

Bakersfield's 2800-acre project primarily spreads Kern River water, which accounts for 70 percent of the water spread (1977-86), but other surface water supplies include the State Water Project (SWP) and federal Central Valley Project (CVP), which account for the remaining 30% (about 20% and 10% respectively). The City initially anticipated the project would be able to store between 350,000 and one million acre-feet of water.

From 1978 through August 1986, some 761,010 acre-feet of water was recharged by the City, or on average about 80,000 acre-feet per year (before many of the recharge basins were completed). However, the project is now capable of recharging 200,000 acre-feet of water per year, when that much water is available. Over the same period of time, significant amounts of water have also been recharged under contract by the Buena Vista Water Storage District, Kern County Water Agency, and Olcese Water District. Through August 1986, some 672,561 acre-feet of water had been banked in the recharge facility, although overdraft during the subsequent drought reduced water supplies.

Project Costs and Cost Sharing

The construction cost for the spreading basins and related facilities for Bakersfield's 2800-acre project totaled some $2 million, in addition to the cost of the lands and water, which the city had acquired earlier. Operation and maintenance costs are described later, along with cost recovery and project financing. The City also has production wells in the area.

Project Benefits and Beneficiaries

The primary benefit from the 2800-acre project is the increased reliability and stability of Bakersfield's water supply. Careful conjunctive use of both ground water and surface water resources, by artificially enhancing recharge using flood flows and other surface water sources when available, and later recovery recharged water during periods of high demand or drought, has significantly increased the efficient use of the area's water resources, increasing the overall system yield and assuring the long-term stability of water supplies. The surrounding area similarly benefits, as does the local economy, to the extent that other local water entities participate in the project.

Another benefit from recharge relates to water quality. Natural and artificial recharge creates a mounding of ground water near the river that helps prevent the migration of poor quality ground water contaminated by agricultural use, which leaches salts and other contaminants from soils and carries pesticides and herbicides.

Energy and related cost savings due to reduced pumping lifts are also a significant benefit, which have been estimated at as much as $12-$15 per acre-foot of water. Pumping lifts in the area influenced by the recharge project are between 90 to 120 feet, compared to 180 to 200 feet of average lift in other areas around Bakersfield.

Wildlife also benefit from the project as habitat has increased. Bakersfield's recharge facilities enhance wildlife habitat by restoring native habitat and providing wetland areas. In the usually dry lower San Joaquin Valley, the ponds provide valuable resting places for waterfowl, shorebirds, and other migratory

birds, as well as habitat for many species of resident wildlife. Natural vegetation --grasses, shrubs, and trees -- are allowed to grow in the recharge basins (which are alternatively wet and dry). The vegetation helps keep soil pore spaces open, maintaining recharge rates and reducing management needs. The primary operation and maintenance requirements involve sterilizing the levees and discing the main river channel. Water is delivered and distributed throughout the project by gravity.

Project Financing and Cost Recovery

The City of Bakersfield financed the 2800-acre Project, but there is no direct cost to city taxpayers, as the full cost is recovered through contracts and recharge fees.

In 1984, an operation and maintenance (O&M) fee was established at $.50 per acre-foot for recharge, and this fee has been indexed upwards with inflation. In addition, a facilities improvement fee was set at $2.84 per acre-foot in the same year. The spreading fee currently is $5.00 per acre-foot. The total is under $9.00 per acre-foot if a water entity pays all its costs of participation up-front. To these fees, the cost of the water recharged and recovery costs must be added to determine the total cost for a user to participate in the water bank. No pumping tax is levied on users of the project.

The Bakersfield recharge project is a working example of how to effectively encourage ground water storage and recovery among area water user groups. Project operating and maintenance fees are maintained at levels which encourage water users to store water rather than use their water unwisely or develop other uses for their water (possibly including their own recharge operations).

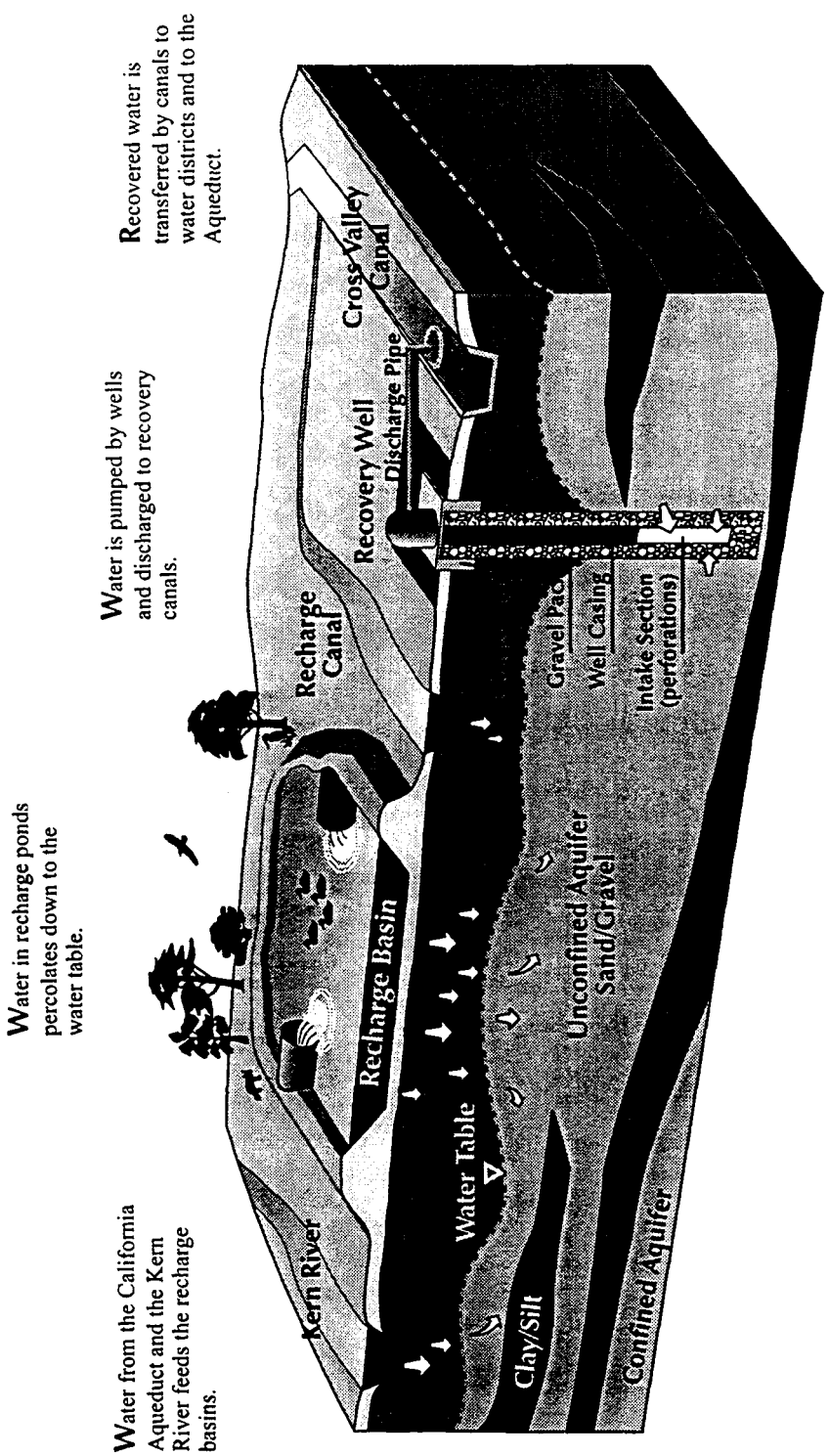
The wildlife benefits provided by the project raise questions related to willingness to pay for such environmental values. As the benefits are incidental to the primary purpose for the project and may minimize operation and maintenance costs, no serious concerns were raised related to project financing. However, as higher and higher public value is placed on environmental benefits, particularly in arid regions such as the San Joaquin Valley, some communities may wish to consider wildlife habitat as an intended use of artificial ground water recharge projects and may need to search for ways to finance and recover related costs.

Legal and Institutional Issues

Institutional and environmental obstacles have been cited as the major obstacle to greater development and use of artificial recharge in California. The need for state and federal permits include meeting requirements imposed under the National Environment Policy Act (NEPA)/California Environmental Quality Act (CEQA), as well as public involvement, and the political process. The Endangered Species Act (ESA) is another concern, though at the time of the development of the Bakersfield project, listed species did not present a major obstacle. However, ESA has proven to be an obstacle to other projects and the expansion of recharge in the area.

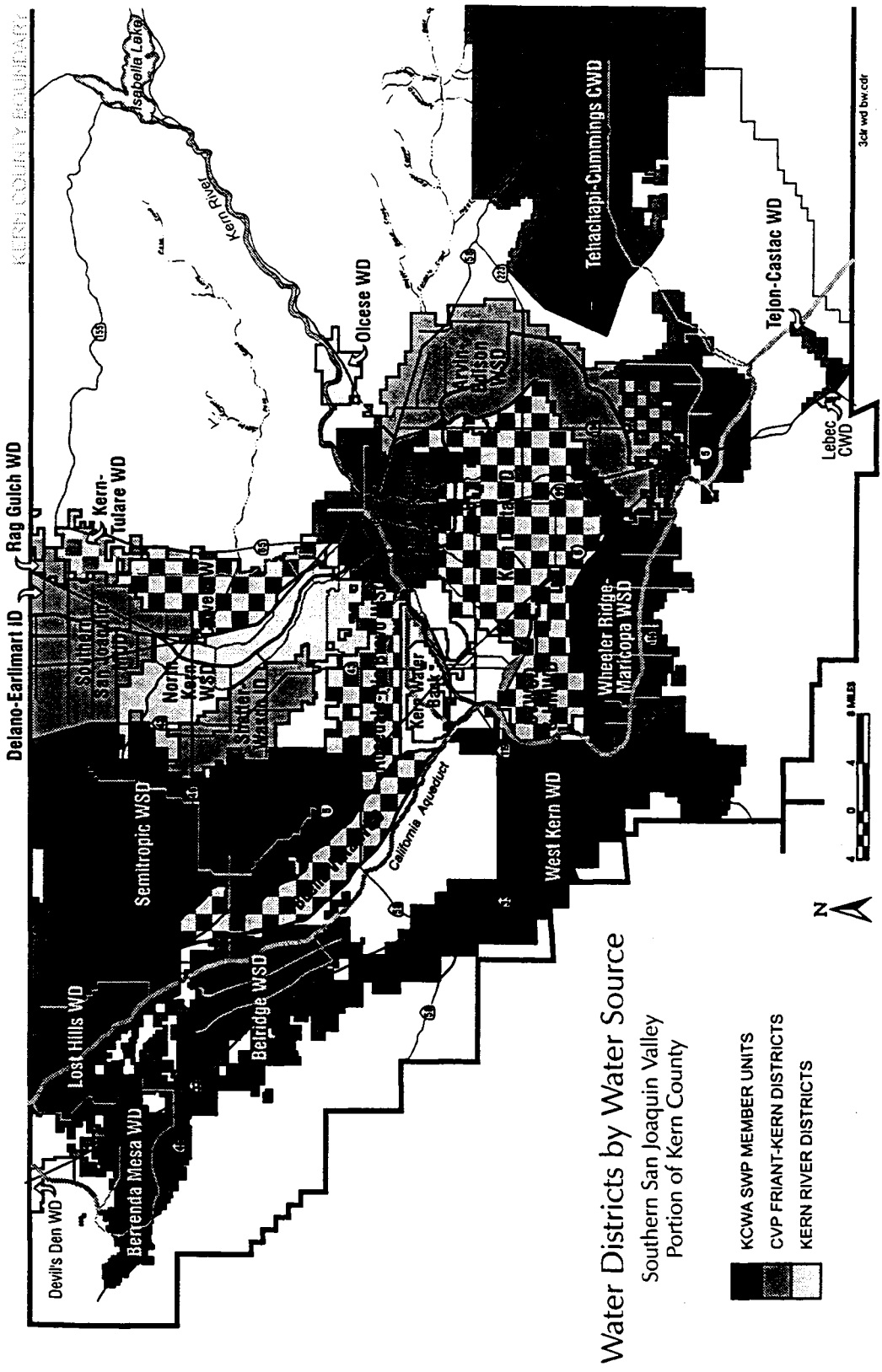
Other concerns are related to social and rural values. Transfers of water from agricultural to urban uses appear to be the trend in southern California. Indeed, Bakersfield is growing rapidly, and subdivisions are replacing fields, and water uses are similarly changing. Urban growth and the subsequent loss of some significant amount of farmland is an issue around Bakersfield and changes the nature of the demands placed on the area's water supply.

Kern County Ground Water Recharge and Recovery



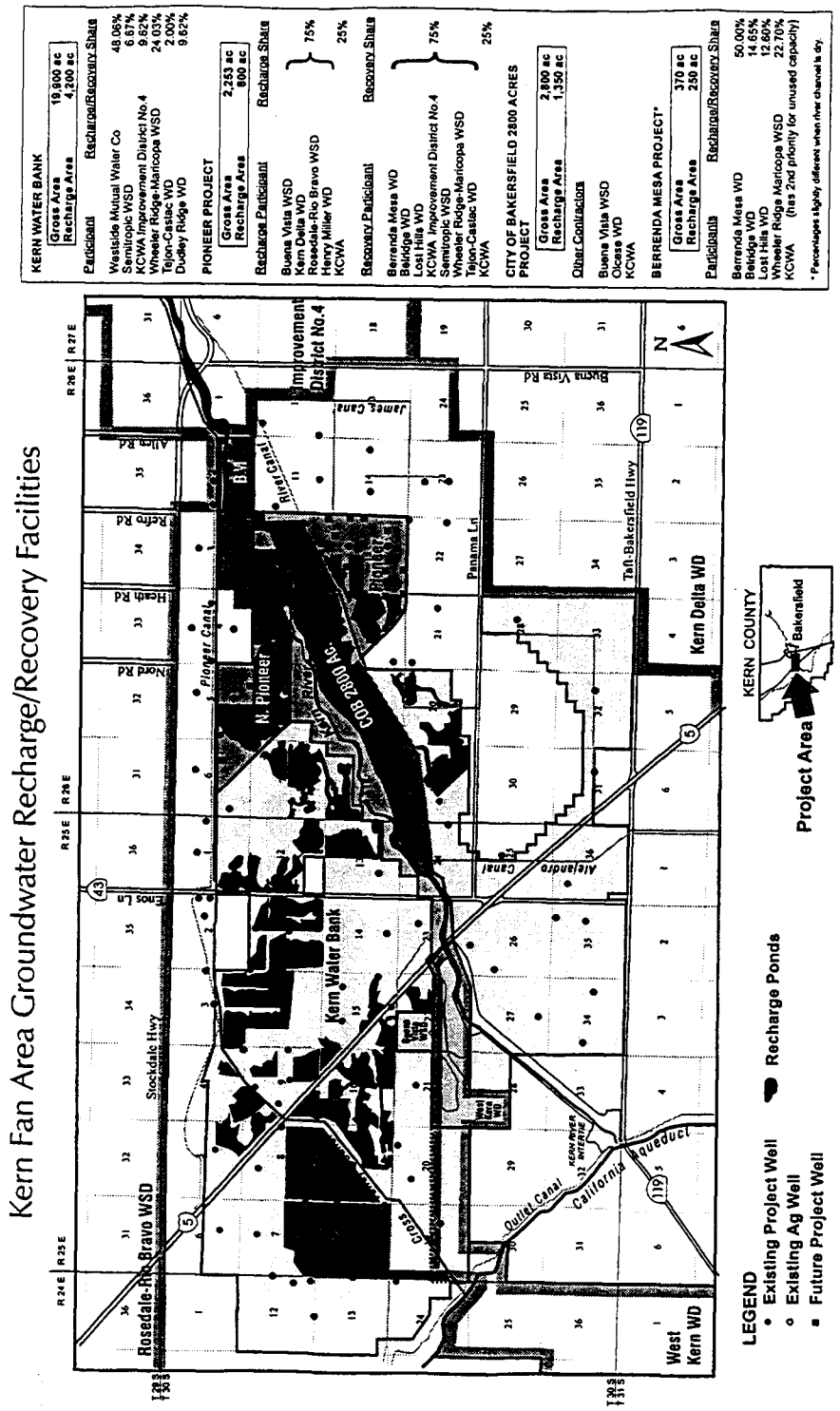
Source: Kern County Water Agency, dd3:\presenta\ltws1094\rechrecv.cdr, 3-22-95

Kern County Water Districts



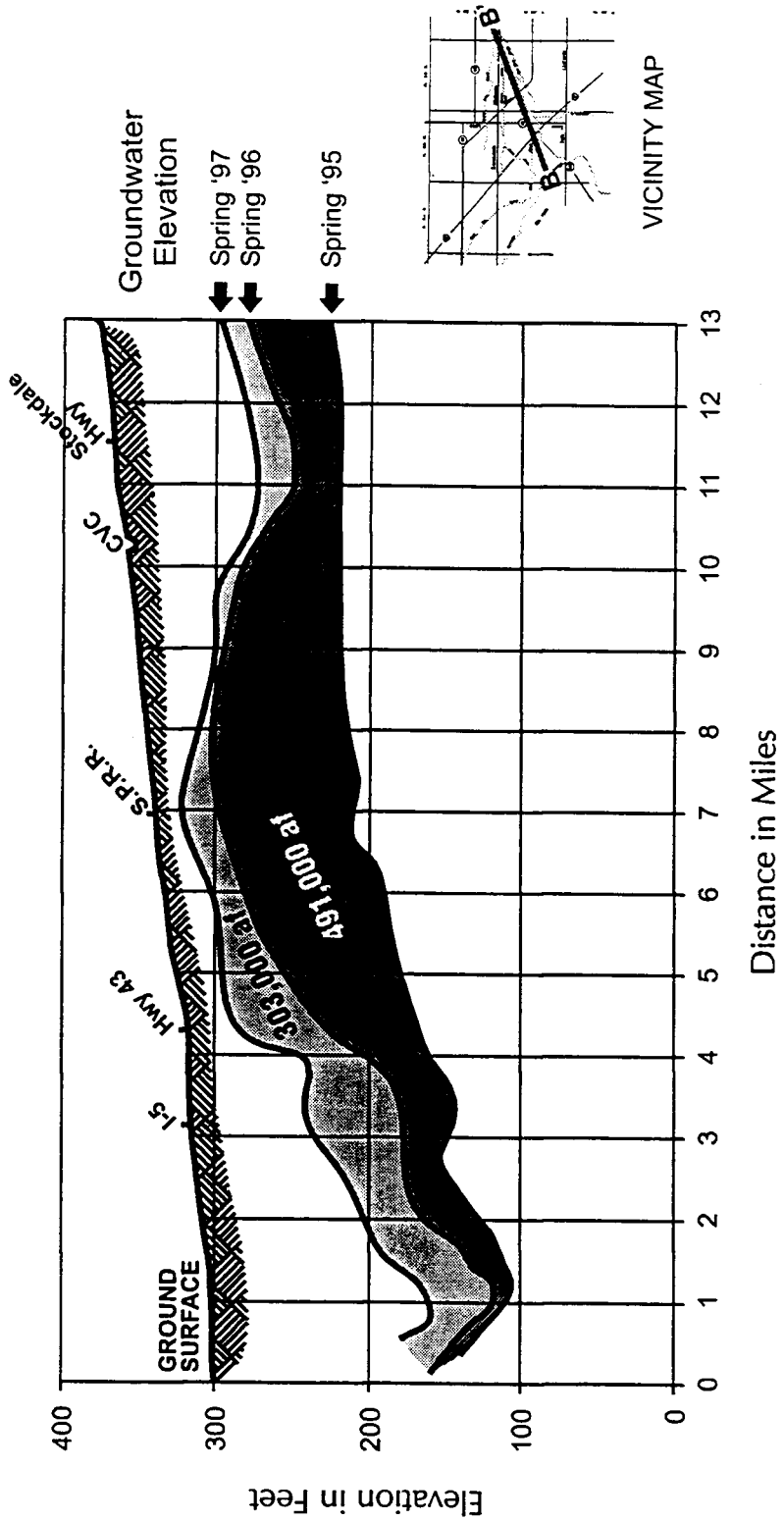
Source: Kern County Water Agency, 3clr wd bw.cdr, 10/15/97

Kern Fan Area Facilities



Source: Kern County Water Agency, kern fan participants.cdr, 10/9/97

Kern County Hydrologic Profile



Source: Kern County Water Agency

An even larger local concern may be over the development of water supplies for export to the populous southern California coastal plain.

Overall, institutional and environmental obstacles to development are viewed as primary concerns, and financing economically viable projects is viewed as a secondary concern.

Many political boundaries and overlapping jurisdictional issues related to ground water development, use and recharge and recovery could make project administration problematic, but do not appear to be a major problem as different entities have successfully cooperated.

KERN COUNTY WATER AGENCY

The Kern County Water Agency (KCWA) and other water and water storage districts are involved in a number of ground water recharge projects. KCWA was formed in 1961, and covers all of Kern County. KCWA's State Water Project (SWP) entitlement totals up to 953,130 acre-feet (af) for agriculture and 134,600 af for municipal and industrial purposes. This accounts for 26% of the SWP's service obligation. The agency's SWP supply is then distributed to its sixteen member agencies, including the Bakersfield area (KCWA Improvement District No. 4).

KCWA is a multipurpose agency authorized by law to make water available for beneficial use for the land and people within its jurisdiction. It may acquire, appropriate, conserve, import and store water. It is also responsible for flood control, drainage, reclaiming lands, preventing contamination of water, and developing and selling wholesale hydroelectric energy to aid in water project financing. KCWA encompasses many water districts and municipalities, which may retain overlapping jurisdiction and authorities.

KCWA is governed by a board of seven directors, elected from different divisions. Member units may include any municipality, town, or district wholly or partially within Kern County. KCWA may sell and deliver water to any water district or water company, with one exception. KCWA may also contract with member units for the repayment of project construction costs. Further, KCWA may cooperate and contract with the federal government or the state for project construction, or the joint acquisition of works or property, or the acquisition, exchange, purchase or sale of water.

KCWA revenues include monies from fees on land and water deliveries (similar to water districts) as well as the sale of hydroelectric power and falling water charges, the sale and lease of property to member units and others, charges for member services, and various assessments. An annual ad valorem assessment may be levied on all taxable property if revenues are inadequate for operations. This assessment is not to exceed five cents on each $100 of assessed value, but that is excluding any member unit delinquency assessments, bond assessments and other special assessments, such as ground water replenishment assessments and improvement district assessments.

KCWA may issue general obligation bonds for member units or improvement districts, and such debt is segregated from other agency obligations. It may also issue revenue bonds.

KCWA is particularly unique in its ability to levy differential assessments for various purposes based on defined "zones of benefit." Improvement districts may be created within KCWA, for bonding and assessment purposes, by a two-thirds majority of registered voters. The Agency may collect different assessments from within the improvement districts in order to retire promissory notes and bonds.

KCWA also has the power of eminent domain in acquiring property for agency purposes, including supplying water for public use, but it must provide an equivalent water supply and substitute facilities in order to condemn water or other property.

Berrenda Mesa Project

The 370-acre Berrenda Mesa project is a joint venture of the KCWA and the Berrenda Mesa, Belridge and Lost Hills Water Districts, and Wheeler Ridge Maricopa Water Storage District. It primarily uses State Water Project (SWP) water. According to information from the California Department of Water Resources (unpublished data, Phil Wendt, April 1993), the Berrenda Mesa project has a total cost of $2.69 million and has a total project yield of 5,436 acre-feet per year. The undiscounted capital cost per acre-foot over 50 years is about $10. The total recharge costs at Berrenda Mesa would also include additional costs for operation and maintenance and imported water.

KCWA Improvement District No. 4 raised revenues to finance the Berrenda Mesa project with fees and ad valorem taxes. The annual cost (for the fee and tax) total about $20 per acre-foot to pump water, which is a fee to replace water pumped from the aquifer with SWP water. In addition, as described earlier, KCWA has the ability to create zones of benefit for agricultural users and levy fees on irrigators based on their location relative to the recharge area and expected benefits.

Pioneer Project

The KCWA also has a 25% interest in the 2,253-acre Pioneer Project (for purposes to be designated by its board of directors), which it received in return for providing the property for the project. KCWA may use its share to correct overdraft conditions or for water supply for its expanding urban population.

The project is unique in that a number of different water entities are involved either as recharging or recovering participants, but not both. As it is, certain ground water basin districts financed construction of the ponds, levees and turn outs and have first priority for recharging water for overdraft correction, while other participating districts financed construction of recovery works and have first priority for recovering water.

Further, specific principles of agreement allow for borrowing between overdraft correction accounts by districts banking water. Further, its allows for the transfer of water in bank accounts from other projects for recovery using Pioneer Project wells and vice-versa, subject to monitoring committee's review and approval. The project is also operated in accordance with the provisions of the Kern Water Bank Memorandum of Understanding.

These cooperative arrangements provide maximum water supply flexibility and greater areawide operations efficiency.

Kern Water Bank

The Kern Water Bank is by far the largest project in the county, covering 19,900 acres. In 1985, the KCWA and the California Department of Water Resources (DWR) began developing the Kern Water Bank as a component of the State Water Project (SWP), in order to allow for the conjunctive use of surface and ground waters and increase the SWP's yield. It was designed to allow DWR greater flexibility in meeting its obligations to deliver water to its southern California contractors.

DWR purchased 20,000 acres of land that overlies the Kern River alluvial fan, southwest of Bakersfield, idling some 16,000 acres of farmland. DWR planned to build 3,000 acres of spreading basins and recharge as much as one million acre-feet of water per year (more than the current yield of Lake Isabella, a Corps project of the Kern River). The water would be imported from the Sacramento-San Joaquin Rivers Delta, through the existing California Aqueduct. This became known as the SWP's Kern Fan Element. However, environmental concerns and Endangered Species Act restrictions delayed development and eventually led to the state withdrawing from the project.

The fallowing of farmland after its purchase by the state unintentionally opened up habitat and allowed the populations of a number of endangered species to expand, blocking the implementation of the project as originally intended. Listed species potentially at risk of "takings" included the kit fox, kangaroo rat, and blunt-nosed leopard lizard.

Moreover, subsequent federal regulatory actions and restrictions on the amount of water available for export from the San Francisco Bay-Sacramento/San Joaquin Delta (Bay-Delta), given federal water quality and environmental concerns, made the project less valuable as a source of SWP water. Under the circumstances, an agreement was reached to transfer ownership and operation of the project to a local joint powers agency, the Kern Water Bank Authority (KWBA).

KERN WATER BANK AUTHORITY

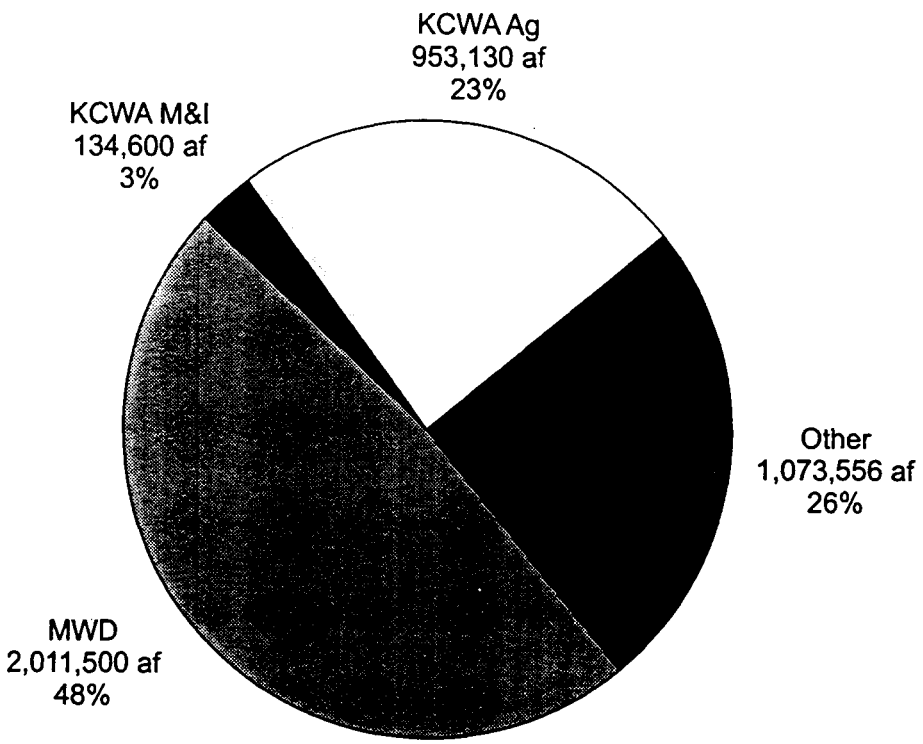
In December 1994, DWR and SWP water contractors signed the "Monterey Agreement," and among other things, the state agreed to transfer its Kern Fan Element property to the SWP agricultural water contractors, the KCWA and the Dudley Ridge Water District. In return, KCWA and other SWP contractors agreed to permanently return to the State entitlements to up to 175,000 acre-feet of water, thus reducing the SWP's delivery obligations and demands for Bay-Delta exports. Only the Metropolitan Water District (MWD) of Southern California takes more SWP water than KCWA.

The first transfer involved relinquishment of 45,000 acre-feet (af) of water (40,670 af from KCWA and 4,330 af from Dudley Ridge).

An additional 130,000 acre-feet of SWP agricultural entitlements is to be sold on a permanent basis to urban contractors on a willing buyer-willing seller basis. As of April 1997, the KCWA had transferred 25,000 acre-feet to the Mojave Water Agency for recharge for municipal use, and was transferring another 9,000 acre-feet to the Castaic Lake Water Agency.

The Kern Water Bank Authority (KWBA) has been operating about 3,000 acres of recharge basins under an emergency California Environmental Quality Act (CEQA) exemption and interim agreement with the U.S. Fish and Wildlife Service, following an ESA Section 7 consultation. These temporary environmental permits have allowed the KWBA to recharge about 450,000 af of winter floodwaters since May 1995, while at the same time preparing a 75-year habitat conservation plan/natural community conservation plan covering the Kern Water Bank property, which sets aside 10,000 acres to be managed for habitat and will allow KWBA to construct another 6,400 acres of ponds and expand its conveyance structures at an estimated cost of $30 million dollars.

Kern County Water Authority's State Water Project Entitlements
(maximum annual entitlements)



TOTAL
4,172,786 af

Source: Kern County Water Agency, 10/14/97

ARVIN-EDISON WATER STORAGE DISTRICT

The Arvin-Edison Water Storage District lies east of Bakersfield, and serves 131,660 acres of land. About 98,000 acres are developed for irrigated crops, of which 52,000 acres are capable of receiving surface water for irrigation. Demand totals 150,000 to 180,000 acre-feet of water for those 52,000 acres. The rest receives water from irrigation wells. Primary crops include vineyards, truck crops, potatoes, cotton, and citrus. Irrigated acreage has fallen steadily from a peak of about 112,000 acres in 1982, with most of the decline due to land idling, conversion to dry native pasture and other dryland agricultural uses.

Project Purpose and Description

Arvin-Edison was specifically formed in order to contract with the Bureau of Reclamation for water from the Central Valley Project (CVP). Arvin-Edison 's primary goal is to provide its agricultural water contractors with stable, reliable water supplies for sustainable agricultural production in the face of rapidly growing municipal and industrial water use throughout southern California.[93] In 1966, two spreading basins were developed. The Tejon site and Sycamore facility cover 776 acres. Fifty production wells pump water from two well fields associated with the two spreading basins. CVP water deliveries that exceed surface irrigation requirements have been recharged during wet years when floodflows exceed contractual commitments that the District has with irrigators who use surface water for crops.

Water Supply and Recharge

Arvin-Edison has an entitlement of 40,000 acre-feet of Class I, or "firm" CVP water, but has received as little as 10,000 af during the 1977 drought. Up to 313,000 acre-feet of Class II, "non-firm" water is delivered to Arvin-Edison during wet years via the Friant-Kern and Arvin-Edison Canals. In addition, Arvin-Edison has an agreement through the Cross Valley Canal Exchange to reduce fluctuations in its water supply, assuring a minimum of 128,300 acre-feet of water during most years. Exchange water is delivered via the California Aqueduct and Cross Valley Canal to the Arvin-Edison Canal. When CVP and Exchange water deliveries are ample, water is recharged, and when these supplies are insufficient to meet surface acreage irrigation demands, previously recharged water is pumped from Arvin-Edison wells to meet the deficiency.

Arvin-Edison's recharge ponds have a maximum recharge rate of about 200 cubic feet per second. Prior to 1993, approximately one million acre-feet of water had been percolated through Arvin-Edison's surface spreading basins, while more than three million acre-feet of water had been delivered directly to surface water irrigators. A net increase of 436,307 acre-feet of water had been accumulated in underground storage as of February 1992, which was down from a maximum accumulated storage of 697,175 acre-feet at the end of the 1986 water year, prior to a prolonged drought.

Project Costs

No information was available regarding Arvin-Edison's construction costs for their artificial recharge project. Existing delivery

[93] Information based on interview with Cliff Trotter, Arvin-Edison Water Storage District, on April 5, 1993.

systems and other facilities are used to move water for recharge to the spreading basins. CVP water service costs Arvin-Edison $14 per acre-foot, which covers Reclamation's full federal operation and maintenance charges to operate the CVP's Friant Unit. An increase of $6 per acre-foot was levied in September 1993.

Primary operation and maintenance costs involve pumping water to the upper basin when the capacity of the lower, gravity-fed spreading basin is exceeded -- and maintaining spreading basin infiltration rates by managing silt concentrations that sometimes reduce rates to unacceptable levels.

Some methods used to maintain infiltration rates include: (1) periodically drying soils in the spreading ponds; (2) promoting grass growth in pond bottoms to enhance pore spaces; (3) terminating spreading when total suspended solids in imported water exceeds 25 parts per million; (4) restricting vehicular travel within the basins; (5) scarifying pond surfaces by chiseling or discing; and (6) mechanically removing silt.

Project Benefits and Beneficiaries

Again the primary benefit is a more secure and stable water supply for agricultural water contractors and as a result long-term sustainable agricultural production. Conjunctive use of surface water and ground water matches an erratic water supply to growers' irrigation demands, using artificial recharge, storage and recovery opportunities. Ground water overdraft has been relieved by providing surface water to land that was previously irrigated with ground water. Artificial recharge of surplus water during wet years and reduced ground water pumping has stabilized declines in ground water levels.

Prior to the recharge project, land was being abandoned in the area because of water supply and related water quality problems. Ground water overdraft once exceeded 200,000 acre-feet per year, prior to construction of the CVP and local recharge efforts. Overdraft now averages 10,000 acre-feet per year, compared to what would have been an estimated 126,000 acre-feet per year, with current land uses, in the absence of artificial recharge.

Many areas in Arvin-Edison had pumping lifts that exceeded 600 feet prior to the CVP and artificial recharge project. The depth to ground water now is a little over 400 feet. Average annual water table declines are 0.7 feet, versus 8.4 feet had artificial recharge not been developed and implemented. Therefore, there are significant energy savings, in addition to the obvious water supply benefits. The district would like to expand its underground storage capacity to one million acre-feet.

Project Financing and Cost Recovery

All costs for artificial recharge in Arvin-Edison's conjunctive use program are paid by district irrigators. Arvin-Edison's canal, pumping plant, and other distribution facilities were initially financed by a $41 million loan that was made and administered through Reclamation. The terms of the federal loan included a 40-year repayment period, following the completion of construction in 1972, but it was retired early in 1988. Therefore, the recharge and other project facilities were supported by Reclamation initially, but continued operation and maintenance of the project is funded entirely with water users' fees.

Total water service charges to irrigators for surface water service in the area total $79 per acre-foot. Other service charges are levied on

all lands in Arvin-Edison, and amounted to $8.65 per acre in 1993. Costs for the artificial recharge project are paid from these combined water service assessments.

The District has since spent $1.5 million on a plan to build 500 acres of new ponds, at an estimated cost of $8.5 million. The costs were determined to be beyond the ability of the District to finance and repay. As a result, in part, the District then entered into a $22 million agreement with Metropolitan to further develop recharge opportunities and transfer banked water to southern California. The proposed project involves building a 4.3 mile pipeline to the California Aqueduct from Arvin-Edison's recharge/recovery facilities, in order to allow the District to purchase, recharge, store, recover and transfer CVP water to MWD. The initial proposal called for the transfer of up to 350,000 acre-feet of water (including CVP water), but that amount was reduced to 150,000 af due to local opposition in the District. No CVP water is now being transferred.

ROSEDALE - RIO BRAVO WATER STORAGE DISTRICT

The Rosedale-Rio Bravo Water Storage District is located west of Bakersfield and north of the Kern Water Bank. It was created in 1959 in order to conjunctively manage local ground water and surface water supplies and imported surface waters. The District serves an area of 43,000 acres, and developed acreage has risen and land uses changed over the years. In 1961, there were about 25,000 acres of cropland. Agriculture was the only land use. By 1995, of 34,500 developed acres, urban growth had claimed 6,000 acres for residential, commercial and industrial land uses. The irrigated cropland is primarily cotton (44%) and alfalfa (22%) but also includes deciduous trees (12%), grains (11%), and vegetables (9%). [94]

More irrigated lands means greater water demands. It is estimated the applied water requirements have increased from 85,000 acre-feet per year (af/yr) in 1961 to 110,000 af/yr in 1995, while consumptive use has risen from 62,500 af/yr to 82,000 af/yr over the same period. Available water supplies vary widely seasonally and from year to year. Average surface water deliveries from all sources total 55,000 af/yr, including firm supplies from the Kern River of 10,000 af/yr and from the State Water Project (SWP) of 30,000 af/yr surplus water from these sources and the federal Central Valley Project (CVP) are taken as available.

Project Purpose and Description

Obviously, available surface water supplies are not sufficient to meet demands, and the remainder is drawn from ground water. Actual and projected water level declines averaged 9.2 feet per year, prior to initiation of recharge activities. The Rosedale-Rio Bravo Project was originally constructed in 1961, using Goose Lake Slough, a historic Kern River overflow, to recharge the local aquifer. The aquifer serves as a storage reservoir and allows the District to manage the erratic nature of its water supplies and meet demands. Project facilities have been modified and expanded over the years and cover some 730 acres. A number of East and

[94] "Conjunctive Use Agricultural Water Supply with Artificial Ground Water Recharge," by Thomas S. Maddock, President and David L. Hardan, Regional Vice President, Boyle Engineering Corp., Newport Beach, California, January 1996.

West basins and channels provide 568 acres for surface water spreading.

Water Supply and Recharge

Delivery of Kern River and CVP waters began with initial construction of the project in 1961. In 1976, construction of the Cross Valley Canal provided access to SWP deliveries. As noted earlier, only Kern River and SWP waters are firm deliveries, with surplus water taken as it is available. Through 1995, water deliveries to the project from all surface water sources totaled 1,872,000 acre-feet. Assuming losses due to evaporation and evapotranspiration are 6% of the total, about 1.76 million acre-feet of water has been effectively recharged (or 51,800 acre-feet/year).

As would be expected, water deliveries, recharge and ground water levels declined during the drought of 1976-77 and again during the extended drought of 1987-92.

Project Costs and Cost Sharing

The District's landowners have paid all of the estimated $80 million cost of the project facilities, operation and maintenance and water supply purchases. More than half the project's surface water deliveries come from the Kern River (55%), at a cost of $2.33/af for firm water and $11.71/af for surplus water. SWP deliveries account for 31% of surface water supplies at a cost of $45.75/af for firm water and $22.35/af for surplus water. The remaining surplus CVP water, when available, is $10/af.

The unit cost for water to recharge has been estimated at $43/af, with additional recovery costs estimated at $36/af, for a total estimated cost of $79/af.

Project Benefits and Beneficiaries

Some of the direct benefits from the recharge project for both agricultural and urban water users include the reduced energy costs and capital improvements that would have otherwise been required to continue pumping ground water as water levels declined. Over the years, as a result of recharge project operations, the actual decline in ground water levels has been 2.6 ft/yr, compared to the projected 9.2 ft/yr without the project.

It is estimated that the water table is 218 feet higher than it might have been otherwise. The District's landowners benefit as long-term savings accrue from reduced energy costs for pumping and lower capital expenditures for improvements to wells and pumps. The estimated savings over time total $129 million. Given these estimated savings alone and the estimated project cost of $80 million, with a 7% discount/interest rate, the benefit/cost ratio is 1.6 for the project.

Other project benefits, not easily quantified, include the profits realized from a more stable water supply that might have been foregone without the project due to water shortages. No attempt has been made to quantify this and other benefits, but they would further increase the favorable benefit/cost ratio.

CONCLUSIONS

Water supplies in Kern County have long been conjunctively managed successfully to increase reliability.

Various water districts are using recharge opportunities to stabilize and increase supplies.

Kern County projects do demonstrate the willingness and ability of local farmers to pay for costs associated with ground water recharge, storage and recovery.

These projects provide examples of the successful cooperative/integrated management of federal, state and local water supplies and projects.

These agricultural projects are cost effective, using available infrastructure (primarily the existing surface water distribution systems and ground water wells and pumps), given the current water supplies and prices.

Moreover, these projects demonstrate that spreading basins are a feasible recharge option and may be more appropriate in agricultural areas than injection wells.

However, high capital and operation costs, and the cost of water, may preclude the use of recharge for many agricultural projects.

Some opportunities may exist to develop additional spreading basins and further expand ground water recharge, storage and recovery if financing can be found.

Financing arrangements may involve more deals between urban water districts and farmers providing for exchanges and transfers of water.

Given existing municipal demands and continuing population growth, California state water planning documents project shortages will be a problem even during normal water years, which may lead to even more transfers or long-term leases of agricultural water to municipal and industrial users in the future.

Willingness to pay, a traditional economic measure of the value some people place on a resource, is not always viewed by some as an equitable way to distribute water.

Some concerns focus on wealthy urban areas obtaining all the water they demand at the expense of agricultural and other water users.

Recharge opportunities may offer at least one alternative that may help preserve rural lifestyles, while at the same time meeting urban needs during critical dry periods.

Dry year contracts have been entered into which allow farmers to temporarily transfer their water to meet critical urban needs, while at the same time receiving or preserving some source of income.

Substantial wildlife habitat benefits may be provided coincidental to recharge project operation while minimizing project operation and maintenance costs.

Many water supply projects that are technically feasible may be jeopardized by water requirements for environmental purposes, such as new Bay-Delta water quality standards, requirements of the Omnibus Reclamation Bill (P.L. 102-575), the Endangered Species Act and other environmental mandates.

JULESBURG, COLORADO

BACKGROUND

The Lower South Platte Water Conservancy District is located in the north-eastern corner of Colorado. It diverts water from the Platte River, just west of the small town of Julesburg. The District and the State of Colorado are recharging water through a joint project. While a relatively small project, it demonstrates that ground water recharge may be a cost effective agricultural water supply option. Further, there may be significant environmental benefits. Compared to federal demonstration program projects, the Julesburg project has been built with a small amount of money and very few regulatory conditions. However, this private-state partnership plans to recharge a significant amount of water.

Project Purpose and Description

The purpose of the project is to mitigate the effects of pumping during the irrigation season and avoid the usual need to shut down wells with junior rights during the late summer, thus maintaining or increasing the area's agricultural production. The area receives around fifteen inches of precipitation annually, and wells provide a supplemental supply. The project uses two spreading basins along the upper edge of the river alluvium. The project site includes 43 acres, with about 10 acres in the two recharge ponds. Because it is an unconfined aquifer, recharged water moves downgradient toward farms which have reduced their ground water table levels due to over pumping.

The project takes advantage of temporal differences in water supply and demand. Recharge takes place from October through April when flow requirements under a South Platte River agreement (Platte River Compact) between Colorado and Nebraska are not restrictive. [95] It uses off-season river flows. The project captures winter flows, about 5 cubic feet per second (cfs), and recharges this water. A ground water mound is created that moves slowly towards the river, augmenting supplies and reducing pumping lifts. What water isn't recaptured will finally reach the river in late summer, when instream flows for fish and wildlife are most important.

Permits and paperwork took 60 days to complete, while construction of the ponds, dikes, turnout and "T" box was completed in only two weeks. Water quality degradation is not a significant concern, thus minimizing the monitoring requirements for the project. There are ten monitoring wells on site.

Water Supply and Recharge

The South Platte River is the source of the recharge water, which is diverted through the Peterson Ditch. The river water for this project is essentially composed of return flows from upstream irrigation and is recharged through two spreading basins into the unconfined alluvial aquifer tributary to the river. Recharge started at two cfs and is being increased by increments of one-half cfs to determine how much water can be recharged through the

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[95] Information based on interviews with Lower South Platte Water Conservancy District (Marian Law) and Colorado State Engineer's Office (Brian Ahrens and Alan Berryman), October 20, 1992.

spreading basins. Recharge during October 1992 was being conducted at a rate greater than five cfs, and maximum recharge was reached at between 5.3 - 5.5 cfs. The goal is to recharge 2,500 to 3,000 acre-feet of water per year.

Water Quality

No significant water quality concerns have arisen, even though the recharge site is near community and private drinking water wells. Monitoring wells are sampled quarterly for nitrates (up to 4 ppm have been detected) and a few other constituents. Nitrates in return flows average 2-3 parts per million (ppm), and have been measured at 7.5 ppm in production wells. Levels in one well fluctuated from 26-70 ppm.

As noted elsewhere, two other small projects in northeastern Colorado, on ephemeral streams, the Frenchman and Plains-Arikaree projects, dropped out of the federal program, even with the 80% federal cost share, largely due to the high costs of monitoring.

ECONOMIC EFFICIENCY AND FINANCIAL FEASIBILITY

The costs for this project are much less than for projects in the High Plains Program. The availability of inexpensive recharge water and the lack of federal monitoring requirements allow much quicker, easier and inexpensive implementation of ground water recharge for agricultural purposes.

Project Costs and Cost Sharing

The total cost for the project was approximately $80,000, including $20,000 for a utility company to bury a natural gas pipeline that ran through the property. The remaining $60,000, the construction cost for recharge facilities, was paid by the State. Monitoring well costs are included in the construction cost. Beyond these start-up costs, fees related to the recharge water and other project operation and maintenance costs appear to be perhaps $8,000 to $10,000 per year. If recharge averages 2,500 to 3,000 acre-feet per year, the variable cost of recharge will be approximately $3.25/af. Irrigators will pay these variable operation and maintenance costs.

Project Benefits and Beneficiaries

The primary beneficiaries of the project are the landowners and irrigators with about 60 wells on over 1,000 acres. The water is used to irrigate relatively low-value feed crops. Irrigated land values range from $700 to $1,000 per acre. Besides securing supplemental water supplies, recharge raises ground water levels and reduces irrigation pumping costs, which can be significant.

However, the project also provides benefits for waterfowl and wildlife. The two recharge ponds provide seasonal wetland habitat. They are alternatively wet and dry, to allow for maintenance. The ponds support shad, perch and carp, along with various species of ducks, Canadian and snow geese, sandhill cranes, marsh hawks, gulls and beaver and coyotes.

Project Financing and Cost Recovery

Irrigators pay $17.50 per acre of cropland to the irrigation district for its normal operating

expenses. Irrigators pay $2.00 per acre-foot (a running water fee) to the ditch company for the recharge water (about $5,000-$6,000 per year). A ground water pumping fee of $1.50 per acre of land has been added as a special assessment to cover project operation and maintenance.

The state issues a ground water permit and the fee has been increased from $25 to $60 for new well permits in the project area as an additional assessment to help cover the costs of the project.

LEGAL AND INSTITUTIONAL ISSUES

No significant legal and institutional or state or federal environmental issues have been raised. Indeed, given the fish and wildlife habitat benefits, the project would appear to be a good example of a win-win situation.

However, there are serious concerns related to protection of instream flows for endangered species in the Platte River basin, and any project that would cause a net depletion during critical periods would face strong opposition.

CONCLUSIONS

The use of appropriate technology for recharge projects, such as the one in Julesburg, can provide cost-effective solutions for agricultural users.

Spreading basins generally appear to be a more feasible recharge option in agricultural areas than injection wells.

The use of existing infrastructure and inexpensive water supplies are keys to successfully implementing artificial ground water recharge for agricultural purposes.

The ready availability of institutional arrangements and entities with revenue producing authority are also important.

Restoration of native habitat and enhancement of wildlife benefits can be a significant benefit of artificial recharge projects that use spreading basins, whether planned or coincidental to the project.

LAS VEGAS VALLEY, NEVADA

BACKGROUND

In 1855, thirty men sent from Salt Lake City by the Mormon prophet Brigham Young, built a fort and established a settlement and mission at what would become Las Vegas. Along the old Spanish Trail to southern California, Las Vegas was an important stop, because it had water. The desert didn't lend itself to farming, but the settlement eventually grew due to mining and the railroad. In 1905, the Las Vegas Land and Water Company was formed to supply water for domestic use and railroad locomotives, from springs and ground water.[96]

Under the Colorado River Compact of 1922, Nevada's consumptive-use allocation is 300,000 acre-feet per year. Construction of Hoover Dam, on the Colorado River, began in 1931. Thousands of construction workers came to the Las Vegas Valley, and by 1944 ground water resources were dwindling. In 1947, the Nevada State Legislature authorized formation of the Las Vegas Valley Water District (LVVWD) and the piping of water from Lake Mead, behind Hoover Dam, to the valley. In 1954, the District completed the purchase of the old Land and Water Company.

Rapid population growth in the Las Vegas Valley was about 6% annually from 1986-95, which created corresponding increases in demands for water and domestic water hook-ups. The LVVWD is one of three municipal water providers in the Las Vegas Valley. It is the largest, now supplying about 70% of the area's water needs.[97] Residential use accounts for approximately 60% of the LVVWD's total demand (414,000 acre-feet in 1996), and averages 190 gallons per day (gpd), per capita, although average use in the Valley is 344 gpd because of tourism and other commercial uses.[98]

Today, about 15 percent of the Valley's water supply comes from ground water, with the remainder from Colorado River supplies. These supplies were projected to meet demands well into the next century, but annual increases in water demands and production peaked at 14-17% per year in 1988-89, causing near panic and redefining projections. Valley governments implemented conservation measures and other water use restrictions and began looking for new supplies to meet water needs after 2006.

In 1941, the Nevada State Engineer designated much of the Las Vegas Valley as a special ground water management area. Pumping peaked at almost 90,000 acre-feet per year, or about three times the natural recharge rate. However, no one wanted to make the hard choices related to restricting uses or developing alternative supplies. It took 20-30 years before many important changes were accepted.

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[96]Przybys, John, "Mormons Celebrate Pioneer Legacy in Local Celebration of Sesquicentennial," Las Vegas Review-Journal, June 19, 1997.

[97] Information based on interview with Las Vegas Valley Water District (Terry Katzer, Alan Bernholtz, and Nicholas Braybrook), January 11, 1993.

[98]Las Vegas Valley Water District, SNWA Resources Department, Nov. 1998

For example, in 1962, a newly built casino in Las Vegas applied for permits to drill a number of freshwater wells to irrigate a golf course. The State Engineer denied the applications and suggested effluent might be used, an unheard of recommendation! When he denied the applications a second time, after being ordered to approve them, he was fired![99]

The Southern Nevada Water Project was authorized by the U.S. Congress in 1965, and construction of the first phase began in 1968. Surface water deliveries from Lake Mead began in 1971. The second phase was completed in 1983.[100] Up to 500,000 acre-feet annually can now be diverted. Over the last 20 years, ground water overdrafting has been reduced by 25,000 acre-feet annually through active management, including enforcement of forfeiture statutes and ground water recharge.

Project Purpose

LVVWD's active and longstanding ground water recharge program is intended to allow full use of rights to surface waters of the Colorado River and the banking of any water surplus to current needs for future use. Ultimately, the objective of this and other water supply conservation and augmentation efforts is to be able to sustain a healthy area economy and avoid serious social and political consequences of limiting growth. Artificial recharge and conjunctive use of surface and ground waters will continue to be part of Las Vegas' long-term supply strategies. Providing water to meet peak demands is also an important purpose of the program, as is the storage of water for emergencies and drought.

Project Description

LVVWD has one of the largest deep-well artificial recharge systems in the United States. A demonstration program in 1987 was followed by initial recharge activities in 1988. In 1989, the first 1,100 acre-feet of recharged water was credited to the District. The District's ground water supply system includes 69 production wells and a total of 47 wells for artificial recharge. Twenty-eight of the production wells have been retrofitted for recharge and recovery (joint-use wells), and 19 wells are operated as dedicated artificial recharge wells. Four new joint-use wells are coming on-line in 1999.

Water Supply and Recharge

The Colorado River is the sole source of surface water for the Valley.[101] The Southern Nevada Water System brings water from Lake Mead. It consists of an intake on Saddle Island, treatment facilities, thirteen pumping plants, sixteen rate-of-flow control stations, a three-mile long main aqueduct, four-mile River Mountain Tunnel, and about 60 miles of distribution lines. The system is controlled by computer from the Alfred Merritt Smith Treatment Facility. The total construction cost was about $320 million. The system serves

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[99]"Water Supply Challenges for Southern Nevada," Western States Water Council minutes of a panel presentation held in Las Vegas, Nevada, on January 15, 1993.

[100]"Southern Nevada Water Project," Project Data [Book], Water and Power Resources Service (Bureau of Reclamation), 1981, pp. 1177-86.

[101]Southern Nevada Water System, pamphlet published by the U.S. Bureau of Reclamation.

North Las Vegas, Las Vegas, Henderson, Boulder City, Nellis Air Force Bases, and adjacent unincorporated areas in Clark County.

The Southern Nevada Water Authority (SNWA) now operates the system as a cooperative venture of all the above entities, which have pooled their Colorado River resources, regardless of priority dates, in order to maximize efficient use of Nevada's Colorado River entitlement. The District's ground water recharge and banking program is a vital component of SNWA's long-term management strategies for the entire area.

For example, the Mojave Powerplant on the Colorado River near Laughlin, Nevada is owned and operated by Southern Cal-Edison Power Company. It has a contract for the consumptive use of 23,000 acre-feet of water for cooling purposes. In return for the use of that water, which with return flows would amount to an estimated 41,400 acre-foot increase in the supply for Southern Nevada, the SNWA's purveyor members have agreed to ensure the plant a 20-year water supply. This will be accomplished through paper trades. When the powerplant must be supplied water from the ground water bank, the purveyor will withdraw one acre-foot from the bank for each acre-foot the plant withdraws from the river.[102]

The LVVWD's goal is to bank up to 350,000 acre-feet of water by 2007 for SNWA. Artificial recharge occurs during the off-peak period of October to May, through dedicated artificial recharge wells and through existing production wells that have been retrofitted for injection (joint-use wells) at system pressures (pressures vary from 10 to 105 psi at the well head). About 5,000 acre-feet per month are being recharged, with maximum volumes of greater than 6,000 per month occurring during low demand months in December and January. Injection rates range from 250 to 2,850 gallons per minute. The average injection rate is 1,100 gallons per minute. At the end of 1997, a total of 131,917 acre-feet of water had been banked using artificial recharge.

Water Quality

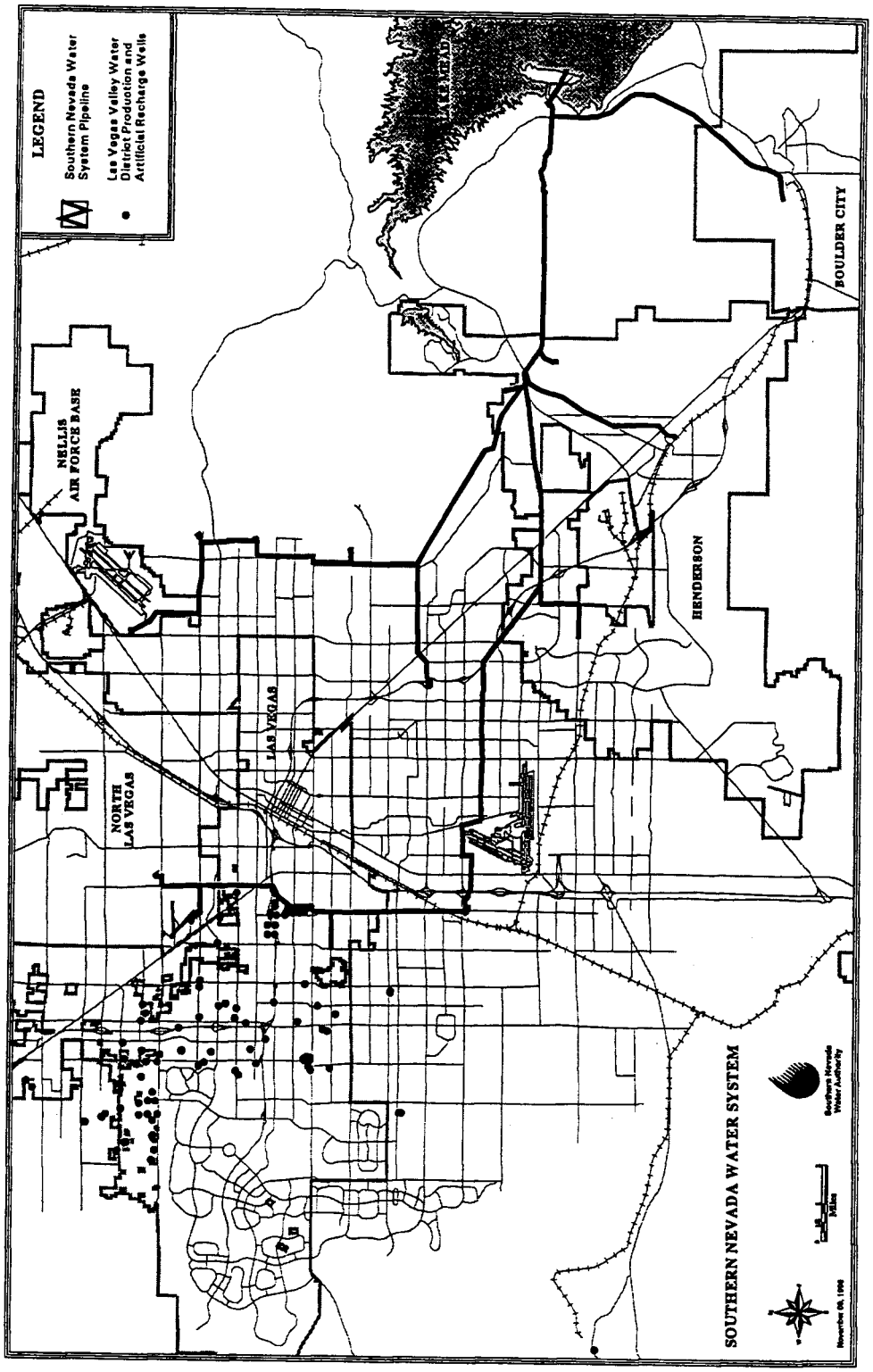
The water withdrawn from Lake Mead is treated to drinking water standards before use, using chlorine as a disinfectant, with ferric chloride as a coagulant and zinc orthophosphate as a corrosion inhibitor. Extensive water sampling requirements, for both the raw water supply and finished product, cover microbes, synthetic and volatile organic compounds, inorganics (including metals and non-metals), radionuclides and disinfection by-products (including trihalomethanes). The latter have been detected in ground waters following recharge but at acceptable levels.

There was some concern over the chemical compatibility of the recharged water and the native ground water. The local aquifer is characterized by calcium carbonates, which led to concerns over the possible precipitation of calcites and clogging of the recharge wells, but this has not been a problem. To date, no loss of production has been experienced. Water from the District's well field is retreated when recovered, but only disinfection is required before it is distributed. The following maps illustrate the location and extent of the Southern Nevada Water System and the Las Vegas Valley Water District's well field.

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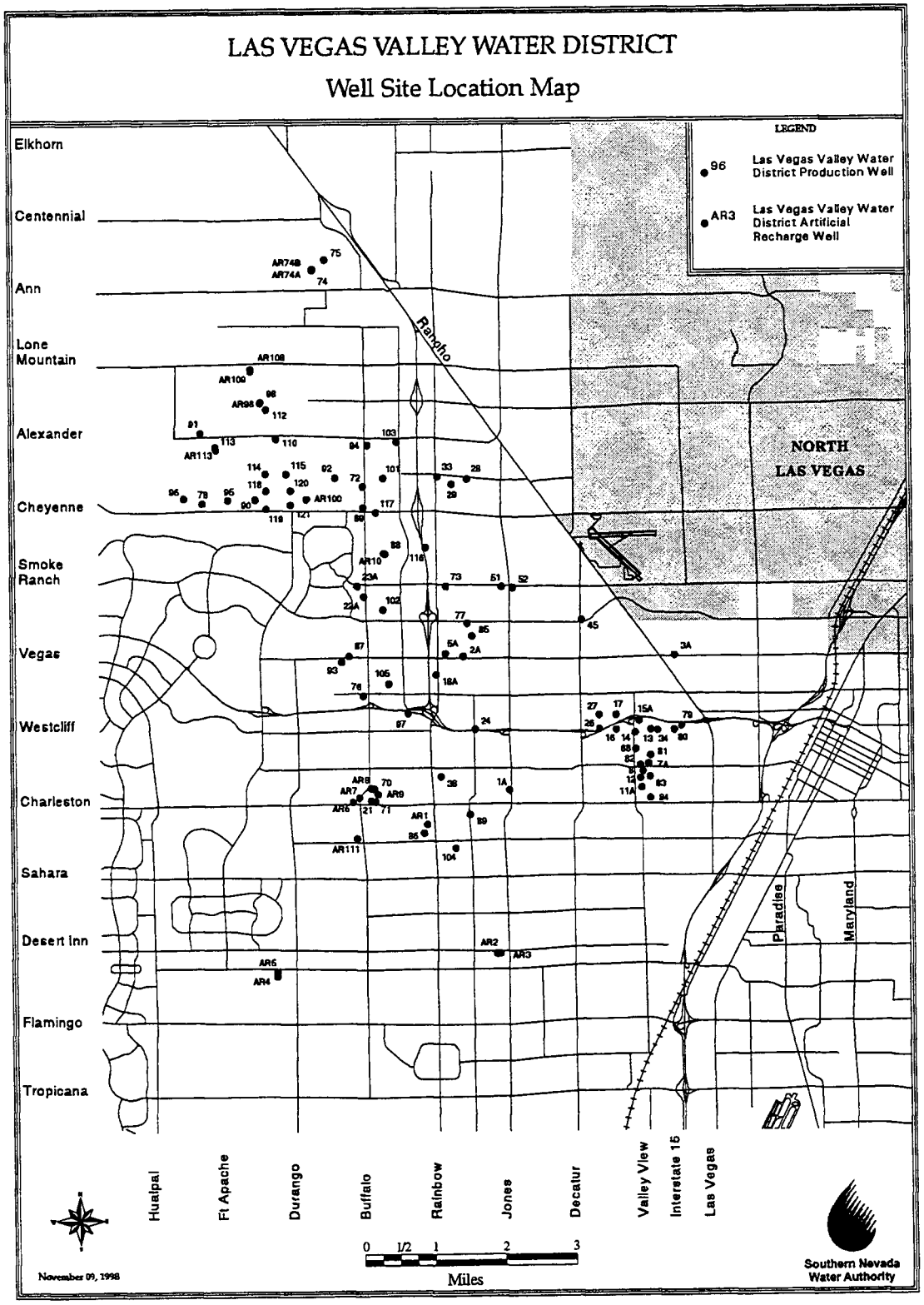
[102]"Water Supply Challenges for Southern Nevada," Western States Water Council minutes of a panel presentation held in Las Vegas, Nevada, on January 15, 1993.

Southern Nevada Water System



Source: Southern Nevada Water Authority, November 9, 1998

Las Vegas Valley Water District Well Field



Source: Southern Nevada Water Authority, November 9, 1998

ECONOMIC EFFICIENCY AND FINANCIAL FEASIBILITY

In the early years of the artificial recharge program, the LVVWD retrofitted 26 existing production wells for "joint-use," and thus was able to avoid significant capital costs for new construction. However, when more production wells were retrofitted for joint-use, a significant increase in clogging rates was observed in these newer wells. In order to minimize maintenance costs, LVVWD began constructing wells dedicated solely for artificial recharge. Of the nineteen wells dedicated for artificial recharge, only two were older wells (that were no longer in use for ground water pumping) retrofitted for recharge.

Project Costs and Cost Sharing

Total costs through 1992 for artificial ground water recharge facilities and capital, monitoring and analysis, and staff time were approximately $500,000. The production wells first retrofitted for recharge are gravity-fed, 20 inches in diameter and average 1,000 feet deep. Other significant costs include raw water from the Colorado River at $46.00 per acre-foot, energy costs, and water quality monitoring.

LVVWD's current annual injection capacity of 45,000 to 50,000 acre-feet has been achieved with a total investment of around $20 to $25 million. The total cost for recharging water, including both variable costs and average capital costs, has been about $230 per acre-foot. Average costs will continue to decline as additional water is recharged, spreading fixed costs over greater volumes of water.

Nevada Power, a private company, serves the project. SNWA is its biggest energy user, now pumping about 340,000 acre-feet of water from Lake Mead each year. Energy costs to pump Colorado River water are $.16 per 1,000 gallons during the off-peak period, October to May. This amounts to about $52 per acre-foot. SNWA's pumping costs during the summer peak period are $.24 per 1,000 gallons. The energy required to withdraw ground water costs about $.04 per 1,000 gallons. There is a net energy savings of about $.04 per 1,000 gallons of water recharged during off-peak seasons and later recovered and supplied by SNWA to its customers. LVVWD's ground water bank is a cost-effective, energy efficient means of meeting peak demands by avoiding the higher energy charges for pumping water from Lake Mead during the summer.

Only a small additional variable cost is associated with required monitoring and water quality testing and operation of the injection wells, about two to three cents per 1,000 gallons. Monitoring and analysis cost the District about $55,000 in 1991, including $25,000 on chemical analysis plus $30,000 for staff time. Monitoring costs have been reduced over time with experience as testing has shown uniformity of water quality parameters.

Other costs include those associated with securing state permits from the Nevada State Engineer's Office and Nevada State Engineer Department of Environmental Protection.

Project Benefits and Beneficiaries

The chief short-run benefit is the cost-effective delivery of peak-demand water during the summer from the District's well field without mining the ground water aquifer. The costs for meeting peak demands from the well field are less than those for pumping water from Lake Mead during the summer. The long-run

benefits are more difficult to quantify, but can be described as a more stable, reliable supply of water during droughts and other possible interruptions in surface supplies. Both LVVWD and SNWA benefit from the artificial recharge program.

There may be broader regional benefits, both economic and environmental, to the extent that using LVVWD's recharge capacity as a regional water bank and maximizing the use of Nevada's current entitlement to Colorado River water may delay the need to seek other sources of water. Importing more surface water and/or ground water from remote areas is not now a cost effective, nor politically, environmentally or institutionally acceptable and viable alternative.

Project Financing and Cost Recovery

Water use charges and connection fees make SNWA self-supporting. Further, LVVWD has bonding authority to undertake capital improvement projects, including any investments for dedicated recharge wells to expand the current programs capacity. All costs for LVVWD's recharge activities are paid by users according to their water use. Currently, LVVWD customers pay about $1.80 per 1,000 gallons of delivered water, which is an average rate, including fixed costs, charged across the system. The Southern Nevada Water System is a federal reclamation project, federally financed, with local repayment under federal law. The Bureau of Reclamation did provide a small amount of money for a ground water monitoring well in 1987, but not as part of its recharge demonstration program.

LEGAL AND INSTITUTIONAL ISSUES

In 1922, when the Colorado River Compact was signed and its waters were divided, no one envisioned the recent explosive growth in southern Nevada. The State of Nevada may withdraw about 450,000 acre-feet of water from the Colorado River, based on a consumptive-use allocation of 300,000 acre-feet per year. Not all the State's allocation is currently used, but will be by about 2006. Nevada's unused Colorado River allocation cannot be stored in Lake Mead, under the Law of the River, and is therefore "lost" downstream. LVVWD's recharge program allows the state to fully use its unused entitlement now, as well as any surplus water available in wet years, thus banking water to meet future needs.

State Water Law

The State of Nevada has regulated ground water use since 1939.[103] LVVWD has the majority of ground water rights in the Las Vegas Valley, about 40,000 acre-feet per year. Ground water was over allocated and severely over pumped in the Las Vegas Valley during the 1940's and 1950's. Since 1955, the state has issued revocable permits for ground water use and this practice was terminated only in recent years. Revocable permits were used as a means to continue to allow further development while the Southern Nevada Water System was constructed to bring surface water from the

[103]Western State Ground Water Management, Western States Water Council, October 1986, pp. 37-39.

Colorado River to the Valley. However, the state's current entitlement to that water supply is now being exhausted.

The perennial yield of the Las Vegas principal aquifer is estimated to be about 35,000 acre-feet per year, while total ground water withdrawals in the Las Vegas Valley reach 65,000 to 70,000 acre-feet per year, or nearly double the estimated perennial yield. As a result, the ground water system is overdrafted, while water use continues to be reduced through a combination of conservation and other efforts.

In 1998, artificial recharge will reach 30,000 acre-feet, and increase to 45,000 to 50,000 acre-feet per year, once transmission facility constraints are overcome. At the anticipated capacities, artificial recharge will result in a net recharge (artificial plus natural) of 90,000 to 95,000 acre-feet per year, which will likely sustain current ground water withdrawals without overdrafting the ground water system.

In order to accommodate and encourage Las Vegas recharge efforts, with the support of the Nevada Department of Conservation and Natural Resources, the state legislature enacted a specific ground water recharge statute in 1987.[104] It gives the State Engineer authority to regulate recharge and recovery activities. The source of water for recharge must be covered by existing rights and the amount recovered may not exceed that recharged. The applicant must demonstrate the amount that is recoverable.

Recharge project operations are regulated by procedures set forth in the statute, and an annual report must be submitted to the State Engineer. The project sponsor is responsible for demonstrating the hydrologic feasibility of a project and the amount of water that is recovered, while the State Engineer keeps track of recharge and recovery amounts through a project storage account. Recovery is regulated by the State Engineer to protect both the project sponsor and third parties. Permitted recharge and recovery activities may be limited, suspended or modified as necessary to protect prior water rights. Significant penalties may be imposed for project mismanagement.

In July 1997, the Nevada Legislature passed another bill requiring the Southern Nevada Water Authority to develop a program to manage ground water in the Las Vegas Valley. The primary goal of the program is to protect the local ground water basin from overdrafting as well as any potential sources of contamination. The importance of having a single authorized program is evident as there are a number of Valley well owners pumping ground water. The Las Vegas Valley Water District is the largest, but only one of many public and private entities, including about 5,000 domestic well owners. The Authority runs the program with input from a citizen advisory committee, which represents the various public and private well pumpers throughout the Valley. The program consists of education, conservation, an inventory of all existing wells, water level monitoring, water quality protection, and an investigation of opportunities for additional recharge.

Regional and Interstate Issues

Numerous potential new water supplies are being considered to help meet Las Vegas's burgeoning demands in the next 20-50 years. Projected needs for surface and ground water

[104]Nevada Revised Statutes, Sections 534.250 to 534.340.

diversions are likely to exceed 550,000 acre-feet by 2020. Some of the alternatives include importing significant amounts of new surface and ground water from a variety of sources. At the present, serious consideration has been given some potential sources of supply, including the Virgin River, the Moapa River Indian Reservation and the development of ground water filings in counties to the north.

SNWA has a number of future resource possibilities, including the "wheeling" of water from in-state tributaries to the Colorado, more Colorado River water banked in the Southern Nevada Groundwater Bank, Colorado River water banked in Arizona, managed surpluses of Colorado River water, Colorado River transfers and marketing, and construction of pipelines to import in-state tributary water and ground water from rural Nevada counties. At the moment, most of the Colorado River options face serious legal and institutional questions.

However, SNWA is convinced that these hurdles will ultimately be cleared and that southern Nevada's future water supplies will come from the Colorado River, through interstate transfers and ultimately through marketing, rather than through construction of pipelines. In any event, ground water recharge will continue to play an important role in helping address the water supply challenges in southern Nevada and in the Lower Colorado River Basin.

CONCLUSIONS

The Las Vegas Valley Water District's project has a much lower cost per acre-foot of water recharged than comparable High Plains Program projects.

These lower costs primarily are because of cost-effective capital investment for retrofitting an existing well field, relatively low monitoring costs, and economies of scale.

Operation and maintenance costs per acre-foot of water recharged also appear much lower than the costs for High Plains Program projects.

Monitoring costs are low relative to similar costs for High Plains Program projects.

Economies of scale are achieved by spreading monitoring, staff, and other costs over a large volume of recharged water.

The project successfully integrates a federal project, the Colorado River Storage Project, with local artificial recharge and recovery efforts.

The project is an example of the use of ground water recharge and storage opportunities to maximize efficient resource use.

Further, it is an example of the use of recharge opportunities to at least in part solve complex legal and institutional problems, and within such constraints effectively manage limited water resources.

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