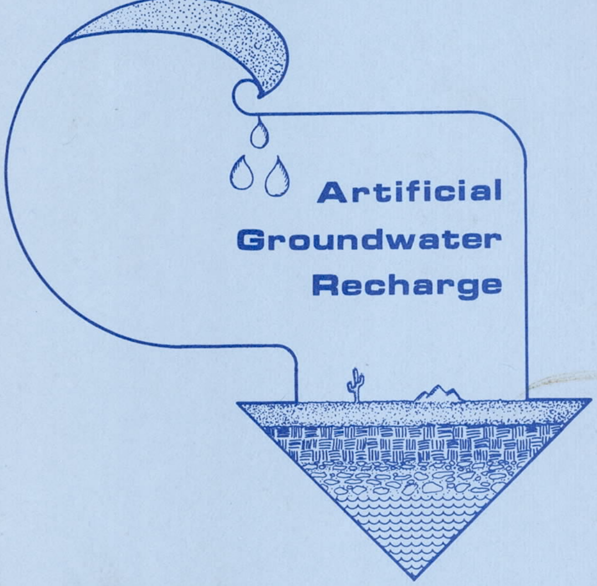
THIRD SYMPOSIUM ON ARTIFICIAL RECHARGE OF GROUNDWATER IN ARIZONA

May 20 & 21, 1987

Symposium Proceedings

"Let's get moving"



PUBLISHED BY:

Salt River Project
Phoenix, Arizona

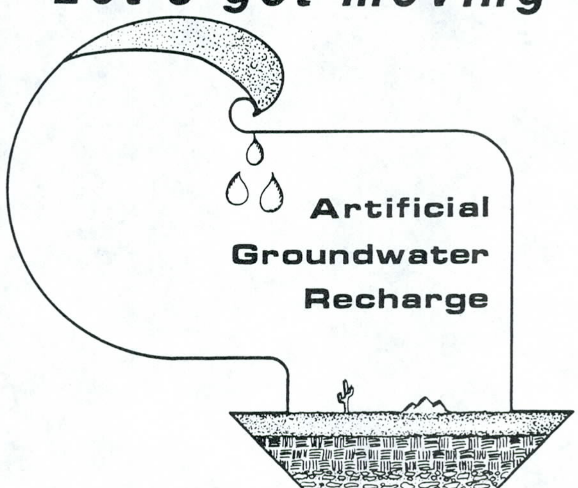
J. Lemmon

THIRD SYMPOSIUM ON ARTIFICIAL RECHARGE OF GROUNDWATER IN ARIZONA

May 20 & 21, 1987

Symposium Proceedings

"Let's get moving"



PUBLISHED BY:

Salt River Project
Phoenix, Arizona

TABLE OF CONTENTS

SESSION V: OPPORTUNITIES FOR RECHARGE
Moderator: Bill Wheeler
Central Arizona Project Assoc.

FOREWORD

The Groundwater Recharge Symposia in Arizona have progressed from skepticism in the first one (1978) to optimism in the second one (1985) and to a "let's get moving" theme in the third and present one (1987). As shown in these proceedings, the Third Symposium had ten papers on proposed projects in Arizona! Even in dry climates like Arizona's there can be water surpluses, including storm runoff, excess imported water (Central Arizona Project Aqueduct), and sewage effluent. Proper management and storage of these waters are important in meeting future water requirements. In arid areas, the time to prepare for water shortages is during water surpluses. Long-term storage of excess water is best achieved underground, through artificial recharge of groundwater. Many years of artificial recharge in California and other areas have established recharge as a dependable and successful practice. Systems for artificial recharge of groundwater are, however, very much site-dependent, and local investigations and experimentation often are required to formulate design and management criteria for optimum performance of the system. Water quality considerations are very important. As the recharge water moves through the vadose zone and aquifers, there can be positive and negative quality effects. Both must be considered in light of the quality of the water used for artificial recharge and the intended use of the water when it is pumped from the aquifer. Legal and institutional constraints can be more difficult to solve than technical issues. Artificial recharge of groundwater must be practiced for the common good of the public, with technical, legal, and regulatory people working together to achieve the best solution for our water problems. Let us hope that the next recharge symposium will have presentations on operational groundwater recharge projects in Arizona!

Herman Bouwer

GROUND WATER RECHARGE PERSPECTIVES FOR ARIZONA

SID WILSON, ASSOCIATE GENERAL MANAGER, WATER

SALT RIVER PROJECT, PHOENIX, ARIZONA

Recently I visited the City of San Antonio and it gave me some ideas related to artificial ground water recharge. I did not realize it, but San Antonio is the next largest city in the United States behind Phoenix. San Antonio doesn't have as large of a metropolitan area as Phoenix, but the city itself is about a million people. They claim that the "jewel" in city development is their water feature, the famed "river walk" of the San Antonio River. After being there only two days, I would hardly qualify as an expert on water matters in Texas or San Antonio, but my impression is that the river walk is indeed beautiful. There has been a tremendous amount of economic development centered around that water feature. It has been good for San Antonio. The whole city is revitalizing, but they really haven't gone far enough because the San Antonio River provides just the aesthetic backdrop for that economic development. The river's head waters develop a few miles outside the city, the water passes through the city and is not used in any way other than for the river walk, yet that city is solely dependent on ground water. At the same time, they are mining the ground water and ultimately, their pumping may jeopardize the flow of the San Antonio River. San Antonio may need to do a little planning, just as we are doing in the state of Arizona, to ensure that we have a dependable water supply for the future.

Let's look at the Arizona situation for a minute. History indicates that Senator Daniel Webster passed through this area in the mid-1800s. His observation was that this was a worthless area, a region of savages and wild beasts, of shifting sands, whirlwinds of dust, cactus and prairie dogs. His final observation was to question how we could ever hope to put these great deserts and endless mountain ranges to use. He saw little value to this area. Fortunately, there were other individuals with different visions.

The same country was seen with a different perspective by John Wesley Powell who saw the potential that could be realized with the development of water resources for this region. Today we are the beneficiary of his vision and similar visions of our own. I think we, as water resource planners, have a responsibility to carry that vision on, not only through the few remaining years of this century, but into the next century. How are we going to do that? We are going to have to do it through an effective, creative program of water resource management that conserves our ground water supplies. Artificial ground water recharge is one such opportunity available to us in Arizona.

This is the third symposium on artificial ground water recharge that we have had here in Phoenix in the last nine years or so. I remember the first symposium I attended in 1978. That seminar was a "get acquainted" seminar as I recall it. There were many of us who weren't that knowledgeable about ground water recharge and we wanted to know what it was, how it worked and where it was being done. To be honest with you, I think there was a lot of skepticism. I certainly was skeptical. It appeared to be too costly there didn't seem to be a good supply of water available for recharging or suitable recharge sites. Times change, needs and opportunities change, and people's perspectives change. There were some common beliefs about recharge, that in looking back, a good many of which were erroneous.

First, we thought that since agricultural lands were urbanizing in the Phoenix area there would be plenty of water to go around. Secondly, many people thought that the Central Arizona Project (CAP) was the answer to all our water problems and that it would provide a secure future for much of Arizona.

In 1980, Arizona passed a landmark law known as the Ground Water Management Act. It has been described as one of the toughest measures enacted in the nation. This law was passed because many individuals recognized that we were "mortgaging" our future by mining ground water supplies. This law mandates that we can no longer pump ground water as a routine source of water to meet our needs, thus it mandates conservation and provides for augmentation planning and implementation. Current studies on water supply and demand by the Salt River Project (SRP), the City of Phoenix and others, indicate that Arizona still could face the prospect of water shortages in the future. We are going to have to do a very effective job of managing our water resources to avoid those shortages or to minimize their impacts. We now have ongoing water rights adjudications for many rivers of the state including the Gila, San Pedro and the Little Colorado. When a settlement has been reached, the question of who has the right to pump water should be resolved. There are many claimants including the federal government, Indian tribes and non-Indians. When you total the claims, they greatly exceed the average water supply. It appears that there are going to be some shifts in water allocations, which will further complicate our ability to meet demands in the future.

So what are the benefits of artificial recharge for Arizona? Is it a viable tool to supplement water supplies? I think the answer is yes. With a great deal of effort and cooperation by Arizona's water management community, ground water recharge can be used as an effective tool to help us manage our resources in the future.

Ground water recharge is not a new subject in Arizona. One of the first recharge efforts was the Beardsley Project, where ground water recharge was conducted by Sol Resnick and co-workers at the University of Arizona in the early 1960s. This project was done in cooperation with the Beardsley Irrigation District, using water that was collected behind McMicken Dam, as runoff from the White Tank Mountains. The project studied recharge in a pit-type facility. Another project called Flushing Meadows was built in 1967 and consisted of six long, narrow infiltration basins, each about three-tenths of an acre in size. This test project was located in the Salt River bed, downstream of the 91st Avenue water treatment plant.

It was the first of two experimental projects initiated by Dr. Herman Bouwer and his colleagues at the U.S. Water Conservation Laboratory. The purpose was to study the applicability of wastewater renovation for use in agriculture, in essence, recharge as a method of wastewater cleanup. Unfortunately, Flushing Meadows was washed out in 1978, the first year in a long time that we had really large flows in the Salt River.

Based on the results of the Flushing Meadows recharge test, Dr. Herman Bouwer, in a cooperative effort with the City of Phoenix, built a much larger recharge demonstration facility downstream from the Phoenix 23rd Avenue Wastewater Plant in 1975. It was constructed with the intention of expanding the operation to a fullscale project.

Several other projects that are worth mentioning are the City of Phoenix's Cave Creek recharge project that will utilize a dual purpose recharge and recovery well to store and later recover CAP water. The City of Tucson has a recharge test facility located on the west bank of the Santa Cruz River near their new wastewater treatment facility. In addition, SRP, the City of Mesa, and others currently have recharge projects on their drawing boards.

The time for operational recharge programs is here. In my opinion, one of the major impediments to recharge operating was removed last year with the passage of ground water recharge legislation. That law provides for two types of recharge. The first type is recharge projects which are intended to replenish basin ground water supplies with no specific recovery rights accruing to the recharger. The water recharged becomes ground water and is administered under the state ground water law. The second type of recharge project is the underground storage and recovery project. The water in this case is stored for future recovery and use by the recharger. When recovered, the stored water retains the legal right of the water that was originally placed in the ground.

Some of the more specific criteria for obtaining recharge permits under the auspices of the Department of Water Resources (DWR) and the Department of Environmental Quality (DEQ) are listed below.

1. The applicant must demonstrate:

   - technical and financial capability to construct and operate a project.

   - a right to water that they propose to use and that the project is hydrologically feasible.

2. It must be determined that the:

   - project will not cause unreasonable harm to land or other water users within the area of hydrologic impact of the project.

   - applicant must have applied for any water quality permit that is required by the DEQ.

   - recovery wells must generally be located within the area of hydrologic impact to the storage projects.

RESEARCH NEEDS FOR WELL INJECTION SYSTEMS

By

Richard A. Randall
Water Resources Engineer
CH2M HILL
Tucson, Arizona

INTRODUCTION

Using well injection systems for artificial groundwater recharge is perhaps the most difficult of all the recharge methods both from a design and an operations viewpoint. Design criteria for the construction and operation of injection wells is scarcely available and conflicting design recommendations often exist between different sources. While numerous injection wells have been constructed and many are currently operating, the purposes for which they are used and the conditions under which they operate vary drastically from site to site. Design experience with large capacity injection wells for augmenting groundwater supplies is limited to a few locations. Consequently, the use of injection wells to recharge significant supplies of imported water here in Arizona will require detailed site evaluations and a moderate amount of research-oriented activities. The research would be conducted during site investigations and pilot scale studies to develop adequate design and operational experience for implementing large scale projects.

RELEVANT EXPERIENCE

The bulk of the experience with injection wells has been applications for oil field recovery enhancement, waste disposal, and aquifer thermal energy storage. Injection wells have played an important role in increasing the yield during oil field recovery operations. Water is injected at high pressures to facilitate the recovery of petroleum reserves. Deep well injection to dispose of various types of industrial and municipal wastes has also been used extensively. Disposal wells are typically completed into an isolated strata below the fresh water aquifer, if one exists, and injection rates are generally quite low. Aquifer thermal energy storage involves a pair of wells, one for supply and the other for injection. Water from the supply well passes through a heat exchanger and then returned to the aquifer for thermal storage through the injection well. Later in the season the injection well is pumped to recovery the latent heat stored in the aquifer.

With increasing frequency injection wells are being used to protect, manage, and augment groundwater supplies.

Injection wells have been used extensively along coastal areas to reduce the inland migration of saline waters. Projects in Southern California using treated effluent and imported water have successfully operated for many years. Projects in the southeastern United States inject treated water into brackish aquifers for seasonal storage. Recovery efficiencies at these projects have been very good. A project at El Paso, Texas injects tertiary treated effluent for augmenting the groundwater supplies.

Good documentation is needed from past projects to facilitate the planning and implementation of new projects. Detailed accounts of the site conditions and the factors influencing the success or failure of previous projects is helpful in developing design and operations criteria. Fortunately, some injection well experiments and projects have been well documented. The U.S. Geological Survey (USGS) has conducted numerous injection well experiments since the 1950's. Other projects studied by the U.S. Department of Agriculture (USDA) and several universities have provided valuable injection well experience. Some examples of well documented projects and a summary of their contributions to injection well technology are listed below.

Grand Prairie Experiments, Arkansas

One of the first USGS experiments with injection wells, conducted from 1955 to 1966. Experiments were conducted with two wells specially constructed for injection. The studies were able to identify clogging due to air entrainment and chemical precipitation. During these experiments different equipment configurations and methods were tried for injection, well redevelopment, and pretreatment of the silt laden recharge water.

High Plains Experiments, Texas

Numerous injection tests were conducted at various locations in Texas and New Mexico. Researchers investigated the feasibility of recharging runoff water from playa lakes into the Ogallala aquifer. Clogging due to sediments suspended in the lake water caused the most problems. In most cases, the sediments moved several feet into the aquifer and made redevelopment of the wells difficult.

Leaky Acres, Fresno, California

This project injected high TDS water received from a subsurface drain collector system. The construction of the recharge well provided enhanced redevelopment capabilities through controlled mining of the aquifer face during pumping. Pumping sand during redevelopment helped to remove the clogging materials.

Coastal Plains Wellfield, Israel

The Israeli's have 20 years of experience operating over 100 injection wells. They currently recharge about 80,000 acre-feet of lake water annually. They have developed practical methods for equipping dual-purpose wells and redeveloping them effectively.

Bay Park Experiments, New York

About 300 acre-feet of tertiary treated effluent was injected during these experiments. Clogging due to microbial activity and suspended solids was encountered even though the effluent was near potable quality. Geochemical reactions involving iron were also detected.

Wastewater Disposal, Oahu, Hawaii

Numerous hotel and condominium developments along the coastline are turning to injection wells for disposal of secondary effluent. About half of the 500 wells in operation experience severe clogging problems. A 2-year study was conducted to develop a better understanding of the clogging mechanisms and to find preventative measures. It was determined that air binding due to the release of nitrogen gas by denitrifying bacteria was the principal cause of long-term clogging.

OPERATIONAL LIMITATIONS

The operation of an injection well is the mirror image of a pumping well. Theoretically the head buildup during injection is the same as drawdown during pumping at a given flow rate. However, due to clogging, injection rates rarely exceed pumping rates and are usually less. Clogging is the major problem encountered during well injection. The degree of clogging is a function of the quality of the recharge water and characteristics of the receiving aquifer. The processes that cause clogging can be divided into four categories:

Filtration of Suspended Solids
Microbial Growths
Chemical Reactions
Air Binding

Filtration of Suspended Solids

Suspended materials in the recharge water can include minerals, colloidal particles, decayed organic matter, and microorganisms, i.e., bacteria and algae. Clogging due to suspended solids can occur even at low concentrations. Instances where significant clogging has occurred with less than 2 mg/l suspended solids have been reported when recharging into alluvial materials. Injection wells constructed into consolidated materials and fractured rock typically experience less problems with clogging from suspended solids.

From the available data it is not possible to predict rates of clogging due to suspended solids. From previous studies it appears there is little correlation between clogging rates and turbidity or total suspended solids concentrations. Apparently, there are other variables, i.e., particle size distribution, aquifer permeability, etc., that influence rates of clogging.

Microbial Growths

Bacteria can utilize nutrients contained in the recharge water as an energy source and their growth can contribute to clogging. Initially, these nutrients may be at low concentrations, but filtration at the borehole face tends to concentrate these materials and stimulate biological activity. A common practice is to chlorinate the recharge water (1 to 2 mg/l) prior to injection. The chlorine residual prevents active growth of the organisms during injection. However, if injection is interrupted for more than a day or so, the bacterial will flourish. The result is very turbid, foul smelling water during early pumping and redevelopment. Often high levels of bacteria will persist in the pumped water for days or weeks. In which case, the pumped water must be disinfected prior to customer deliveries.

Chemical Reactions

The chemical environment for in-situ groundwater and aquifer materials is near equilibrium. The introduction of recharge waters with a new chemistry can create significant chemical changes. These chemical changes can reduce the permeability of the aquifer due to precipitation or ion exchange processes. An increase in permeability can occur if the recharge water causes the dissolution of aquifer minerals.

Disturbing the chemical equilibrium of certain minerals can result in precipitation. One of the most significant is calcite (Calcium carbonate) since calcium and bicarbonate are major constituents in native waters. Calcite equilibrium is sensitive to the concentration of dissolved carbon dioxide (CO_2) contained in the water. Several instances have been reported where calcite precipitation has occurred during injection.

Ion exchange processes can cause swelling or dispersion of clays that result in reduced permeability. Calcium rich clays can be converted to less permeable sodium clays through ion exchange. Another process is the solution of aquifer minerals that results in the formation of new minerals. Figure 1 is an electron micrograph of some dirty calcium rich sand grains. The star shaped features are gypsum crystals that have formed on the sand grains. The formation of minerals within the aquifer matrix can reduce porosity and permeability. The mineral crystals also have a tendency to break off and further plug pore spaces during injection.

Air Binding

Air binding is caused by a concentration of tiny gas bubbles contained within the interstices of the aquifer matrix that causes a decrease in permeability. Gases can be introduced into the aquifer through several pathways. Entrained air in the recharge water has often been reported as a cause of clogging during injection. Air entrainment is typically caused by allowing the recharge water to cascade inside the well. To eliminate air entrainment, the recharge water must be introduced below the water table under positive pressure. Gases can also be released within the aquifer by dissolution due to a decrease in pressure or an increase of temperature. Biochemical processes can release gases sufficient to cause air binding. Air binding due to nitrogen gases released by denitrifying bacteria has also been reported.

SITE INVESTIGATIONS AND MODELING

Important tasks to be conducted during initial site investigations should include a thorough investigation of aquifer characteristics, an evaluation of the potential for geochemical reactions, and a determination of applicable methods for equipping the injection well. Performing these tasks will help insure long-term operational success of an injection well project.

Aquifer characteristics to be determined include not only hydraulic parameters, i.e., transmissivity, specific yield, porosity, etc., but information on aquifer mineralogy, lithology, and in-situ water quality is also needed. Modeling the response of the aquifer system to recharge will help determine the hydrologic impacts and storage capabilities of the aquifer. Various analytical techniques as well as sophisticated computer models are available for these

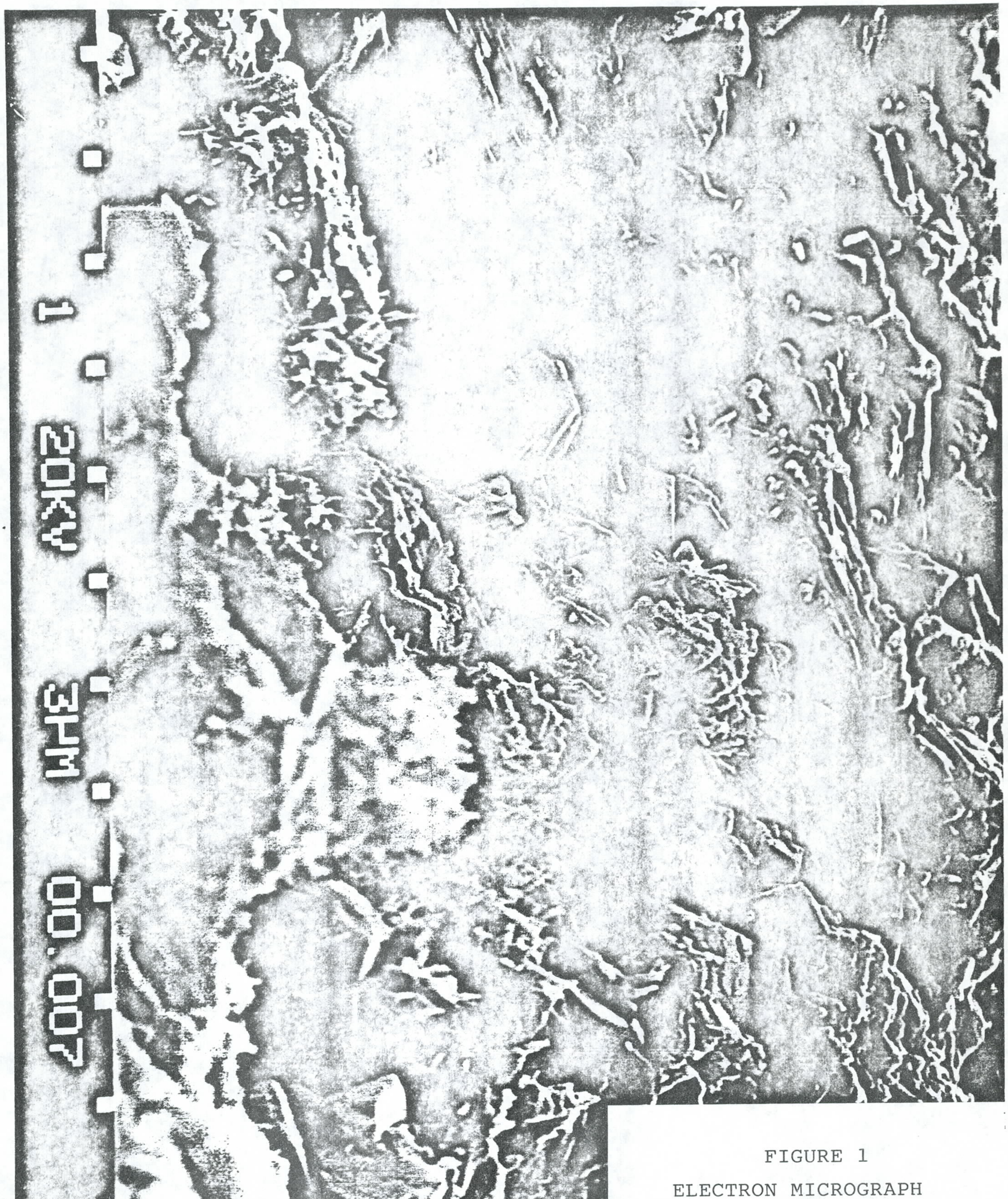


FIGURE 1

ELECTRON MICROGRAPH
OF CARBONATE RICH SAND
WITH GYPSUM CRYSTALS

analyses. Water quality and mineralogy data are used to investigate the existing geochemistry and the potential for adverse geochemical reactions during recharge. The USGS has computer-based models, WATEQF and PHREEQE being the most commonly used, available for analysis of mineral stability and chemical equilibrium. The PHREEQE model is especially useful for examining the effects of mixing differing waters. For detailed mineralogical studies of drill cuttings, there are x-ray diffraction analyses and electron microscopy techniques available.

The specific configuration of above ground piping and downhole injection facilities needs attention early in the feasibility studies. There are many options available and also certain equipment limitations that must be considered. Determination of the appropriate equipment and system configurations can impact project feasibility. Particularly, where existing wells are retrofit for injection, the size and construction of the well, depth to water, injection and pumping rates, and the redevelopment requirements must be factored into the equipment needs. An example of the piping arrangement for an injection well with a vertical turbine pump installed for pumping/redevelopment is shown on Figure 2. In this example, the recharge water can be discharged both into the well annulus and through the pump discharge head down the pump column pipe. The design flow rate will determine whether one or both of these discharge options is needed. A flow control valve is shown upstream of the well discharge head to regulate the recharge flow rate into the well. Figure 3 has examples of some options for discharging/regulating the recharge flows downhole. The options shown in Detail A include an air operated control valve on the pump column and a flow restricting collar on the pump column pipe. The restriction created by the collar maintains a positive pressure above the water table. To use the flow collar requires a strong, water-tight well casing with no perforations above the water table. Detail B shows a modified check valve on the pump column and a conductor pipe contained within the well annulus with a flow restrictor on the end. Some wells will not have sufficient clearance in the well annulus to place conductor pipes.

PILOT STUDIES

Pilot studies are needed to develop design criteria and to gain operational experience before implementing a large scale project. The specific behavior of injection wells is dependent on actual site conditions, equipment configurations, and the quality of the recharge water. The experience gained during pilot studies includes determining reliable injection rates, workable equipment configurations,

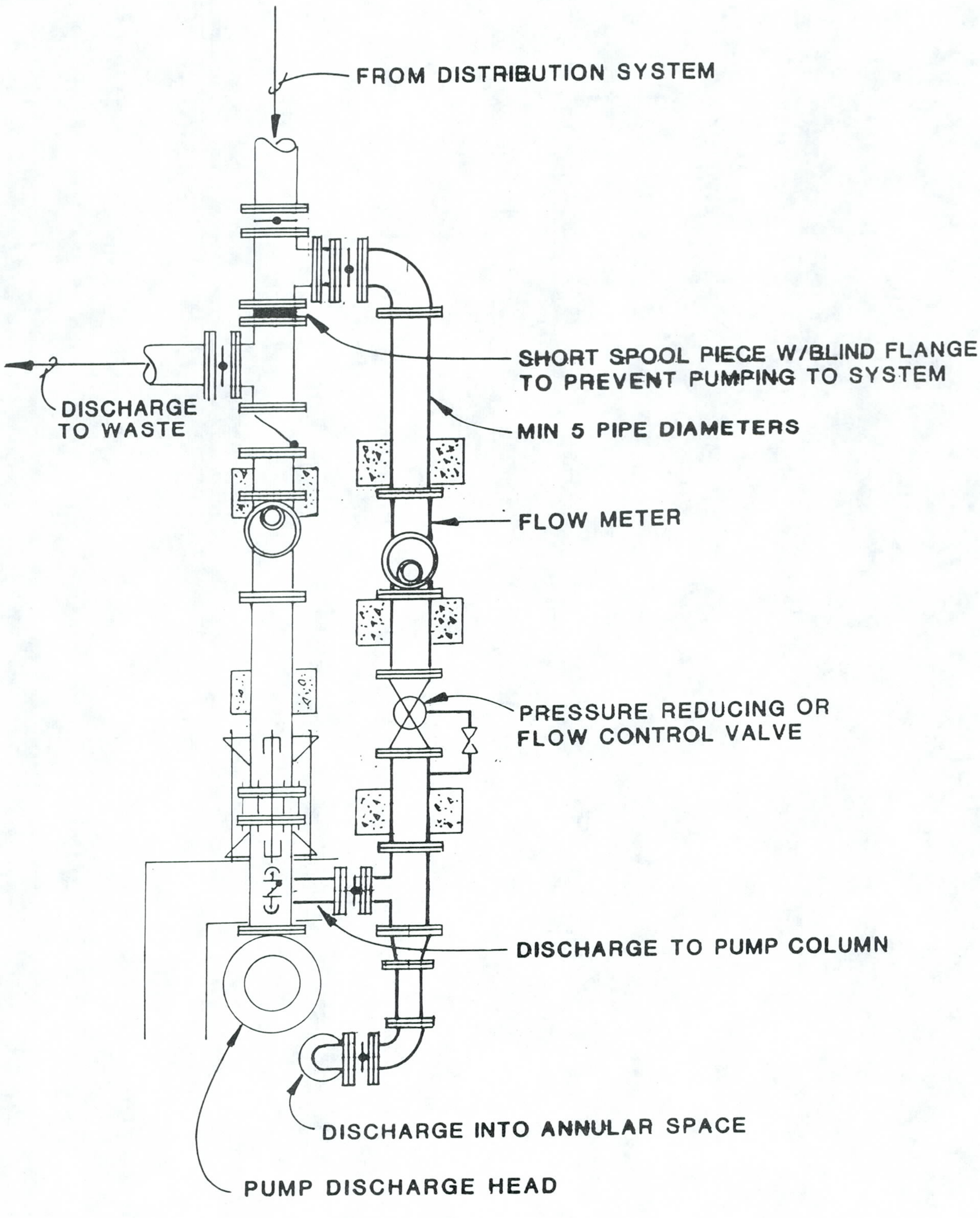


FIGURE 2

RECHARGE WELL PIPING WITH VERTICAL TURBINE PUMP

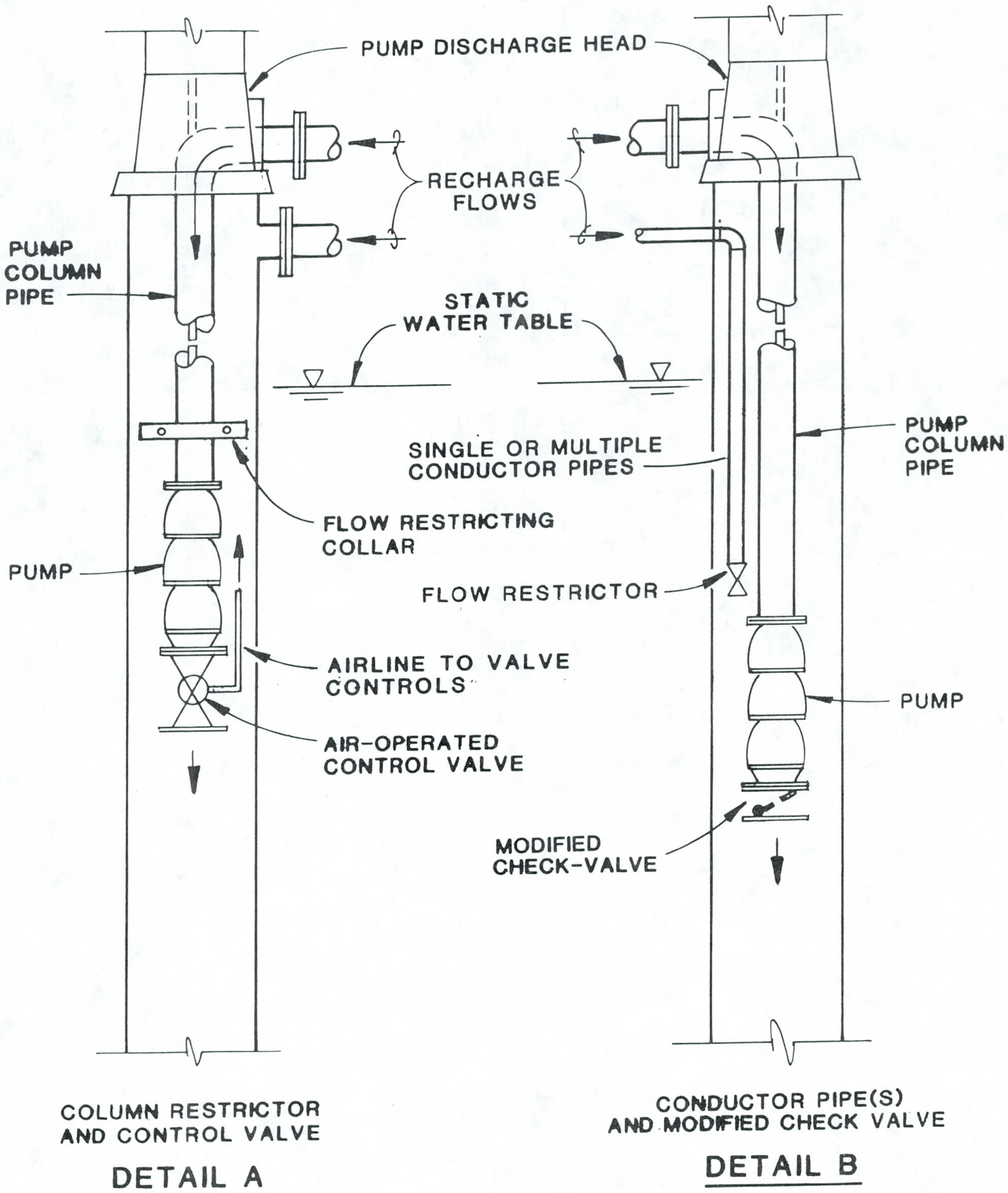


FIGURE 3

OPTIONS FOR WELL DISCHARGE WITH VERTICAL TURBINE PUMP rates of clogging, appropriate methods and time intervals for redevelopment, impacts on water quality, and response of the aquifer system. A detailed operations plan and monitoring program is needed during the pilot studies to insure that the appropriate data is collected and analyzed. The length of time required for pilot studies will vary depending on the needs of the project, but six months is probably a minimum. Much of the data to be collected requires that the facility be continuously operated for a long period of time to produce measurable impacts and establish trends. Operations during pilot studies provide the opportunity to experiment with different equipment configurations and to try out a variety of operational schemes. The objective is to find ways of optimizing the system operations to maximize recharge rates while minimizing the redevelopment requirements. While pilot studies certainly will not provide all the answers, the experience gained will go a long ways towards reducing the operational headaches and minimizing costs on a large scale project.

RAR1/59:jk

REFERENCES

CH2M HILL, Task 2: Literature Review, Volumes 1, 2, and 3, Phase A, Tucson Recharge Feasibility Assessment, 1987.

CH2M HILL, Task 3: Research of Water Quality Requirements for Recharge, Phase A, Tucson Recharge Feasibility Assessment, 1987.

CH2M HILL, Task 4: Evaluation of Existing Water System and Wells for Recharge of Treated CAP Water, Phase A, Tucson Recharge Feasibility Assessment, 1987.

CH2M HILL, Task 6: Prioritize Water Sources for Potential Recharge Sites, Phase A, Tucson Recharge Feasibility Assessment, 1987.

NOTE: This paper is brief synopsis of the information developed on recharge with injection wells during the Tucson Recharge Feasibility Assessment, Phase A. For a more thorough discussion of this topic and a complete bibliography of original references, the reader is referred to the report documents listed above.

Richard A. Randall
CH2M HILL
310 South Wilmot, Suite B-210
Tucson, Arizona 85711

(602)748-9144

BIOGRAPHICAL SKETCH

Rich Randall is a Water Resources Engineer with CH2M HILL in Tucson. A native Arizonan, Mr. Randall has been with CH2M HILL for 9 years and has been working on wastewater reuse and groundwater recharge projects in Arizona for the last 4 years. His current responsibilities include the Tucson Demonstration Recharge Project and task leader for water quality considerations and injection well options for the Tucson Recharge Feasibility Assessment. He is a registered Civil Engineer and is currently pursuing a graduate program at the University of Arizona which includes geochemistry, water treatment, and hydrogeology. His ongoing research effort is to investigate the impacts on water quality during artificial groundwater recharge.

TSC5/018

RESEARCH AND DEMONSTRATION NEEDS FOR ARTIFICIAL RECHARGE OF GROUND WATER WITH INFILTRATION BASINS

Herman Bouwer
United States Department of Agriculture
Agricultural Research Service
U. S. Water Conservation Laboratory
Phoenix, Arizona 85040

Abstract

In dry climates, natural replenishment rates of aquifers (safe yields) are quite small. Many of these aquifers are being depleted. This is giving rise to an increasing interest in artificial recharge of ground water or ground water augmentation. While artificial recharge with infiltration basins is an established practice, there is still not enough information available to optimize the design and management of such systems. The new program on demonstration projects under the High Plains States Ground Water Demonstration Project Act of 1985 provides an excellent opportunity for additional research. Projects should be selected to cover a range of conditions so that the results form a broad data base that can be used to develop design and management criteria for other projects. Other techniques for augmentation of ground water, in addition to well injection, include vegetation management, runoff enhancement, and increasing seepage from streams.

Demonstration Projects for Infiltration Systems

The passage in 1983 of the High Plains States Ground Water Demonstration Project Act (PL98-434) has stimulated interest in demonstration projects for artificial recharge of ground water. The law will authorize and support twenty-one demonstration projects in the High Plains states (Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming) and other western states (California, Arizona, Idaho, Montana, Nevada, North Dakota, Oregon, Utah, and Washington). Demonstration projects are also desirable in states where the law does not apply if there is a need for underground storage of water or replenishment of aquifers.

Demonstration projects for infiltration basins should involve more than constructing a basin, filling it with water, and, when the water disappears at a pretty good rate, declaring the demonstration a success! In reality, there is still a lot of research to be done before the design and management of systems for artificial recharge of ground water can be optimized. Demonstration projects should incorporate as much of these research needs as possible so that a data base can be compiled that will permit best design and management practices for a wide spectrum of conditions of soil, climate, water quality, and ground water hydrology. Some of the more critical research needs are listed in the following paragraphs.

Prediction of Hydraulic Loading Rates

It is often desirable to have some idea of hydraulic loading rates (long-term hydraulic capacity of basin, usually expressed as accumulated infiltration per year or per recharge season) before an artificial recharge system is installed. For example, a city or other entity may want to recharge 20,000 acre feet per year (25 million m^3/yr) and needs to know approximately how much land may be required to get the water underground, or a city or district may have 500 acres (200 ha) of land available for ground water recharge and would like to know about how much water that land could take for artificial recharge of ground water, or a water district may just wish to get some idea about the feasibility of artificial recharge without putting up much money for preliminary investigations or pilot projects.

To see how well hydraulic loading rates can be predicted, demonstration projects should be preceded by a program of hydraulic conductivity and/or infiltration measurements at the site. This will permit calculation of potential infiltration rates for the infiltration basins. Allowing for some reduction in these rates due to clogging of the bottom of the basins and for dry-up times for a restoration of infiltration rates and possibly cleaning operations, then permits calculation of the hydraulic loading rate in, for example, feet per year. This figure would then be compared later with hydraulic loading rates observed for the actual infiltration basins after they have been in operation for some time. If this is done for enough different soils, climates, and water qualities, prediction of hydraulic loading rates of recharge systems from soil permeability and infiltration measurements may prove to be a reliable procedure.

Basin Management for Maximum Performance

As a rule, infiltration rates in recharge basins decline with time of inundation because of sedimentation of suspended solids and biological activity which clog the bottom. Usually, once the basins are installed, some experimentation is needed to find the optimum combination of flooding and drying cycles and the need for cleaning and possible disking of the basin bottoms during drying. If flooding is continued too long, not enough water enters the ground anymore. Drying the basins is necessary for restoring infiltration rates, but, of course, during drying, no infiltration occurs. Thus, there is an optimum combination of flooding, drying, and cleaning the basins that has to be determined experimentally. Sometimes, flooding and drying cycles are controlled by environmental factors, such as breeding cycles of mosquitoes, midge flies, or other insects, or growth of algae or weeds in the basins.

Optimum Water Depth

Theoretically, increasing the water depth in infiltration basins will have little effect on sustained infiltration rates if the bottom of the basin is clean and unclogged (provided, of course, that the bottom of the basin is well above the ground water level). If the bottom is clogged, increasing the water depth will produce an almost linear increase in infiltration rate. However, increasing the water depth will also compress the clogged layer due to an increase in the seepage force across this layer. This will reduce infiltration rates. Also, increasing the water depth without a proportional increase in infiltration rate will diminish the rate of turnover of the water in the basin, exposing the water longer to sunlight and increasing the opportunity for growth of suspended algae in the water. These algae filter out on the bottom and form a filter cake, which greatly decreases the infiltration rate. In addition, heavy growth of algae can cause precipitation of calcium carbonate due to an increase in pH of the water as the algae remove carbon dioxide from the water for photosynthesis. This precipitation of calcium carbonate further increases the hydraulic impedance of the clogged layer on the bottom. Thus, there may be the paradoxical phenomenon that increasing the water depth in infiltration basins for ground water recharge will actually decrease infiltration rates. The water depth for maximum infiltration depends on water quality, climate, and type of bottom soil, and is best found by on-site experimentation.

Pretreatment of Water

If the water for ground water recharge has a relatively high sediment content, the suspended solids can be taken out before the water enters the infiltration basins, or they can be allowed to accumulate on the bottom of the basins. Removal of suspended solids before entry of the water in the infiltration basins costs money because it usually requires addition of coagulant, mixing, and sedimentation ponds. Leaving the solids in the water and letting them accumulate on the basin bottoms also costs money because of decreased hydraulic loading rates and the need for more frequent cleaning of the basins. The economically optimum combination of pretreatment of water and cleaning and drying of the basins can be determined only by on-site experimentation.

Stagnant vs. Flowing Water

Horizontal velocities of water in infiltration basins are very small or almost zero, and the water is essentially stagnant. Thus, all suspended solids in the water can settle out on the bottom of the basin, including the very fine particles. Such particles can greatly increase the hydraulic impedance of the clogging layer and greatly reduce the infiltration rates. If, on the other hand, the water is kept flowing horizontally, as in infiltration channels, fine sediment may be kept in suspension and will not contribute as much to the clogging problem as in stagnant basins. The question of whether an infiltration system would consist of flowing water in channels or of stagnant water in basins must be answered by local experimentation.

Significance of Best Management

Optimum design and management of an infiltration system for artificial recharge of ground water can yield hydraulic loading rates that are considerably higher (two, three, four, or five times higher and maybe even more) than the rates obtained with haphazard design and management of the basins. Maximizing hydraulic loading and the necessary on-site experimentation are especially important where suitable land for infiltration is limited and/or expensive.

Vadose Zone

Ground water recharge demonstration projects should also include studies of the vadose zone, primarily to detect presence of restricting layers and perched ground water that could restrict infiltration for the full-scale project. The work could consist of measuring the hydraulic conductivity profile of the soil and of soil exploration before construction of the basins. Water content profiles beneath the infiltration basins can be measured with, for example, the neutron method (saturated zones indicate perched ground water and semipermeable restricting layers). Piezometers and tensiometers can be installed to measure positive or negative water pressures at various depths.

Another item of interest in the vadose zone is the amount of water that has to be "invested" in the wetted zone below the infiltration system. If, for example, the water content is 10% by volume in the original vadose zone and 30% in the wetted zone below the basins, 2 feet (0.6 m) of water need to be invested in the wetted zone for every 10 feet (3 m) of depth of the ground water table below the basin bottom before the recharge water reaches the aquifer. Thus, if the water table is at a depth of 300 feet (90 m), 60 feet (18 m) of water must infiltrate before recharge of the aquifer can begin. If the hydraulic loading rate is 300 feet (90 m) per year and the projected duration of the project is 20 years, the total infiltration will be 6,000 feet (1800 m), of which 60 feet (18 m), or 1%, are "stored" in the vadose zone. This yields a recovery efficiency of 99%. In the long term, however, most of the water in the wetted zone will eventually drain back to the aquifer if ground water recharge is ceased. The only "true" losses from the system are evaporation losses from the basins. This is on the order of 6 feet (1.8 m) per year in the Phoenix area for a free water surface or continuously wet soil, and less in cooler, more humid areas.

Ground Water Mound

The demonstration project should also include monitoring wells to measure the rise of the ground water table below the infiltration basins. From this rise, an effective transmissivity of the aquifer for ground water recharge can be calculated with Hantush's or Glover's equations (Bouwer, 1978) and used in the design of the prototype system. For thick aquifers, ground water recharge flow will not be uniformly distributed across the entire thickness of the aquifer. Most of the flow in the vicinity of the basins will occur in the upper or active region of the aquifer, while ground water deeper in the aquifer moves a lot slower (passive region). Thus, the effective transmissivity for ground water mound calculation below recharge basins may be significantly less than the transmissivity of the entire aquifer, as evaluated from a pump test on a completely penetrating well. Studies with an electrical resistance network analog have shown that the thickness of the active portion of the aquifer is about equal to the width of the recharge basin or infiltration area (Bouwer, 1962).

The ground water table response in the demonstration project can be used to predict the ground water table response in the full-scale, prototype project, including ground water levels at great distances from the infiltration basins. Basin geometries and layouts can then be selected to avoid undue ground water mound rises below the infiltration basins. If there is a natural ground water gradient in the area, the projected mound can be superimposed (Bouwer, 1978) on the moving ground water system, yielding a ground water ridge instead of a ground water mound. If there are pumped wells, recharging streams, deep percolation flow, and other sources or sinks in the area affected by the recharge system, ground water level responses in the region can best be predicted with a computer model using the Prickett-Lonquist or other aquifer simulation model.

Water Quality

The main quality concern is with the input water. Depending on the source of this water, complete chemical analyses may be desirable. Bacteria and viruses should also be determined. Some undesirable constituents, including microorganisms, can be effectively removed from the water as it moves through the vadose zone and through the aquifer (Bouwer, 1985).

From an infiltration standpoint, the most important water quality parameters are suspended solids, sodium adsorption ratio (SAR), and total salt concentration (TDS). The SAR and TDS content determine the status of the clay in bottom sediments or original soil below the infiltration basins through which the water flows. The lower the TDS and the higher the SAR, the more the clay will be dispersed and the lower the hydraulic conductivity, K, and hence, the infiltration rate will be (Bouwer, 1978, p. 44).

Another matter of concern is leaching of toxic substances from the vadose zone due to downward percolating water. In addition to calcium, which would increase the hardness of the water, toxic trace elements may also leach out. The selenium problem in California is a good example of what can happen. Selenium leaching apparently is not confined to California and is much more widespread than previously thought. Other toxic trace elements that could be leached from vadose zones include arsenic, boron, cadmium, molybdenum, and mercury. Monitoring wells for taking water samples from the top of the ground water mound and farther away in the aquifer should be installed. Problems of leaching chemicals from vadose zones tend to be more severe for relatively fine textured materials in vadose zones that have no history of frequent natural leaching, than for sandy or gravelly formations in river beds or flood plains that have already been regularly leached for a long time.

Environmental, Social, Economic, and Legal Aspects

In addition to engineering and chemical aspects, demonstration projects should include research on the environmental aspects, such as relations between infiltration basin management and insect, algae, and odor problems. Social aspects to be considered include multiple use of the basins (recreation, wildlife, scenic enhancement, aesthetics) and community acceptance. Economic aspects, of course, are always important. Legal issues may arise as to the ownership of the input water, the rights of pumping recharged water from the aquifer, who benefits, who pays, and who administers the project.

Other Techniques for Groundwater Recharge Enhancement

Other methods for augmenting ground water resources include vegetation management, runoff inducement, and increasing seepage from streams by increasing the wetted width of the channel or lowering the ground water level in the flood plain. Vegetation management for augmenting ground water recharge normally consists of replacing trees or other deep-rooted vegetation with grasses or other shallow-rooted vegetation. This can produce more runoff and cause ground water levels to rise, sometimes with undesirable effects like the mobilization of salt from the vadose zone in parts of Western Australia. Higher ground water levels could also lead to more seeps, springs, or base flow in gaining streams. This flow could be conveyed to areas of lower ground water levels for aquifer recharge.

Runoff inducement is accomplished with water harvesting techniques where soil is covered or treated to minimize infiltration (Frasier and Myers, 1983). This produces runoff from small rains which normally would wet only the top portion of the soil profile and be returned to the atmosphere via evapotranspiration during the next few days. The treated areas could be in small catchments, or as strips between benches or furrows in a terrace-type layout (Fink and Ehrler, 1986). The runoff water produced by water harvesting systems can be infiltrated on site, or conveyed to channels or basins for ground water recharge.

Increasing the wetted width of losing streams or other channels can be accomplished by levees or low dams (weirs) across the streambed, or by installing longitudinal and transverse levees in the flood plain to create off-channel basins, as done in the Santa Ana River in Orange County, California.

Ground water levels in flood plains of losing streams can be lowered by drilling wells and pumping ground water for irrigation or other use in the flood plain or use elsewhere. Lowering the water table can have two effects: (1) it can reduce water use by vegetation in the flood plain, especially the deep-rooted vegetation that lives off the ground water (phreatophytes), and (2) it can increase the seepage from the stream. Phreatophytes can consume copious amounts of water. In the western USA, for example, phreatophytes are estimated to occupy about 6.4 million ha (15 million acres) of flood plain area and to use about 30,000 million m^3 (25 million acre feet) of water per year (Bouwer, 1975, and references therein), or about one-and-one-half times the entire flow of the Colorado River! While eradication of phreatophytes was the indicated solution a few decades ago, environmental and aesthetic concerns now preclude such an approach. Possibly, water use of phreatophytes can be reduced without killing them by lowering ground water levels in the flood plain (Figure 1). There is, however, very little field information available showing how much the water use of phreatophytes can be reduced by lowering ground water levels (Bouwer, 1975). Hopefully, new developments in remote sensing of evapotranspiration can be used to obtain more data on this (Jackson, 1985; Jackson, et al. 1987).

Graphs of seepage from losing streams as a function of ground water level for different water depths in the stream and different geologic conditions were developed by electrical analog and are shown on pages 273 and 274 of Bouwer (1978). The curve for a uniform soil to great depth and a channel with a water depth equal to 0.25 of the bottom width is shown in Figure 2 where

I_s = seepage rate per unit area of stream water surface (m/day)
K = hydraulic conductivity of soil (m/day)
D_w = depth of water table below water level in stream at 10 W_b from stream center
W_b = bottom width of stream

The curve applies to a trapezoidal channel with 1:1 side slopes. Furthermore, there is no sediment or other clogging material on the wetted perimeter so that there is a direct hydraulic connection between the water in the stream and the underlying ground water (Bouwer, 1978). The graph shows that lowering the ground water table in the flood plain causes a linear increase in seepage when D_w is less than about 2 W_b. Then the rate of increase in seepage with increasing D_w becomes smaller, and when D_w has reached a value of about 4 W_b, the seepage is already close to the seepage obtained when $D_w = \infty$. Thus,

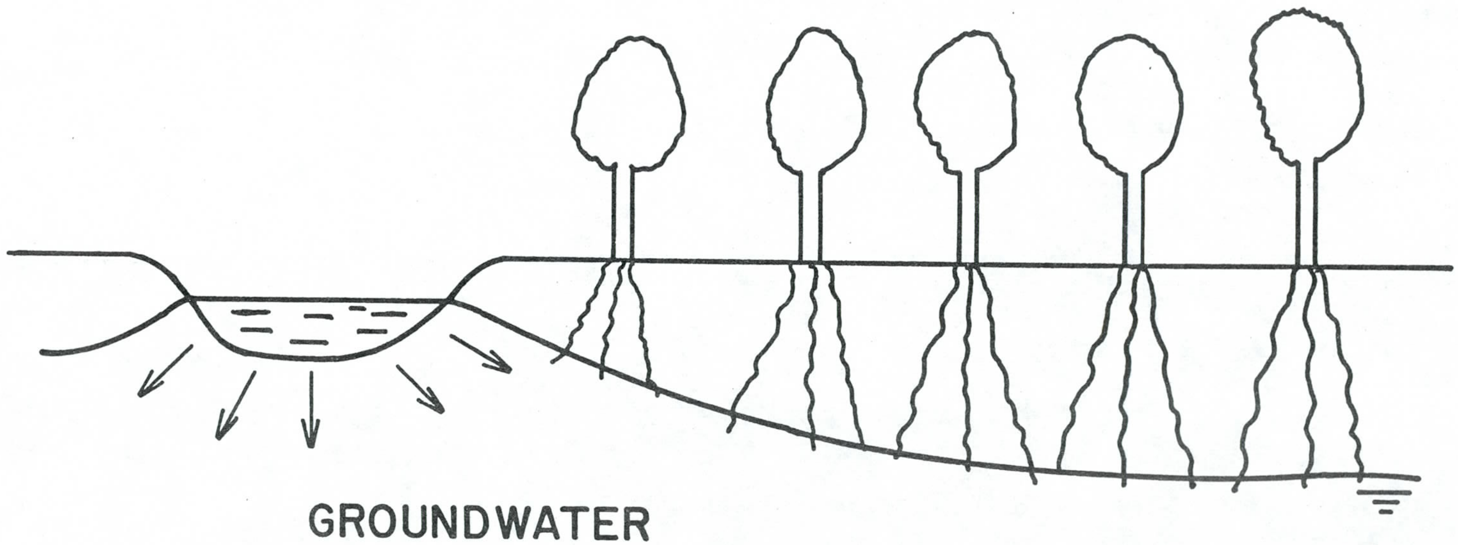


Figure 1. Schematic of seepage flow system with phreatophytes in flood plain.

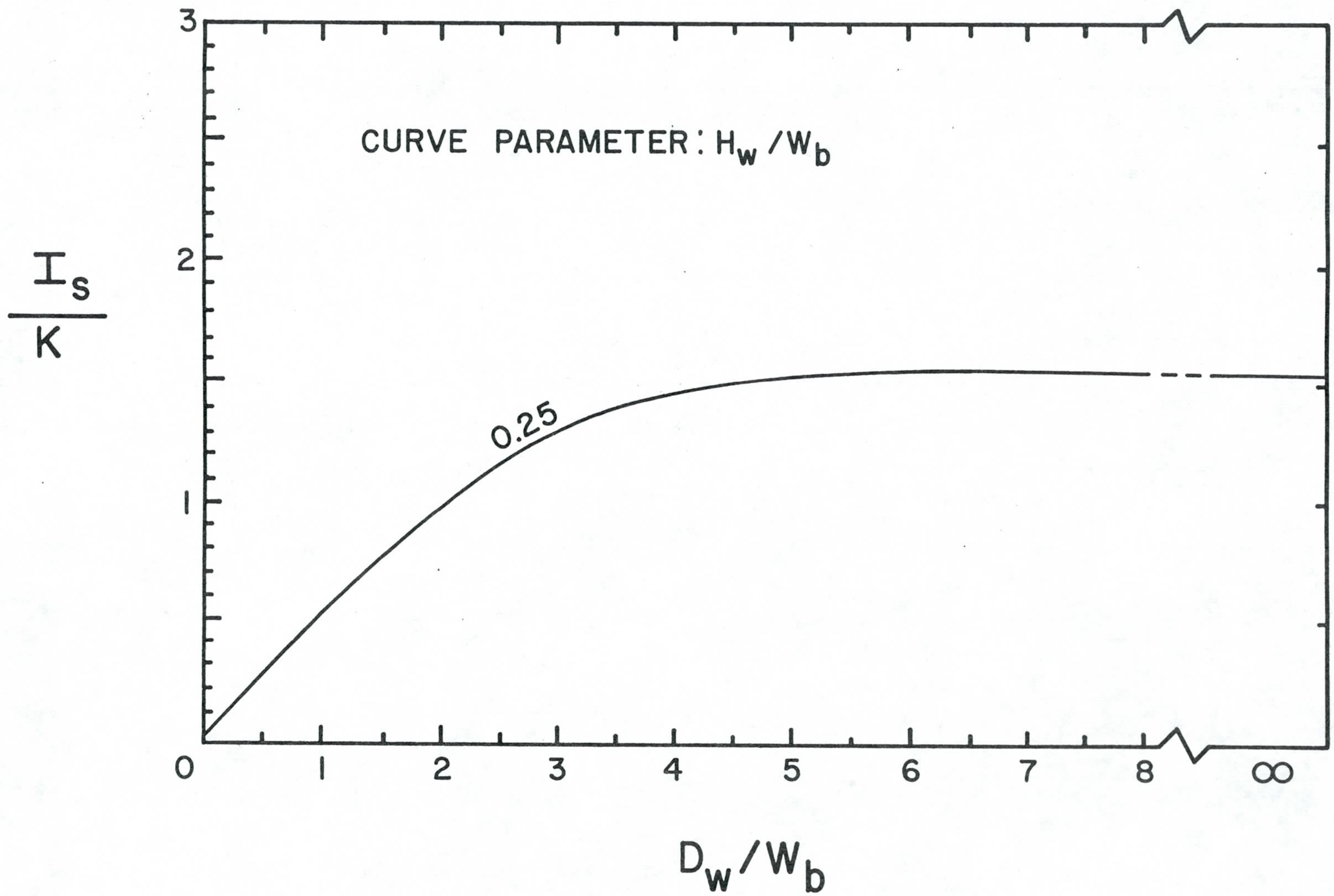


Figure 2. Dimensionless graph of seepage rate as a function of water table depth for trapezoidal channel with 1:1 side slopes.

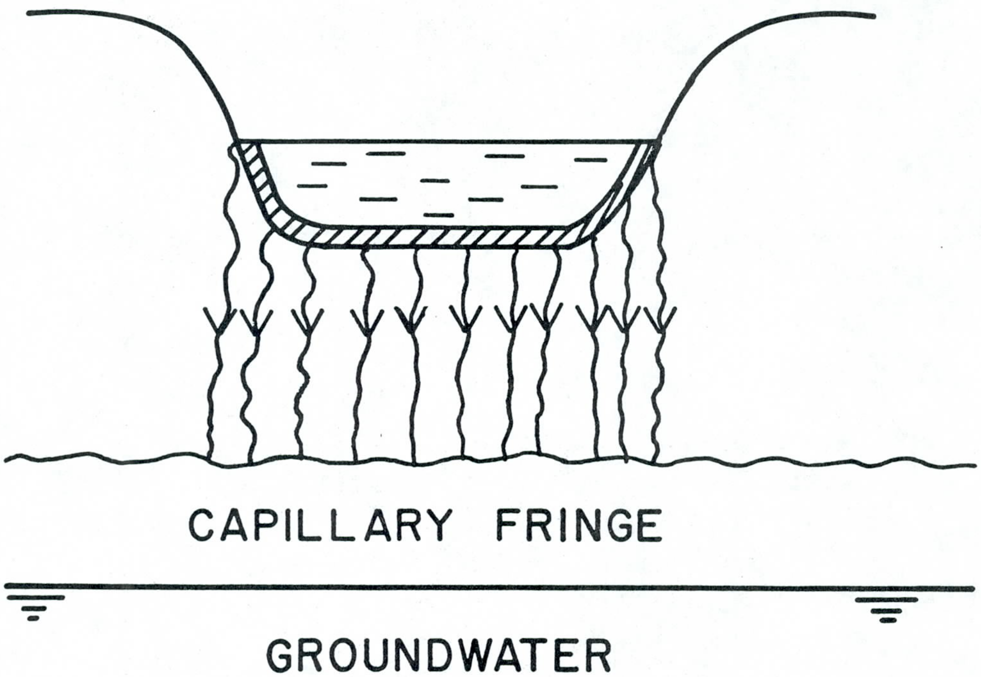


Figure 3. Schematic of seepage from stream with a clogging layer on the wetted perimeter and unsaturated flow to underlying groundwater.

lowering D_w from 4 W_b to "infinite" depth does not significantly increase seepage. This is because at D_w = 4 W_b, seepage is already pretty well controlled by a zone of predominantly vertical flow due to gravity and at unit hydraulic gradient below the stream. Further lowering of the ground water merely elongates this zone at unit hydraulic gradient without increasing the seepage.

When the stream wetted perimeter is covered by fine sediment or other clogging material (Figure 3), seepage is controlled by the clogging layer. The head due to water depth is then completely dissipated across the clogging layer and the flow below the stream channel is unsaturated. The pressure head of the water in the soil below the clogging layer is negative (Bouwer, 1982). In this situation, the seepage from the stream is not affected by ground water depth as long as the water table is deep enough so that the top of the capillary fringe is below the stream bottom. This will usually be true if the water table is at least 0.5 m (1.7 ft) below the stream bottom. Thus, the ground water table can vary from infinite depth to about 0.5 m (1.7 ft) below the stream bottom, and the seepage from the stream will be essentially constant. If ground water levels are high and the water table, or rather, the top of the capillary fringe, is above the stream bottom, stream seepage will vary linearly with depth to ground water, as expressed by the vertical distance between the water surface in the stream and the ground water table.

REFERENCES

Bouwer, H. 1962. Analyzing ground-water mounds by resistance network. 1962. Irrig. and Drain. Div., Amer. Soc. Civ. Engin. Proc. v. 88, no. IR3, pp. 15-36.

Bouwer H. 1982. Design considerations for earth linings for seepage control. Ground Water v. 20, no. 5, pp. 531-537.

Bouwer, H. 1978. "Groundwater Hydrology." McGraw-Hill Book Company. New York, NY. 480 pp.

Bouwer, H. 1985. Renovation of wastewater with rapid-infiltration land treatment systems. "Artificial Recharge of Groundwater," T. Asano, Ed. Butterworth Publishers. Boston, MA. pp. 249-282.

Fink, D. H., and W. L. Ehrler. 1986. Christmas tree production using the runoff farming system. Hortsci. v. 21, no. 3, pp. 459-461.

Frasier, G. W., and L. E. Myers. 1983. Handbook of Water Harvesting. U. S. Dept. of Agriculture, Washington, DC, Agriculture Handbook No. 600, 45 pp.

Jackson, R. D. 1985. Evaluating evapotranspiration at local and regional scales. Proc. Institute of Electrical and Electronic Engineers, v. 73, pp. 1086-1096.

Jackson, R. D., M. S. Moran, L. W. Gay, and L. H. Raymond. 1987. Evaluating evaporation from field crops using airborne radiometry and ground-based meteorological data. Irrig. Sci. (in press)

Herman Bouwer received B. S. and M. S. degrees in land drainage and irrigation from the National Agricultural University of Wageningen, The Netherlands, in 1949 and 1952, and a Ph.D. in hydrology and agricultural water management from Cornell University in 1955. In 1959, he became research hydraulic engineer with the U. S. Water Conservation Laboratory in Phoenix, Arizona, and was appointed laboratory director in 1972. He is leader of a research group in subsurface water management. He is adjunct professor with Arizona State University and the University of Arizona. He has written about 180 research publications, about 10 book chapters, and one textbook: Groundwater Hydrology (McGraw-Hill 1978). He received the 1984 R. J. Tipton Award from the American Society of Civil Engineers for sustained excellence in water management research, and a 1985 Scientist-of-the-Year Award from the U. S. Department of Agriculture.

HYDROGEOCHEMISTRY OF GROUND WATER RECHARGE IN ALLUVIAL AQUIFERS, SOUTHERN ARIZONA

John D. Hem and Frederick N. Robertson
U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025
U.S. Geological Survey, 300 W. Congress, Tucson, AZ 85701

Abstract

Under natural conditions, alluvial aquifers in the Basin and Range physiographic province in southern Arizona are recharged by runoff near the mountain fronts and along stream channels in the alluvium. The dilute water reacts irreversibly with primary rock minerals such as plagioclase feldspar, producing clay minerals, silica, and solute ions. Dissolved carbon dioxide species participate in these reactions and in reactions that may dissolve or precipitate solid carbonates such as calcite. High-solute concentrations can occur in hydrologically closed basins where most or all the water leaving the basin is discharged by evaporation or transpiration.

Colorado River water has a higher disssolved-solids concentration than most natural recharge in this region. This water may become supersaturated with respect to calcite, especially when the water temperature rises during warm weather. The river water also may react with silicate minerals. Although, under these conditions, some calcite may precipitate along the flow path of the recharge, the volume of such precipitated material probably will be widely dispersed if recharge is accomplished by methods that encourage dispersal.

Cation-exchange reactions are capable of altering physical properties of certain types of clays, particularly smectite, and thereby decreasing aquifer transmissivity. It appears unlikely that such effects will occur as a result of recharging aquifers in southern Arizona with Colorado River water, but a firm prediction cannot be made without additional specific studies of interactions that can occur within the aquifers to be recharged.

Introduction

Areas in southern and southwestern Arizona where aquifers may be recharged with imported Colorado River water are part of the Basin and Range physiographic province (Fenneman, 1931). North- and northwest-trending mountain ranges in the region are separated by broad structural basins that have been filled with alluvium. At various times during their past history, many of the basins were hydrologically closed, and readily soluble evaporite material such as gypsum and halite are interbedded with the alluvial fill in places owing to the concentration of weathering products by evaporation of the water. However, in large areas of the alluvial basins, particularly near the recharge sources, the ground water has not been affected by these evaporites and is of excellent chemical quality.

Ground water that has accumulated in the basins is naturally recharged by precipitation that is intense enough to produce runoff in ephemeral streams. Most of the recharge occurs near the points where stream channels leave the mountains and flow across the alluvium. Basins that are crossed by perennial streams also receive recharge from that source. Recharge from the ephemeral streams generally has low dissolved-solids concentrations. However, as the water moves downward toward the zone of saturation, and as it subsequently moves laterally downgradient toward discharge areas, there is extensive opportunity for interaction between the water and the rock minerals it contacts. Characteristically this can be expected to produce a regional pattern of ground water chemistry, with the more dilute waters occurring near recharge areas, and a trend of higher solute concentrations occurring as the ground water moves away from these areas. In areas recharged by ephemeral streams, the composition of the ground water typically is dominated by calcium and bicarbonate with near-neutral pH values reflecting the higher partial pressures of carbon dioxide (PCO_2) associated with these areas. In downgradient and discharge areas, these dilute waters may evolve into a sodium bicarbonate or a sodium mixed anion type or, as dissolved-solids concentrations increase, into a sodium chloride or sodium calcium sulfate type. The solute composition of the water will be controlled by the feasibility and rates of various chemical processes of dissolution, alteration, and precipitation of solids that may influence the water along its flow path, and pH values are generally higher than in areas near recharge sources.

In this paper we will consider some chemical reactions that may occur in typical aquifer systems during and after recharge is introduced and suggest methods for evaluating whether specific chemical reactions are thermodynamically feasible. These methods can be used to help predict the effects of recharging an aquifer with a water that differs chemically from the native water in the aquifer. Some examples of such applications to specific reactions within aquifers of the Tucson basin and other basins in the region will be given. A model developed for the region for computing mass transfer between solid mineral phases and solution in ground water will be described and some of its implications discussed.

Physical and Chemical Characteristics of Alluvial Aquifers

The basins in the area contain alluvial deposits of late Cenozoic age (Wilson and others, 1969). The deposits may be thousands of feet thick in some places and range in particle size from coarse gravel to silt-clay. Evaporite beds containing gypsum, anhydrite or halite are intercalated in the detrital sediments in parts of some of the basins. The basin-fill sediments were derived primarily from igneous and metamorphic rocks of the surrounding mountains which contain a wide variety of mineral species, and are a readily available source for major and trace elements in the ground water.

An important attribute of ground-water systems in aquifers made up of this granular material is the high ratio of solid-liquid interfacial area per unit volume of water. It is at this interface that dissolution and precipitation reactions will occur, and sites of charge located on the solid surface also will attract and retain ions of opposite charge from the solution. Adsorption and cation exchange at sites of negative charge on mineral surfaces are particularly important as such reactions may change aquifer characteristics.

An indication of the order of magnitude of surface area/water volume ratios can be obtained using certain simplifying assumptions. In an aquifer having an effective porosity (ratio of volume of interconnected pores to total volume of rock) of 0.10, a cubic meter of aquifer will contain 100 L (100 dm^3) of water. If the pores are assumed to be capillary tubes having a mean internal radius of r the length of tube, needed to contain 0.10 m^3, or 100 L can be calculated from the equation

$$\ell = \frac{0.10}{\pi r^2} . \qquad (1)$$

If the mean pore radius is 10 x 10^{-6} meters (10 μm) the value of ℓ becomes 3.18 x 10^8 meters. The internal surface area, A, is computed from

$$A = 2 \pi r \ell . \qquad (2)$$

For this value of ℓ, A = 2.00 x $10^4 m^2$. Thus, the area of surface per liter of stored water is 200 m^2.

The volume of this aquifer material required for storing 1 L of water will be 0.01 m^3, equivalent to a cube of length $10^{-2/3}$ m. Thus, each liter of water will encounter 200 m^2 of surface moving through a distance of $10^{-2/3}$ m, (or 0.215 m), and about 930 m^2 per meter of distance that each liter moves. If the average pore diameter is increased by a factor of 10 the ratio of area per unit volume decreases by a factor of 10. These calculations oversimplify the movement of ground water in granular material in several ways. They are included to emphasize the fact that large areas of solid-liquid interface can be present, but the numbers have a substantial uncertainty.

Chemical Reactions in Recharge Areas

Mineral grains that make up the alluvial fill where natural recharge is occurring are in general, highly resistant to dissolution. Water containing dissolved carbon dioxide may, however, attack silicate minerals such as plagioclase feldspar, producing relatively insoluble products such as clay minerals and releasing cations and soluble silica. Similar reactions may occur with other silicates, ferromagnesian minerals for example, and, depending upon the level of PCO_2, with carbonate minerals.

For the weathering of the sodium feldspar, albite, to form a clay mineral and soluble products for example, one may write

$$\underset{\text{(albite)}}{2NaAlSi_3O_8} + 2CO_2\ g + 11H_2O \longrightarrow \underset{\text{(kaolinite)}}{Al_2Si_2O_5(OH)_4} + 4H_4SiO_4 + 2Na^+ + 2HCO_3^-. \qquad (3)$$

This reaction is irreversible in the sense that the products do not recombine to form albite under the conditions existing near the earth's surface. Chemical thermodynamic calculations are useful in evaluating and predicting the extent to which such reactions may occur, but nonequilibrium systems must be viewed in a different way than might be appropriate for systems approaching thermodynamic equlibrium.

The energy gradient or thermodynamic driving force available to promote the feldspar weathering reaction can be expressed mathematically as the "affinity of reaction", $\underline{A}$. This quantity is computed from the relationship

$$\underline{A} = -\ RT \ln \frac{Q}{K} \qquad (4)$$

where R is the gas constant needed for conversion of measuring units, T is temperature on the kelvin scale, Q is the quotient of measured product and reactant activities in a particular solution (expressed in mass-law form), and K is the thermodynamic equilibrium constant for the reaction being considered. For $25^{\circ}C$ and expression of $\underline{A}$ in terms of kilocalories

$$\underline{A} = -1.364\ (\log Q - \log K). \qquad (5)$$

A positive value for $\underline{A}$ indicates that the reaction being considered is thermodynamically favored to proceed to the right as written.

Applying equation 5 to the feldspar weathering process, equation 3, leads to

$$\underline{A}_3 = -1.364\ (2 \log [HCO_3^-] + 2 \log [Na^+] + 4 \log [H_4SiO_4] - 2 \log PCO_2 - 4.45). \qquad (6)$$

Bracketed quantities are reactant and product activities expressed in terms of moles per liter, and PCO_2 is the partial pressure of carbon dioxide in the gas phase associated with the water. The final term (-4.45) is the negative log of the equilibrium constant for reaction 3 calculated from standard free-energy values compiled by Robie and others (1978). The form of feldspar specified is an albite glass. Unit activities are assumed for solids and for water.

In an open system, common to recharge areas within alluvial aquifers, other factors may be present to maintain a positive value for $\underline{A}_3$ as the reaction proceeds. For example, the partial pressure of CO_2 in the gas phase of the unsaturated zone may be maintained at a relatively high level by respiration of CO_2 by roots of growing plants and decay of organic matter, and movement of the water past the feldspar surfaces transports reaction products away and can maintain lower activities of Na^+ and HCO_3^- than would be expected without the water movement. Both these kinds of effects can be expected in natural ground-water recharge areas.

Similar calculations using anorthite, the calcic end member of the plagioclase (sodium - calcium feldspar) series, show that $\underline{A}$ increases with increasing calcium content, thus tending to make all reactions involving the remaining members of the plagioclase series proceed even more strongly to the right.

Another factor that is important in actual ground water systems is that many other chemical reactions may be occurring at the same time as the one being considered here. Some of these may be processes that can be expected to remain near equilibrium--others can be irreversible. The products of some of these reactions may become available as reactants in other reactions. This linking effect can be an important source of thermodynamic drive for irreversible processes.

Reactions involving CO_2 and water are generally near equilibrium and are readily reversible. When CO_2 gas dissolves, there is a release of H^+ ions according to the general scheme:

$$CO_2\ g + H_2O \rightleftharpoons H_2CO_3\ aq \qquad (7)$$

$$H_2CO_3\ aq \rightleftharpoons H^+ + HCO_3^- \qquad (8)$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}. \quad (9)$$

There may also be equilibria that involve precipitation or dissolution of relatively insoluble carbonate minerals such as calcite in the relatively fast reaction

$$Ca^{2+} + CO_3^{2-} \rightleftharpoons CaCO_3. \quad (10)$$

If the concentration of H_4SiO_4 aq becomes high enough, some form of crystalline silica may precipitate

$$H_4SiO_4 \text{ aq} \rightleftharpoons SiO_2 \text{ c} + 2H_2O. \quad (11)$$

Reactions 7, 8, and 9 may be linked to the slow feldspar weathering process as that process effectively consumes H^+. This linkage can be represented by rewriting reaction 3 as

$$2NaAlSi_3O_8 + HCO_3^- + H^+ + 9H_2O \longrightarrow CO_3^{2-} + Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 \text{ aq} + 2Na^+. \quad (12)$$

This is a reaction path that might be followed if the added new recharge contained more HCO_3^- and less H_2CO_3 than natural recharge.

The presence of other ions in the recharge water might also have effects on the feldspar reaction. The CO_3^{2-} ions produced in reaction 12 might react with Ca^{2+} in the recharge water to precipitate calcite, linking reaction 10 to reaction 12. Weathering of additional silicate minerals or dissolution of gypsum may provide a substantial increase in calcium concentrations. The sum of reactions 10 and 12 is

$$2NaAlSi_3O_8 + HCO_3^- + H^+ + Ca^{2+} + 9H_2O \longrightarrow CaCO_3 \text{ c} + Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 \text{ aq} + 2Na^{2+} \quad (13)$$

In addition to this, the aqueous silica (H_4SiO_4) concentration could be maintained at a fixed value by reaction 11.

These considerations suggest that ground water recharging and moving through granular aquifers containing plagioclase feldspar may follow a general reaction process that attacks the feldspar, while precipitating calcite and silica along the flow path. The reader is reminded that initially carbonates may dissolve before the onset of calcite precipitation if PCO_2 is great enough to give a negative value for A for the sum of reactions 7, 8, 9, and 10. Precipitated solids may accumulate as a cement holding the individual grains together and blocking some of the pore space.

Another way of expressing the thermodynamic feasibility of a chemical reaction is by means of a "saturation index" (SI). The SI is a commonly used way of evaluating analytical data for departure from calcite solubility equilibrium, with positive values indicating supersaturation, and negative values indicating undersaturation or ability to dissolve $CaCO_3$. Waters near equilibrium will have SI values near zero.

After procedures suggested many years ago by W. F. Langelier (1936), a calcite saturation index can be computed by subtracting the equilibrium pH computed for analytically determined concentrations of Ca^{2+} and HCO_3^- from the pH actually measured in that water. One of the authors of this paper (Hem, 1985, pl 2a and 2b) has published a two-sheet nomograph that can be used to compute equilibrium pH values from water analyses, using as input the reported milligrams per liter concentrations of Ca^{2+} and HCO_3^-, the temperature, and the ionic strength of the solution (computed from major ion concentrations).

This form of the saturation index is numerically equal to the reaction affinity for the precipitation reaction divided by the factor R T, however, there is a difference in the sign convention. The reaction considered in the nomograph (Hem, 1985) is written

$$CaCO_3\ c + H^+ \rightleftharpoons HCO_3^- + Ca^{2+}. \qquad (14)$$

A favorable thermodynamic drive (positive A) for this reaction going to the right indicates dissolution would be expected--a condition of undersaturation rather than supersaturation. Hence, at 25°C

$$\frac{A_{14}}{1.364} = -\ (SI)_{14} \qquad (15)$$

Characterization of Solid Phases in Aquifers

The reaction affinity as defined and applied here is an index of the extent of departure from equilibrium that is displayed by chemical analysis data for ground water. Where there is specific knowledge of the composition of the solids that are present in a ground-water aquifer, the application of such a calculation can provide a considerable insight into the chemical processes that are going on, and the effect that might be expected if the system were perturbed by introduction of a chemically different water. Although the need for information as to the actual mineral composition of aquifer materials has been recognized, the field of ground-water hydraulics generally has developed in directions that did not require such information. The computer programs applied to evaluate the chemical properties of ground water commonly yield results showing departure from equilibrium for hypothetical reactions involving a hypothetical set of solid-phase minerals for which chemical thermodynamic data are available. The usefulness of the results is substantially increased if the user knows which of the minerals that might be considered are, in fact, present.

A study by Robertson (in press) of the geochemistry of ground water in alluvial basins of the Southwest includes a substantial amount of mineralogic information on the water-bearing formations in southern and western Arizona. X-ray diffraction and X-ray fluorescence analysis of more than 170 samples of drill core and well cuttings from eight basins showed that quartz, plagioclase, calcite, potassium feldspar, and muscovite are the dominant minerals in the bulk sediment (diameter less than 62 μm fraction). Smectite with minor kaolinite and mica were dominant minerals in the clay (less than 2 μm) fraction.

A study of ground water resources in the Tucson basin published in the early 1970's (Laney, 1972; Davidson, 1973) also included a considerable amount of information on the mineralogic composition of the basin fill. In the northeastern half of the Tucson basin, the fill is mainly composed of granitic detritus from the Santa Catalina and Rincon Mountains (Davidson, 1973, p. E57) and plagioclase feldspar probably is a major consituent of such material. The X-ray diffraction analysis data (Robertson, in press) confirmed the presence of albite in 7 of 13 plagioclase occurrences at various points in the Tucson basin.

Geochemical Reaction Models

In evaluating processes such as artificial recharge, understanding the natural system is imperative. Much knowledge was gained about the geochemical proceses in the alluvial basins through the development of conceptual chemical models, which were subsequently tested by field observations and the mineralogic and chemical data of the aquifer materials (Robertson, in press). Reactions were identified through chemical flow-path modeling, which consists of reacting water with gases and minerals as the water moves downgradient along flow paths.

For example, in a simplified system showing weathering of rocks,

$$\text{a(unweathered rocks)} + \text{b(water)} \longrightarrow \text{c(clays)} + \text{d(dissolved species)} \qquad (16)$$

it is possible in theory to solve the reaction coefficients a, b, c, and d and define the mass transfer of each respective phase associated with the reaction. Mass transfer is defined as the amount of the reactant or product phase that enters or leaves the aqueous phase. The computer code BALANCE (Parkhurst and others, 1982) was used to facilitate the calculations of the reaction coeffcients. The determination of reactions and mass transfer is a powerful tool in evaluating and quantifying geochemical processes when used in conjuction with the cited thermodynamic constraints. The Tucson basin was not one of the basins modeled in detail during the regional study, but the reactions determined for other basins appear markedly transferable and should be applicable to the Tucson basin.

Simplified Feldspar Weathering Chemistry Applied to the Tucson Basin

Five chemical analyses from published literature are given in table 1 and are shown graphically in figure 1. The analyses show, in general, how the composition of the relatively dilute surface flow in Rillito Creek, a natural recharge source, is changed by reactions with rock minerals in the basin fill during and after recharge. Two samples representing wells relatively near the recharge source and wells a greater distance away, near the Santa Cruz River, show how solute concentrations may increase along the ground water flow path.

Thermodynamic Calculations

A quantitative indication of the ability of the waters to attack rock minerals or form precipitates can be obtained by computing reaction affinities or saturation indices for reactions with rock minerals known to be present in the Tucson basin. Although kaolinite is present in the alluvial fill of many basins in Arizona, the predominant clay mineral species in these basins apparently are higher in silica content and are presumably more stable than kaolinite under the chemical conditions in the region. The major clay mineral identified by Robertson (in press) in the fill material is a montmorillonite smectite similar in composition to beidellite. Thermodynamic calculations for the feldspar weathering reaction in the Tucson basin have been made assuming a sodium beidellite with the composition $Na_{0.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2$ is the clay mineral product. The balanced reaction is

$$7NaAlSi_3O_8 + 6HCO_3^- + 20H_2O \longrightarrow 10H_4SiO_4 + 3Na_{33}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 6Na^+ + 6CO_3^{2-} . \qquad (17)$$

If coupled to the calcite precipitation reaction (reaction 10 multiplied by 6 to maintain stoichiometric balance)

$$7NaAlSi_3O_8 + 6HCO_3^- + 6Ca^{2+} + 20H_2O \longrightarrow 10H_4SiO_4 + 3Na_{.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 6Na^+ + 6CaCO_3 . \qquad (18)$$

The equilibrium constant for reaction 17 is computed to be $10^{-7.49}$, based on thermodynamic data from Robie and others (1978) and from Plummer and others (1976). The equilibrium constant for 18 is computed as $10^{42.31}$. These values are for a temperature of 25^oC which is a few degrees higher than shallow ground-water temperatures in the Tucson basin, but the effect of these small temperature differences is negligible compared to other uncertainties in the calculation. However, it should be noted that the solubility of calcite, as expressed by reaction 10, is strongly influenced by temperature. The equilibrium solubility of calcite at 10°C is about twice as great as the solubility at 30°C. The equilibrium constant for reaction 10 used in equation 20 was computed by subtracting log K_{17} from log K_{18} and dividing the result by six.

Table 2 contains values of reaction affinities for albite weathering (reaction 17), for calcite precipitation (reaction 10 calculated for 25°C) and for the coupled reaction (reaction 18) for those analyses showing significant calcite supersaturation. Analysis 1 in the table gives a negative affinity for calcite precipitation and this water would tend to dissolve $CaCO_3$. The equations used to compute affinites are:

$$\underline{A}_{17} = -1.364\ (6 \log [CO_3^{2-}] + 6 \log [Na^+] + 10 \log [H_4SiO_4] - 6 \log [HCO_3^-] + 7.49). \qquad (19)$$

$$\underline{A}_{10} = -1.342\ (-\log [Ca^{2+}] - \log [CO_3^{2-}] - 8.30). \qquad (20)$$

and

$$\underline{A}_{18} = 1.364\ (6 \log [Na^+] + 10 \log [H_4SiO_4] - 6 \log [Ca^{2+}] - 6 \log [HCO_3^-] - 42.31). \qquad (21)$$

The stoichiometry of reactions 17 and 18 entails the dissolution of 7 moles of albite. Values for $\underline{A}_{17}$ and $\underline{A}_{18}$ given in table 2 should be divided by 7 to give the affinity of reaction per mole of albite. Reaction affinities for reaction 12, in which the clay mineral specified is kaolinite, would be somewhat more positive than those for reaction 17. If both are computed as kcal per mole of albite reacting, the difference is bewteen 1 and 2 kcal.

Quantities in brackets are thermodynamic activities of solutes, measured concentrations corrected for effect of ionic strength using the Debye-Hückel equation (Hem, 1985, p. 15-17). The activity values are given in table 2 in log form. The carbonate activities in the table were computed from pH and determined HCO_3- alkalinities, assuming equilibrium for equation 9. No pH data were given by Laney (1972) for the samples from Rillito Creek and the value given in the table is an estimate, with an uncertainty of perhaps 0.5. The estimate, derived from measured values of similar recharge waters, is supported by a field-measured pH of 7.4 from a well adjacent to the creek that receives recharge from the creek (Austin Long, University of Arizona, oral commun., 1987). The molar activity of H_4SiO_4 is equal to that of aqueous SiO_2 reported in the analyses of table 1. The formula H_4SiO_4 probably represents more accurately the actual form of dissolved silica.

Uncertainties in thermodynamic data used to calculate values for $\underline{A}_{17}$ and $\underline{A}_{18}$ inject an uncertainty about ± 2 kcal into the numbers for these affinities in table 2. The uncertainty caused by this effect in $\underline{A}_{10}$ is much less. Values of $\underline{A}_{10}$ lying between +.30 and -.30 can be interpreted as indicating equilibrium with respect to calcite dissolution or precipitation.

<u>Discussion</u>

Calculated values of the affinity of reaction for weathering of albite (reaction 17) are positive for all five analyses in table 1, indicating that all the waters represented would tend to attack albite. The decrease in values of $\underline{A}_{17}$ for water recharging the Tucson basin (1) and the water moving downgradient (2 and 3) suggest that as the water moves it gradually loses some of its capacity to react with albite, but the affinity remains large and nearly constant even though solute concentrations show substantial increases.

Both Colorado River waters also have large positive affinities for the albite weathering reaction. More importantly, both also have positive values for $CaCO_3$ precipitation. The total-dissolved solids concentration and composition of water at Davis Dam given in analysis 5 in table 1 show the effect of the large volume of dilute runoff produced by abnormally large amounts of upper-basin precipitation in 1983-86. The composition shown for water at Parker Dam in 1983 (analysis 4, table 1) is probably nearer that to be expected in water diverted to central Arizona in the future.

The albite weathering reaction takes place at an extemely slow rate. Mass transfer constraints indicate that a unit volume of water would probably need to move through a distance of about 8-10 kilometers between the recharge and sampling points to attain the sodium concentration of sample 2 in table 1, if all the sodium is derived from the albite reactions assuming an initial PCO_2 of about $10^{-1.7}$ atmospheres in the recharge area. A laboratory study of albite dissolution rates in water saturated with carbon dioxide was made by Busenberg and Clemency (1976). Extrapolation of their rate data also suggests that in a system like that of the Tucson basin a unit volume of water would probably need to move through a distance of at least several kilometers from the recharge area to reach the concentrations in sample 2.

In contrast to albite dissolution, calcite precipitation can occur at a rapid rate. If introduced recharge is already supersaturated with respect to calcite there will be some precipitation of this material on mineral surfaces near the point at which the recharge enters the ground. The supersaturated state of the Colorado River water may be substantially more critical relative to the native water recharging the basin as suggested by the negative value of $\underset{=}{A}_{10}$ for calcite precipitation in table 2. In surface spreading basins such precipitation effects would probably be distributed over a relatively large solid surface area. If recharge is introduced through wells, however, the precipitation effect may be concentrated within a smaller total surface area in the immediate vicinity of the well, and water movement away from the well may be impaired after a time as pores are blocked with precipitated material.

If the calcium concentration of introduced recharge decreases by 1.0 mg/L owing to precipitation of $CaCO_3$, the volume of calcite deposited by a cubic meter of water would be about 0.93 cm^3. The pore volume in a cubic meter of aquifer with an effective porosity of 0.10 is 10^5 cm^3. If all the $CaCO_3$ were precipitated uniformly within the first cubic meter of aquifer it would appear that loss of porosity would not be very significant until many thousands of cubic meters of water had passed through it. It should be noted, however, that $CaCO_3$ precipitation may not occur uniformly and the amount deposited by a liter of water during equilibration could be greater by a factor of 10 or more.

The possible effect of cation exchange processes on physical behavior of clays has been mentioned. Because of the dominance of the montmorillonitic clays, exchange of sodium for calcium in the interlayer position is particularly important because it may cause swelling and distortion of the clay decreasing aquifer porosity. Although this possibility cannot be rigorously evaluated in advance, the sodium adsorption ratio, an index of possible effects of this sort in irrigated soils, may have some value as an indication of potential for cation-exchange effects when recharge of different chemical composition is introduced. The method for computing SAR is given elsewhere (Hem, 1985). The values for this ratio given in table 1 show that the Tucson basin ground water and Colorado River water should have similar cation exchange behavior, and, in this basin at least, this suggests that significant cation-exchange effects are unlikely to occur as a result of recharging with Colorado River water.

The modeling calculations by Robertson (in press) included some estimates of cation exchange effects that also indicate that ion exchange probably will not occur to any great extent. In waters that are dilute (about 500 mg/L dissolved-solids concentrations), ion exchange reactions of all types appear to be absent. Ion exchange of calcium replacing sodium on the clay substrate appears to occur in some basins that contain water with larger dissolved-solids concentrations (1,000 to 3,000 mg/L). The basins with the highest salinity also appear to have some calcium replacing magnesium and potassium. Although all ground waters evolve into a highly sodic water, sodium replacing calcium on exchange sites does not seem to occur. Of all ion- exchange schemes investigated, exchange of sodium for calcium seems the most unlikely. Additional support for the specified smectite behavior is provided by the total dissolved-solids of most ground waters. Owing to the higher charge of the divalent calcium ion, this ion would be preferred in the interlayer position in these dilute waters. As the Colorado River water also is relatively low in dissolved solids and high in calcium concentrations, significant cation-exchange effects of sodium for calcium are unlikely to occur.

Possible Recharge Effects in Other Basins in Arizona

There is in fact a good example of Colorado River water naturally recharging the ground water of several alluvial aquifers in Arizona. Basins along the Colorado River receive most of their recharge directly from the river. River water infiltrates the alluvium beneath the flood plain and may move a considerable distance beyond the flood plain into piedmont-slope areas adjacent to the mountains. The reactions determined in basins that receive local recharge appeared to be applicable to this area. The chemical composition of ground water in the Yuma area was derived from the river starting with a weighted-average analysis of Colorado River water, which is nearly identical to the October 20, 1982, analysis in table 1. The derivation suggested that the major reactions occurring in much of the flood-plain area are the dissolution of calcite, dolomite, halite, and gypsum, and that some weathering of silicates occurs. The dissolution reactions are attributed to high partial pressure of CO_2 in the soil gas; depths to water are on the order of 5 to 15 feet, and the entire flood plain has a high density of phreatophytes. Other reactions can account for ground-water compositions in the Yuma area--namely evapotranspiration, carbonate precipitation and sulfate reduction (Olmstead and others, 1973)--but the above derived reactions are the most compatible with the stable isotope and chemical data and with the field observations. In any event, the reactions that are in fact occurring do not appear to affect aquifer porosity. Transmissivities along the river commonly range from several hundred thousand gallons per day per foot to several million gallons per day per foot.

The chemical models developed for several other basins in the region not along the river indicate that the precipitation and not the dissolution of the carbonates is the major reaction and, thus, such basins or areas in them would not be as suitable for recharging Colorado River to the ground water. Partial pressure of CO_2 in most ground waters in those basins Nange between $10^{-2.5}$ and 10^{-4} atmospheres, considerably lower than those found in the flood plain along the Colorado River, which commonly range between $10^{-1.5}$ to $10^{-3.0}$ atmospheres.

Summary and Conclusions

Problems that may arise through artificial recharge of Colorado River water in Arizona in Arizona include the precipitation of calcite and ion-exchange reactions that would cause swelling of the clays. Such reactions would decrease the porosity of the alluvium and eventually prevent continued use of artifical recharge.

Chemical modeling and major element compositions of the Colorado river water and of ground waters in the Tucson basin and other basins indicate that ion-exchange reactions should not occur to any large degree. Exchange of sodium for calcium is unlikely and swelling of the clays is not expected.

Under the most unfavorable circumstance, a water supersaturated with $CaCO_3$ injected into a well can plug openings and interfere with injection after a fairly short time. On the basis of calcite precipitation constraints, the areas within basins that would be the most favorable for recharge are those along major streams where partial pressures of CO_2 are highest and ground water temperatures are lowest. Artificial recharge would be best accomplished in the Tucson basin through dispersal along the major stream channels, if this is the only concern. Other considerations, such as aquifer hydraulics, location of withdrawal facilities, and potential mobilization of contaminants which may have been concentrated in the beds of ephemeral streams may play an important role in determining the most effective methods to utilize water imported into the Tucson basin.

References

Busenberg, Eurybiades and C. V. Clemency. 1976. The dissoluton kinetics of feldspars at 25°C and 1 atm CO_2 partial pressure. Geochimica et Cosmochimica Acta, v. 40, p. 41-49.

Davidson, E. S. 1973. Geohydrology and water resources of the Tucson basin, Arizona. U.S. Geological Survey Water-Supply Paper 1939E, p. E1-E81.

Durfor, C. N. and Edith Becker. 1964. Public water supplies of the 100 largest cities in the United States, 1962. U.S. Geological Survey Water-Supply Paper 1812, 364 p.

Fenneman, N. M. 1931. Physiography of the western United States. New York, McGraw-Hill, 534 p.

Frisbie, H. R., R. J. LaCamera, M. M. Riek and D. B. Wood. 1985. Water Resources Data, Nevada, Water Year 1984. U.S. Geological Survey Water-Data Report NV-84-1, 247 p.

Hem, J. D. 1985. Study and interpretaion of the chemical characteristics of natural water, 3d Ed. U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Laney, R. L. 1972. Chemical quality of water in the Tucson basin, Arizona. U.S. Geological Survey Water-Supply Paper 1939D, p. D1-D46.

Langelier, W. F. 1936. The analytical control of anticorrosion water treatment. American Water Works Association Journal, v. 28, p. 1500-1521.

Olmsted, F. H., O. J. Loeltz and Burdge Irelan. 1973. Geohydrology of the

Yuma area, Arizona and California. U.S. Geological Survey Professional Paper 486-H, 227 p.

Parkhurst, D. L., L. N. Plummer and D. C. Thorstenson. 1982. BALANCE--A computer program for calculation of chemical mass balance. U.S. Geological Survey Water-Resources Investigation 82-14, 33 p.

Plummer, L. N., B. F. Jones and A. H. Truesdell. 1976. WATEQF - a Fortran IV version of WATEQ, a computer program for calculating chemical equilibrium of natural waters. U.S. Geological Survey, Water- Resources Investigation 76-13, 61 p.

Robertson, F. N. 19 . Geochemistry of ground water in alluvial basins of Arizona and adjacent parts of Nevada, New Mexico and California. U.S. Geological Survey Professional Paper 1406C, (in press).

Robie, R. A., B. S. Hemingway and J. R. Fisher. 1978. Thermodynamic properties of minerals and related substances at 298.15 K and 1 bar (10^5 Pascals) pressure and at higher temperatures. U.S. Geological Survey Bulletin 1452, 456 pp.

White, N. D. and W. B. Garrett. 1986. Water Resources Data, Arizona, Water Year 1983. U.S. Geological Survey Water-Data Report AZ-83-1, 387 p.

Wilson, R. P., R. T. Moore and J. R. Cooper. 1969. Geologic map of Arizona. Arizona Bureau of Mines map, scale 1:500,000.

Table 1
Chemical analyses and related data for natural recharge and ground water from two well fields in the Tucson basin, and two samples of Colorado river water

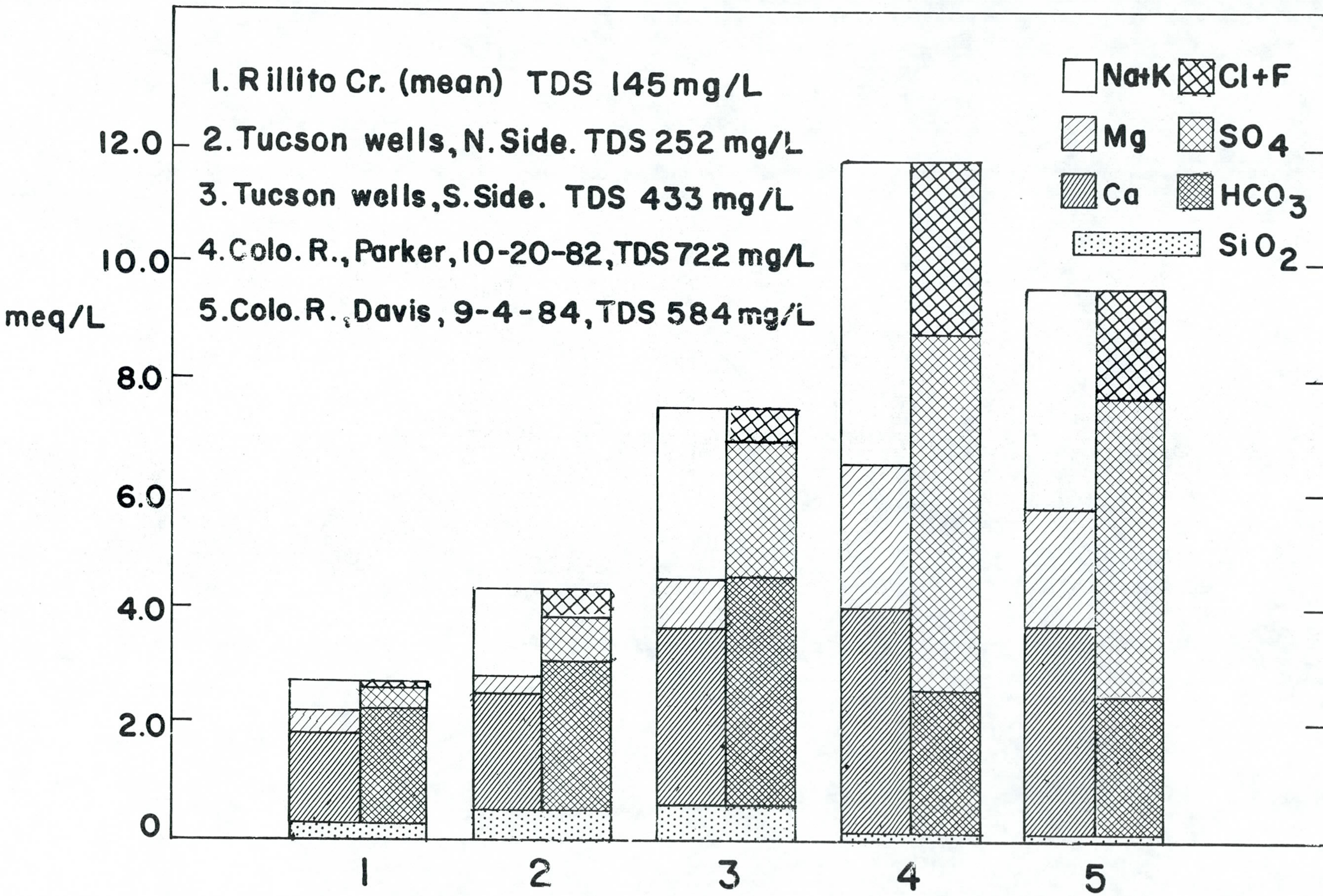
	1		2		3		4		5	
Date sampled	1959-1965		Jan. 10, 1962		Jan. 10, 1962		Oct. 20, 1982		Sept. 4, 1984	
Temp. ^{o}C	----		21.1		22.2		20		18	
pH	7.1 (est)		7.8		7.6		8.3		8.2	
Ionic Strength (I)	0.0037		.0055		.010		.0182		.0150	
Sodium Adsorption Ratio (SAR)	.48		1.4		2.1		2.9		1.2	
	mg/L	log activity (moles/L)	mg/L	log activity (moles/L)	mg/L	log activity (moles/L)	mg/L	log activity (moles/L)	mg/L	log activity (moles/L)
SiO_2	14	-3.63	29	-3.32	35	-3.23	8.5	-3.85	8.2	-3.86
Ca	32	-3.22	42	-3.12	63	-2.96	79	-2.91	73	-2.94
Mg	5	-3.81	3.4	-3.99	10	-3.55	31	-3.11	26	-3.17
Na	11	-3.35	34	-2.87	67	-2.58	120	-2.34	83	-2.50
K	--	--	1.8	-4.37	2.4	-4.26	4.9	-3.96	4.5	-3.99
HCO_3	119	-2.74	158	-2.63	242	-2.45	147	-2.68	141	-2.69
CO_3(Calc)	.06	-5.97	.53	-5.19	.58	-5.20	1.8	-4.76	1.3	-4.89
SO_4	19	-3.82	39	-3.53	115	-3.10	310	-2.72	250	-2.79
Cl	4	-3.98	14	-3.43	16	-3.40	91	-2.65	68	-2.77
F	.3	-4.83	.2	-5.02	1.0	-4.33	.4	-4.74	.3	-4.85
TDS	145	--	252	--	433	--	722	--	584	--

Sample descriptions-(1) Mean of chemical analyses of flood flows in Rillito Creek near Tucson, Arizona (Laney, 1972, p. D12). (2) Composite sample of water from wells in North-side field, City of Tucson water-supply system. Wells located in northeast part of city (Durfor and Becker, 1964, p. 96). (3) Composite sample of water from wells in South-side field, City of Tucson water-supply system. Wells located near Santa Cruz River in southern part of city (Durfor and Becker, 1964, p. 96). (4) Colorado River below Parker Dam, Arizona - California. Oct. 20, 1982, discharge 4560 cfs (White and Garnett, 1986). (5) Colorado River below Davis Dam, Arizona - Nevada. Sept. 4, 1984, discharge 30,000 cfs (Frisbie and others, 1985).

Table 2
Calculated affinities of reaction for albite weathering and calcite precipitation for waters whose chemical analyses are given in Table 1

Analysis number	$\underline{A}_{17}$	$\underline{A}_{10}$	$\underline{A}_{18}$
1	93.15	-1.21	----
2	79.51	- .01	79.43
3	77.46	.19	78.61
4	78.47	.86	83.63
5	80.90	.64	84.75

Figure 1. Graphical representation of chemical composition of water from five sources (Table 1). Silica concentrations in millimoles per liter, other solutes in milliequivalents per liter


1. Rillito Cr. (mean) TDS 145 mg/L
2. Tucson wells, N. Side. TDS 252 mg/L
3. Tucson wells, S. Side. TDS 433 mg/L
4. Colo. R., Parker, 10-20-82, TDS 722 mg/L
5. Colo. R., Davis, 9-4-84, TDS 584 mg/L
Na+K
Cl+F
Mg
SO_4
Ca
HCO_3
SiO_2
meq/L
12.0
10.0
8.0
6.0
4.0
2.0
0
1
2
3
4
5

ESTIMATING RECOVERABLE WATER FOR UNDERGROUND STORAGE AND RECOVERY PROJECTS

by L.G. Wilson

Hydrologist, Water Resources Research Center
The University of Arizona
Tucson, Arizona 86721

Abstract:

The new Arizona legislation dealing with underground storage and recovery projects assigns credits and debits to "recoverable" water, i.e., the amount of water that has reached an aquifer. For recharge well projects the recoverable amount is relatively simple to estimate. For water spreading projects estimating the amount of water that has been added to an aquifer is more complex because of tortuous flow paths in the vadose zone. This paper reviews recent research addressing flow at the microscopic (i.e., pore-size) and macroscopic levels and describes methods for estimating recharge. One study of flow at the pore level shows that lateral spreading of percolating water occurs at a greater rate than expected because of the effect of a moisture dependent anisotropy. The second study suggests that vertical deep percolation rates are greater than expected because of preferential flow paths. Field scale studies illustrate that establishment of transmission zones for deep percolating water may occur faster than expected. Vertical flow rates of 33 ft/day were reported for a site in Arizona. Methods for measuring recoverable amount include solids sampling and neutron moisture logging.

Introduction:

The Artificial Recharge and Underground Storage and Recovery Act of 1986 recognized two classes of artificial recharge projects. "Recharge projects" are designed and constructed for the purpose of adding water to an aquifer (ARS 45-651). Basically, such projects are intended for water conservation. The recharging entity does not have special rights to recover. In contrast, the purpose of "underground storage and recovery projects" is to store water underground for future recovery. The recharging agency maintains a storage and recovery account. By establishing these two classes of recharge projects, the state legislature successfully avoided the onset of prolonged court battles that have occurred when establishing recharge projects in other states, for example, in California. Specifically, the Act circumvents potential lawsuits over the question of who has the right to recharge and who has the right to recover water placed underground.

In addition to its foresight in avoiding legal-institutional impediments the legislation is also progressive from a technical viewpoint by accounting for fundamental hydrological principles. For example, "recharge" means to add water to an aquifer by means of a recharge project (ARS 45-651). Water has been recharged only when it has reached an aquifer. Similarly, the legislation on underground storage and recovery projects deals with the question of recoverable amount. "Recoverable amount" means the amount of water, as determined by the director, that has reached an aquifer (ARS 45-669).

The definition of recharge is technically accurate. However, determining the amount of water that has reached an aquifer is a very complex technical issue.

Estimating recoverable amount depends on the recharge method and local geological conditions. For well recharge, estimating the recoverable amount is fairly simple. Water is metered as it flows into a cased well terminating below the water table. For water-spreading methods the problem is more complex in that water follows a tortuous, circuitous path enroute to the water table. Complex flow patterns are a reflection of the geological heterogeneity of the vadose zone at typical recharge sites.

Hydrogeologists and other scientists and engineers recognize that the complexity of the geology at a typical recharge site adds to the difficulty in predicting flow patterns during recharge. Recent research illustrates that flow patterns are often unexpected both at the microscopic and macroscopic levels.

Because of the complexity of vadose zone flow, planning for either a recharge project or an underground storage and recovery project and for monitoring during the operations of such projects requires detailed hydrogeological investigations. For storage and recovery projects, effective monitoring methods should be selected to ensure receiving full credit for the recoverable amount. Several methods are available to help in arriving at recharge estimates.

The purpose of this presentation is to review recent research that provides technical insights into the recharge process, and to briefly describe methods for estimating the amount of water that has reached an aquifer.

Flow in the Vadose Zone:

Microscopic Flow Effects:

Two recent studies illustrate recent insights into flow at the pore level. The first study shows that lateral flow occurs locally because of local variations in the unsaturated hydraulic conductivity. The second study shows that vertical flow velocities at the local level are greater than predicted because of the presence of preferential flow paths.

Recharge is frequently estimated using simple flow models which assume that bulk flow in the vadose zone is predominantly in the vertical direction. Studies by Yeh, Gelhar, and Gutjahr (1985) found that the anisotropy ratio (horizontal to vertical) of mean unsaturated hydraulic conductivity increases when the mean moisture content decreases. Such a moisture dependent anisotropy can lead to unexpectedly large horizontal flow components in unsaturated media. Accordingly, modelling approaches that assume unsaturated flow is one-dimensional in the vertical direction do not adequately describe field flow systems that are affected by the presence of strong lateral capillary pressure gradients. Multidimensional unsaturated flow is suggested. Moreover, because soils exhibit bedding, the nonuniformity and stratification of the soils produce a moisture-dependent anisotropy in which the horizontal hydraulic conductivity can be many times the vertical, depending on the saturation of the soils. This effect is likely to be more significant for channel recharge systems than for large basins.

A simple approach for estimating recharge is to conduct a water balance. Recent studies by Rice, Bowman, and Jaynes (1986) suggest that water movement through a soil profile may be greater than predicted using the water balance approach. Rapid flow velocities in soils are frequently attributed to the presence of macropores or structural cracks. This is mainly a saturated flow effect. A similar effect has been observed under unsaturated flow conditions. Rice, Bowman, and Jaynes (1986) compared the velocity of downward percolating water, measured using tracer concentration profiles, with macroscopic velocity calculated from a water balance. The deep percolation rate calculated from the trace velocities was about five times greater than the rate determined using a water balance. The results indicate that a significant portion of the applied water moves downward through preferential flow paths in the soil matrix under unsaturated conditions. Accordingly, simple water balance models may overestimate arrival times of surface-applied water to ground water.

Macroscopic Flow in the Vadose Zone:

Water spreading in natural river channels is often the preferred method of artificial recharge. Understanding natural recharge processes provide clues on the potential effectiveness of in-channel spreading operations and on potential recoverable amounts.

The patterns of water movement through vadose zone sediments in Arizona's alluvial basins, as well as the natural recharge process, remain somewhat of a mystery because of the limited amount of data on flow patterns in the highly variable alluvium of the basin. Conceptually, water percolating beneath a stream channel flows into the permeable stream alluvium deposits, sometimes called "shoe-string" aquifers, and then into the adjacent basin-fill deposits of lesser permeability. Figure 1 illustrates two possible conditions. For case 1a, the surficial

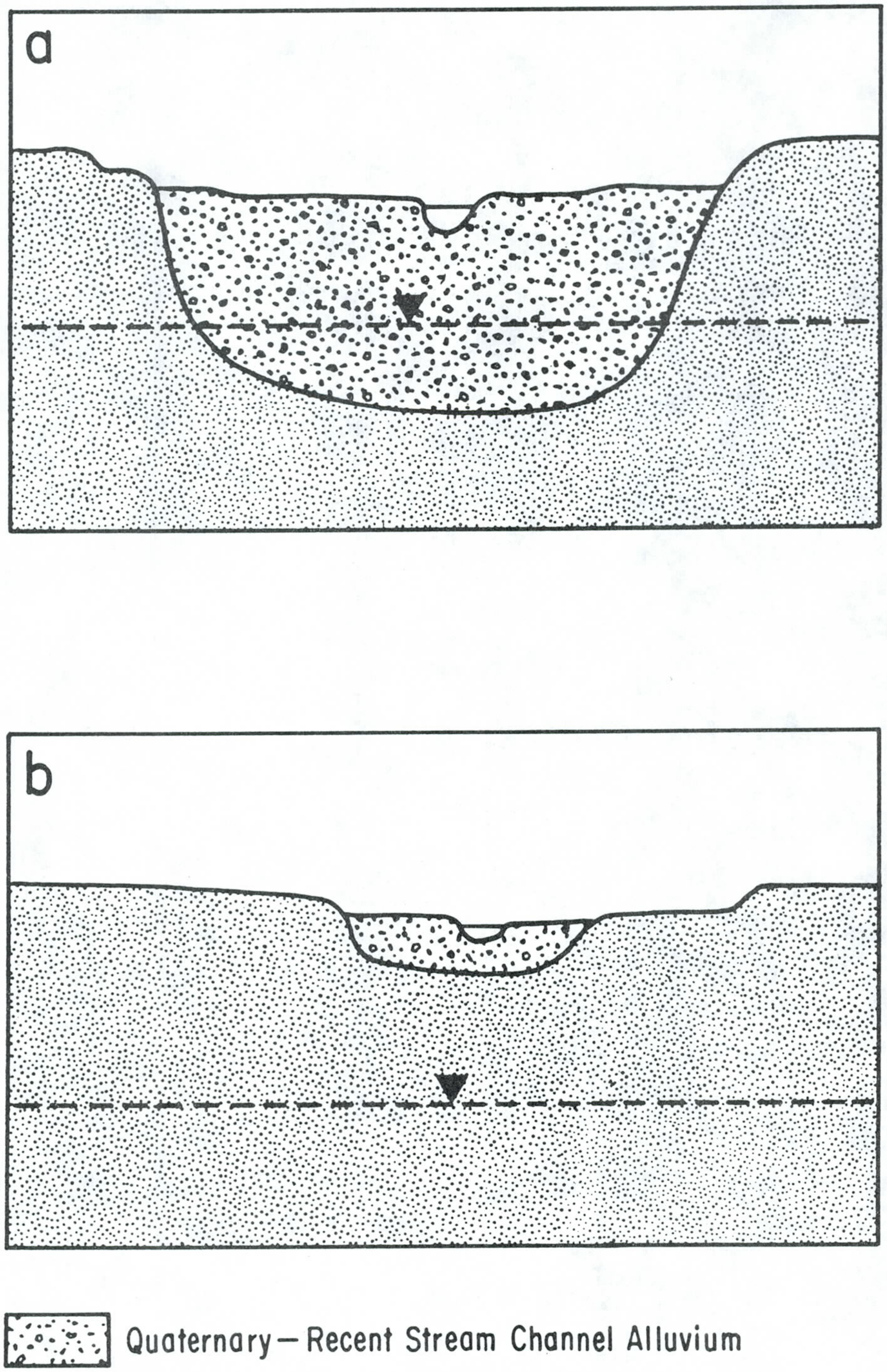


Figure 1. Conceptual cross-sections of two geological profiles along alluvial stream channels (after S. J. Keith, 1980).

alluvium extends below the depth of the water table and recharge occurs fairly quickly. For case 1b, the alluvium unit does not extend below the water table and direct recharge is inhibited. This case is typical of stream channels in the Tucson Basin (CH2M Hill, Montgomery and Wilson, 1987). For both cases, the vertical and lateral transmission rates in the surficial deposits will eventually be limited by the permeability of the contiguous basin fill deposits.

The influence of channel alluvium on the recharge process is demonstrated by water level responses in wells near the Rillito River, in Tucson, during flow events. Matlock (1987) prepared water level hydrographs for a transect of wells along the river during flows in the 1960's (see Figure 2). A marked water level response occurred in wells located within the band of channel alluvium, approximately one half mile from the river channel. In contrast, there was very little response in wells outside the band of stream channel alluvium.

The interface effect which controls flow from the surficial deposits into the basin fill unit will interfere with infiltration rates as the water-holding capacity of the surficial deposits is approached. As this occurs, it is conceivable that water within the surficial region will flow longitudinally, downgradient in the "shoe string" aquifer. This effect has implications for monitoring the area of hydrologic impact of a storage and recovery project and for locating recovery wells.

A concern with recharge projects at sites with deep water tables is that a large quantity of water must be "invested" in the vadose zone to establish a transmission zone from land surface to the water table. Results of a recharge study by J. Marie in an ephemeral channel in south-central Arizona illustrate that this transmission zone may be produced fairly quickly in some channel deposits. During his studies Marie observed a water level response in a well 10 days after the start of a test, where the initial water table was 330 ft below land surface. Accordingly, the vertical velocity of the front reaching the water table was 33 ft/day. Data on water level response were corroborated with neutron logging data in two-inch wells which showed an increase of water content throughout the profile.

The implication of Marie's study for either a recharge or an underground storage and recovery project is that the frequency of monitoring required to detect water level responses may be greater than previously expected.

There is evidence that lateral flow velocities in the vadose zone may also be be substantial during recharge. For example, Wilson and DeCook (1968) reported the patterns of subsurface water movement during natural recharge events at a site in the Tucson Basin. Neutron logging in access well transects along the Santa Cruz River during runoff events revealed the presence of perched ground water at the interface between the surficial deposits and the basin fill unit and a mound above the water table.

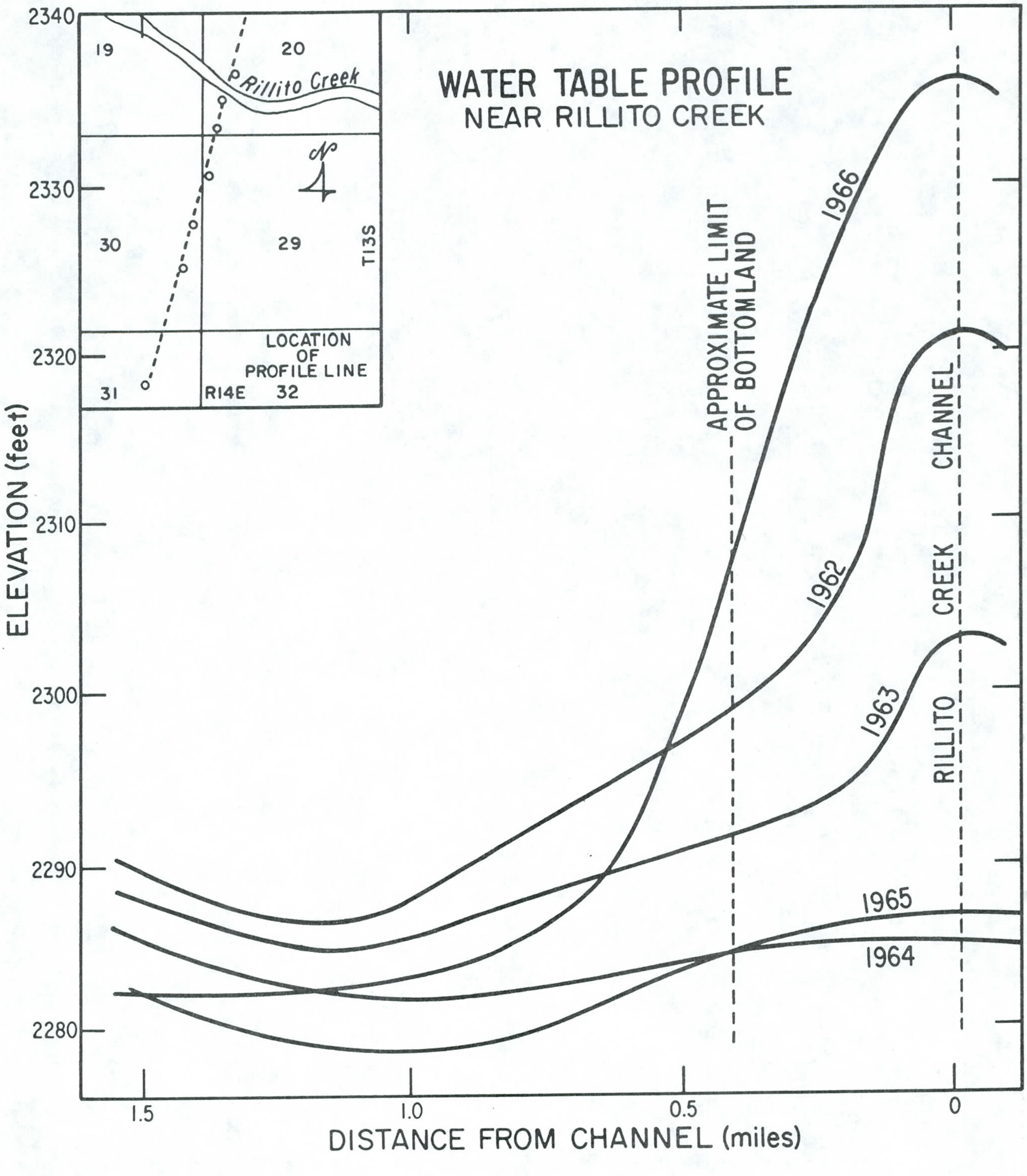


Figure 2. Water table profiles in wells along Rillito Creek during flood events, 1962-1966 (Courtesy W. G. Matlock).

Apparently, the sediments of the perching layer are in hydraulic contact with the river. Vertical leakage of water from the river and from the perched ground-water system into the underlying basin fill deposits appears to have contributed to the growth of the water table mound. Lateral spreading of the recharge pulse was observed travelling in the perched system and water table mound at a rate of between 100 and 150 ft/day. Perched ground water dissipated in two to three weeks, while the lower mound dissipated over a period of 6 months.

The implication of the study of Wilson and DeCook (1968) is that a monitoring network for an in-channel spreading operation should extend far enough inland for accurate representation of the recharge mound.

Monitoring Requirements:

ARS 45-669 specifies that recoverable water is the amount of water, as determined by the director, that has reached an aquifer. Accurate determination of the amount of recharge is a difficult task. This section reviews methods for estimating water that has reached an aquifer.

A common approach for estimating recharge is to observe changes in water levels in monitoring wells and to use specific yield values to calculate the volume of water stored within the water table mound. Water level responses in wells provides clues on the response of the water table to recharge events but fail to provide information on the volume of water in storage under near-saturated conditions.

A study of natural recharge along the Santa Cruz River reported by Wilson and DeCook (1968) revealed the error of using observation well data alone to assess the impacts of recharge. Water levels increased about 15 ft above pre-recharge levels in two observation wells. Neutron moisture logs indicated that an additional 31 ft of sediments were saturated or near-saturated. The amount of recharge was calculated for the 0.34 acre area encompassed by the wells, using an average moisture content change of 25 %. The volumes of water in storage above and below the phreatic zone were calculated to be 2.7 acre-feet and 1.3 acre-feet, respectively. These data demonstrate that measurements from observation wells accounted for only 33 % of the total amount of water that had "reached the aquifer". The remaining volume eventually drains into the water tabel and should be accounted for during determination of recharge credits.

Several methods are available for estimating water in storage within the vadose zone. The most direct method for estimating the water content of a recharging profile is to determine the volumetric water content of solids samples. This requires the use of drilling equipment for obtaining depth-wise samples and a laboratory with a drying oven and auxiliary facilities for determining water contents. This approach is costly and unsuitable for repeated sampling at the same location. Accordingly, indirect methods are frequently used.

Indirect methods for measuring water content changes in a recharging profile relate soil water to an indirect property such as the energy status of water in the porous matrix. Common devices for this purpose include tensiometers, electrical resistance blocks, and Peltier-effect psychrometers. Specific details on these units are described by Everett, Wilson, and Hoylman (1984). Time domain reflectrometry (TDR) techniques relate the apparent dielectric constant of a soil to its water content. These indirect methods depend on a calibration relationship between water content and the property of interest. Obtaining calibration relationships is a costly and time consuming process. Another disadvantage of these indirect methods is that they are difficult to install at depth in the vadose zone. Tensiometers, blocks, and psychrometers provide only point measurements.

Another indirect method that is sometimes used to estimate water content profiles in the vadose zone is neutron moisture logging. The equipment and principles of this technique are illustrated in Figure 3. Basically, when a source of fast neutrons is lowered into a soil through an access well, hydrogen in the water molecules in the soil thermalize or moderate the fast neutrons. The thermalized neutrons are detected, or counted, using the principle of neutron capture. The distribution of water contents is determined from a calibration relationship between volumetric water content and count rate.

The major advantage of the neutron logging technique is that water content changes can be logged in the same profile over time. By using transects of wells, it is possible to define the lateral distribution of mounds and perched water zones in the vadose zone. As indicated in another paragraph, neutron logging in the vadose zone is a valuable technique for detecting stored water that may not be detected by measuring water levels in observation wells.

Marie used neutron moisture logging during his infiltration studies in an ephemeral channel in south-central Arizona. During his second experiment, neutron logs showed a progressive increase in soil moisture from the surface to depth. A significant increase in soil moisture, almost to saturation, occurred in the 50 ft zone immediately above the 330 ft deep water table between the 7th and 16th day after water was discharged into the channel. During the next 5 days, the moisture content had increased a similar amount for a total of about 100 ft above the water table.

A major problem in using neutron logging in deep access wells is assuring that the access well casing are in tight contact with the bore hole to prevent side leakage of water. Side leakage could lead to invalid observation of water content changes in the profile. Drilling methods that ensure tight-fitting casing should be used. This will require installing larger diameter casing than

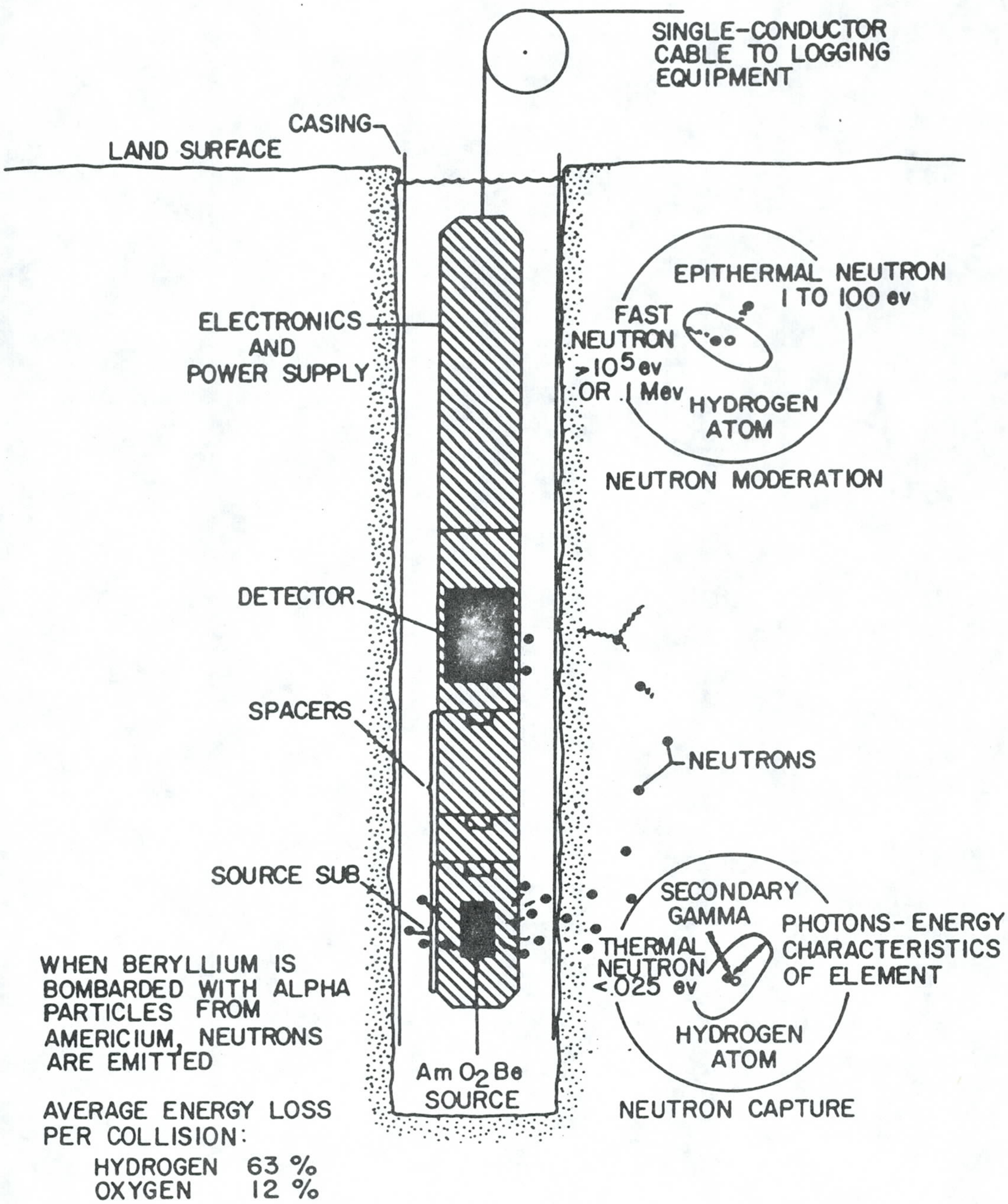


Figure 3. Equipment and principles of neutron moisture logging (after Keys and MacCary, 1971).

used for two-inch diameter logging tools with small neutron sources. Hot neutron sources will be required.

Use of Cl/Br Ratios to Detect Recharge:

The previous sections deal with techniques for determining water accretion to a water table. It may also be important to show that recharge water has mingled with native ground water. Various tracers are possible. Recharge of CAP water may be inferred using a tracer technique developed by S.N. Davis and associates (1987) at the University of Arizona. This technique is based on the principal that the Cl/Br ratios of Colorado River water average about 1250. In contrast, Cl/Br ratios in native ground water in southern Arizona range between 100 an 200.

References:

CH2M Hill in association with Errol L. Montgomery and Associates and L.G. Wilson. 1987. Hydrogeological evaluations for recharge sites. Task 5 Final Draft report. Tucson Recharge Feasibility Assessment. Prepared for Tucson Water.

Everett, L.G., L.G. Wilson, and E.W. Hoylman. 1984. Vadose Zone Monitoring for Hazardous Waste Sites. Noyes Data Corporation.

Keith, S.J. 1980. Stream channel recharge. In: Regional Recharge Research for Southwest Alluvial Basins. Final Report for the U.S. Geological Survey SWAB/RASA Project. Water Resources Research Center, The University of Arizona.

Keys, W.S. and MacCary. 1971. Application of borehole geophysics to water resources investigations. In: Techniques of Water Resources Investigations of the U.S. Geological Survey. Book 2. 126 pages.

Marie, J.R. 1985. Streamflow losses, consequent flow through a thick unsarurated zone, and recharge to an unconfined aquifer. In: Proceedings of the Specialty Conference. ASCE, Irrigation and Drainage Division, San Antonio, TX, July 17-19, 1985.

Matlock, W.G. 1987. Personal communication to L.G. Wilson.

Rice, R.C. 1986. Percolation of water below an irrigated field. Journal Soil Science Society of America. Vol. 50, pp. 855-859.

Wilson, L.G. and K.J. DeCook. 1968. Field observations on changes in the subsurface water regime during influent seepage in the Santa Cruz River. Water Resources Research, vol. 4, No. 6, pp. 1219-1234.

Yeh, T.-C. Jim, L.W. Gelhar, and A.L. Gutjahr. 1985. Stochastic analyses of unsaturated flow in heterogeneous soils. 3. Observations and applications. Water Resources Research, vol. 21, No. 4. pp. 465-471.

Panelist Remarks to
LEGAL AND INSTITUTIONAL ASPECTS:
PROBLEMS AND SOLUTIONS

Floyd L. Marsh
Water Resources Director
City of Scottsdale
3939 Civic Center Plaza
Scottsdale, AZ 85251

Let me first of all say, not knowing what Bill Chase was going to say previous to me, some of my remarks will overlap his. However, they will be more of a generic nature rather than a project-specific nature as he's mentioned.

Introduction

As a prospective municipal recharger, a cursory review of the state proposed aquifer protection permit rules does not make us "warm and fuzzy all over" relative to implementing recharge. The general overall concern is that all the institutional and administrative hoops to jump through in an exhaustive permitting process may, in fact, hinder the implementation of successful recharge projects. Many provisions of these rules appear to be unduly burdensome and restrictive in many cases. The blanket and extremely broad application, rather than flexible facility-specific type of provisions, I think are going to be something that needs to be worked out as the implementation process proceeds. And lastly, in terms of introductory comments, the blanket inclusion of recharge and subsurface storage projects with discharge permitting activities is of some concern to us as well.

Specific Concerns

Next I´d like to focus on a checklist of specific concerns relative to interpretation of the enabling legislation relative to the rule-making process. First of all, the availability of technical information being required, as Bill has previously mentioned, varies site-by-site and case-by-case. The rules and regulations as currently promulgated provide for site-specific permit conditions yet require broad, blanket information in the permit application process, which seems in- consistent. Another concern that has recently come up that we have some concern about is the addition of yet-to-be developed total dissolved solids (TDS) standards including chloride, sodium and sulfates to the existing aquifer quality standards notwithstanding the need and requirement for basic water quality protection. However, will this particular standard be more restrictive than it necessarily needs to be? That is, so restrictive as to prevent otherwise effective recharge operations.

The point of compliance concept, as developed in the rules and regulations, we feel needs greater definition and clarification as to the intent to meet these aquifer water quality standards. In addition a more specific and functional definition of dry wells would be helpful.

One major and fundamental question that we have is will effluent from an advanced water treatment plant, that is a Water Factory 21 type facility, be considered the same as that "... from a waste water treatment works ...", as referenced in the definition of "seepage pit"? An additional point is there needs to be more explicit inclusion of effluent as a source of recharge water in the definition of "underground storage and recovery project", as Bill Chase also previously mentioned.

A joint fee schedule and coordinated reporting process between ADEQ and the ADWR could well assist in implementing groundwater recharge projects. The generally mandated information is frequently difficult and expensive to obtain and perhaps it would be better to negotiate the necessary information on a case-by-case site-specific basis rather than taking a shotgun pattern approach, as is proposed in the rules and regulations.

One final concern that we have before I move into some solutions, is the length of time in processing permits. It´s projected in the AMWUA recharge feasibility study that a groundwater discharge permit may take 7 to 9 months to process. That provides some idea of the magnitude of the concern in terms of the reporting and permitting process. The requirements are going to be quite extensive and exhaustive and time consuming and may stand in the way of doing some ad hoc, short-term recharge that we think is so imperative to get started.

Solutions

In terms of solutions, perhaps there's a possibility to add a provision for a preapplication conference with the Department of Environmental Quality as the Department of Water Resources is doing now in their permitting process procedures. Clarity and practicality in definitions and terms was mentioned. More precise functional definitions of specific terms, such as terms including the discharge impact area, applicable point of compliance and dry wells and injection wells are necessary. Again, the permitting processes should be combined as much as is practical. In fact, the legislation, on which the rules are based, specificaly refers to this in terms of the "to maximum extent practicable." Fourthly, more discretionary flexibility in negotiation of required information should be allowed on a case-by-case basis. In general, many of the informational and reporting requirements could be made director-discretionary or define the criteria more specifically rather than so broadbrushed as they appear to be. So, again, this provides a rather generic synopsis of where we see the major problems areas being in terms of implementing short-term recharge projects specifically and perhaps hindering implementation of some of the long-term recharge programs as well.

Wrapup Summary

I'd like to underscore and echo Bill Chase's comments that we have to utilize to the maximum - the optimum, or whatever the case may be - the effluent resource. It's a very valuable resource and it's going to have to be utilized as best as practically possible. Relative to a wrap-up comment following the open discussion, I would just indicate that it's a good start to make recharge work but let's keep the informational and permitting requirements consistent, practical, and realistic in the rule-making process so that we can keep moving tying back to the symposium theme, as we solve those long-term hurdles required to accomplish recharge effectively and prudently.

Welfare Queens and Wimps: The Saga of HB 2401

by: Bob McCain

Arizona Municipal Water Users Association

My talk is called Welfare Queens and Wimps: The Saga of HB 2401. HB 2401 is the recent bill that was passed in the legislature that established the authority for the Central Arizona Water Conservation District (CAWCD) to get into the recharge and underground storage business. I chose this topic because it is symptomatic and representative of a legal institutional problem in water in Arizona which is that the distribution of water, by economic sector, is inversely related to the value produced by using the water. As passed by the legislature and sent to the Governor, HB 2401 provides the CAWCD with the authority in two areas. The first area is included in Section 01, which describes how CAWCD acts on their own behalf to store surplus CAP water, i.e., water that would otherwise remain in the Colorado River and not be brought into Arizona for any kind of use whatsoever. It's water that would either go to Mexico, go into the Sea of Cortez, or heaven forbid, be used by California.

CAWCD will store this water for use during times of shortage. Any CAP subcontractor will be able to purchase such water, though it's most likely that it will be purchased for drinking water purposes here. There are no problems with this. I think there was total agreement in the water community in Arizona that this should be done. We've got to capture some of that water that's lost in going down the Colorado River to waste. Everyone agrees with this concept anyway. And this is why the cities supported 2401. This section of the bill was vitally important to the state even though we have considerable problems with the other parts of the bill. The specific section of concern is Section 02. Section 02 allows the CAWCD to act as an agent. In Section 01 they were doing it for themselves. They are going to then recover the water, and sell it to others at some later point in time. Section 02 allows them to act as an agent and store a particular CAP subcontractor's allocation that has been granted to them by virtue of contract with the Secretary of the Interior.

In almost all cases, I think, the CAWCD would be storing drinking water for a city. And here is where Arizona's Welfare Queens came off the wall. And in the context of the CAP when I say Welfare Queens I primarily mean Pinal County agriculture. Because that's where most of the CAP agricultural water is going to go. I call them Welfare Queens because they now use federally subsidized hydro power to withdraw groundwater and soon will use federally subsidized surface water (CAP) to grow subsidized and surplus crops. To a large extent their actions in this bill remind me of the welfare mother in Washington with 14 kids who became outraged when the mayor suggested or had the audacity to suggest that she should stop having kids that would only be supported by the welfare system. She said it was her God given right to have as many kids as she wanted and it was society's responsibility to provide her with a house, and enough welfare payments to raise those kids to adulthood. So, too, do the Welfare Queens of Pinal County seem to feel that it's their God given right to have as much CAP water as they want, to grow anything they want, and that the cost should be borne by the drinking water public.

They argued in this bill that if the CAWCD was going to act as an agent and store municipal drinking water for future use, that is to store the water that belongs to the city, the CAWCD must first see if agriculture can use it. Why? Well, they argued that it's much more important to use drinking water today and save groundwater in Pinal County instead of storing drinking water today in Butler Valley or in Maricopa County for future use tomorrow in those areas so we wouldn't have to withdraw groundwater in the future. This is a fundamental question of values over which obviously there is some disagreement. The Welfare Queens also argued that they had always depended on the M&I user increasing its use over time. Therefore they had sized their distribution facilities and had bonded for the distribution facilities under those assumptions. It would be harmful for them and terribly damaging to their interests if the M&I user began to use all of their water at once, either directly through their treatment plants or storage for future recovery.

The problem is that the Pinal County agriculture knew from the beginning that the M&I users could take their entire allocation up front if they wanted and use it for artificial recharge if they chose. It says so in the CAP subcontract. That was the message for the Secretary of the Interior. That was the message from Wes Steiner. They knew this before they bonded for their distribution systems. When the CAP contract was changed for cities, when we moved to a take or pay capacity purchase contract, it was done for the purpose of accelerating M&I use in the beginning including groundwater recharge. Pinal County agriculture was told that this could potentially mean less water for them. Any problem? No problem. Last year when we passed the underground storage and recovery bill, the Department of Water Resources informed Pinal County agriculture that not only do they have an economic incentive to use CAP water, but also they now have the legal and institutional framework where they can recover the water that they recharge. Any problem? No problem to Pinal County agriculture. But now this year it's a big problem. And not only does Pinal County agriculture feel that they have a priority to the use of municipal drinking water, they believe they don't have to pay for it. The M&I user pays for this entire capital, his entire allocation each and every year whether he uses it or not.

According to the legislation, municipal drinking water is a higher value than storage of that drinking water for use in the future. Why did this happen? Well, one of the reasons is wimps. There are a lot of gutless people out there. The inability of several groups to stand up to the Welfare Queens of Pinal County and say you don't rule the roost anymore. You don't pay the freight, you don't get to call the tune. And in my opinion this group includes, and it may come back to haunt me, the State Senate, not the House, the CAWCD, and the City of Tucson.

There are two reasons for this observation. First, in the eyes of the State Senate, the Welfare Queen, the agriculture community has a disproportionate influence when it comes to water. There is a Welfare Queen bias in the Senate. In addition, HB 2401 also came right at the end of the session and there is immense pressure to quiet all outstanding issues and move towards closure.

What they have done, though, is to rank agricultural use of drinking water over the storage of drinking water. There was an editorial in the Scottsdale newspaper Saturday and it said, golf is a big clean revenue producing industry in Scottsdale. Nevertheless, the use of CAP water on golf courses is more ammunition for Congressional opponents of Western water projects. I think establishing a priority of agricultural use of drinking water to grow subsidized crops also sends a very devastating message to Washington and what are they having hearings on in Washington right now? The use of subsidized irrigation water to grow subsidized crops.

Secondly, in terms of the CAWCD, the hardness of its backbone is exceeded only by that of a jellyfish. They put and ran. They bent to the demand of Pinal County agriculture and abandoned those people who had supported them in the past. It was the cities that supported the CAP during Plan 6 regulations. It was the cities that supported the CAWCD during the Hoover hydro power negotiations. The cities supported the CAWCD using their taxing to get into their storage of surplus water. But it was the Welfare Queens of Pinal County who opposed the CAWCD on all of these issues. The upshot of the bill is that the cities will not use the CAWCD to store any city water. We'll do it ourselves. Or we'll use the flood control district because HB 2401 also states that the flood district can act as the agent of a city in the storage of CAP water without establishing any priority for agricultural use whatsoever. If we can deal with the flood control district without any restrictions, why would we want to use CAWCD if we have all those restrictions? I think CAWCD should look at that carefully and decide what this amendment does to their future authority as well. There are groups in the state which would like the CAWCD to remain nothing more than a high class janitor and clerk. Not a water manager.

The City of Tucson also joined the compromise. And traditionally when push comes to shove, unfortunately cities in general, and the City of Tucson in this case, cave in. No guts, no glory.

GROUND WATER RECHARGE: INSTITUTIONAL IMPACTS, ISSUES, IMPEDIMENTS, INCENTIVES AND ILLUSIONS

T. J. Harrison
Assistant Tucson City Attorney

INTRODUCTION:

I am employed as an environmental attorney by the City of Tucson. Any legal research, analysis or advice that I do in the course of my employment is privileged information and may be communicated to others only with the express permission of the City. Therefore, the reader must understand that the following materials do not necessarily represent analysis or advice that I have given or will give to my client. And, it is certainly does not represent the official policy or opinion of the City.

I must also hasten to warn that the following material is not legal advice in the sense that you can plan and order your affairs in dependence upon it. It is in the first and final analysis a rather cursory coverage of a broad and complex subject made by an author with formal training and years of experience in the field of water law. As such, it may be worth considering; it may be worth heeding, but it is not meant to be, nor should it be taken to be, encouragement for you to take any particular action nor that you take that action or approach it in any particular way.

What is this presentation meant to do then? It is meant to alert you to the complex and varied issues inherent in any proposed recharge project. It is meant to alert you to the need to seek competent and adequate legal counsel early in the planning stages of any proposed project. And, it is meant to alert your legal counsel to some of the issues involved in accomplishing your goals. If I accomplish that, it will be a lot.

As will become abundantly obvious as we wade through this presentation, the word "institutional" as used in the title of this paper means, by and large, legal -- that is state and federal laws and regulations, court cases and common law and proposed legislation. In a very few instances, "institutional" means fiscal; however, even then, most fiscal issues are inseparable from legal considerations -- take for example taxes; which are clearly both legal and fiscal.

Lack of time and allotted space are two obvious reasons why I have not expanded this paper into an exhaustive and comprehensive analysis. However, there are two additional reasons for my lack of depth and detail -- to freeze my focus in time and/or space reduces the utility of the analysis. If I involve myself in detailed analysis of Arizona law, I have then ill-served those who propose projects in other places. And, if I blindly proceed based on existing Arizona law and do not acknowledge and account for the potential changes in that law, my analysis might actually mislead any reader involved in long-term planning. You will note mention in several places in this presentation, that state and federal laws impacting on this subject area have undergone numerous changes and additions in recent years. Perhaps more to the point and certainly closer to home, each year there are several proposals before the Arizona legislature which could, if adopted into law, drastically affect ongoing or proposed recharge projects. This is the "illusion" to which I alluded in the title of this piece. Existing law cannot be depended upon. It can and will change. This thought should not freeze you in your tracks - after all, life and business proceed apace in other subject areas despite the dark and shifting path presented by our ever changing laws. On the other hand, recharge projects can involve millions of dollars and thus must, in their planning, financing and design, take into account the lack of surety in the law.

There are bright sides to this "illusion". For one, deep down in the body of the law there are certain given features that can be depended upon to retain their nature even through generations. For example, the concept of property. Thanks to Constitutional protections and to a widespread need, property has been and will continue to be protected. Thus, if you buy a recharge site or a water right, you can be sure that others cannot take it from you without due process and compensation. They can, through the mechanism of the law, regulate your use of property, tax it, reduce its value, etc.; but, they cannot simply take it from you.

And, the malleability of the law is a two-edged sword. Just because existing law would impede your plans is not in and of itself sufficient reason to abandon all hope. Hire a lobbyist. If your cause is just or if your need is shared by many others, if the law has out lived its usefulness or if your power over your adversaries is superior, you can change the law.

The law is meant, after all, to serve us. If, for no good reason (or even if for inadequate reason) it impedes our legitimate objects, it should be changed. And this is particularly so if those changes do not otherwise ill-serve society. Change in the law is not, as some would hold, offensive; in fact, changes in the law in the service of our citizens is the very life and reason of the law. After all, no legislator is absolutely prescient and, conditions do change. The only law that makes sense, is a law that can be changed.

The remainder of this analysis is broken into the following subjects:

1. Obtaining possession and ownership of the water;

2. Transport of the water to and from the place of recharge;

3. Issues involved in recharge itself;

4. Maintaining control of and protecting the stored water;

5. Recovery of the stored water.

I. <u>OBTAINING POSSESSION AND OWNERSHIP OF THE WATER</u>

Recharge, in and of itself, imparts no feature or power of ownership. If you did not own the water in the first place, recharge will not improve your claim to it. This makes perfect sense. For example, I do not in any way advance my claim to stolen money by depositing it into my bank account. It is surprising then the number of people to whom, if they are able to grab onto a drop of water by hook or by crook, recharge represents some illusion of sanctuary. <u>See also</u> A.R.S. Section 45-668 regarding use of stored water once it is recovered.

In the world of water law, just because your capture or use of water offended no particular person's property rights, does not mean that you are home free. Society tends to view unclaimed water as a public resource available only to those who satisfy certain statutory conditions -- both before and during the period of ownership of the water right.

However, in fact, at this late date and level of development, it is difficult to find any water that is not already claimed by one individual or another under an existing water right. Hence, with certain exceptions as discussed immediately below, those who seek to obtain water to recharge must either buy an existing water right or buy land which has an appurtenant water right.

In Arizona, perhaps the most obvious source of "new" water (that is water that is not now available under existing surface water and ground water rights) is Central Arizona Project water. C.A.P. allottees do not hold a water right <u>per se</u> -- instead they possess contract rights. And, those contract rights may not be transferred or sold to others without the permission of the administering authorities - Central Arizona Water Control District (C.A.W.C.D.), United States Bureau of Reclamation and the Arizona Department of Water Resources (advisory only). Thus, if you hope to obtain C.A.P. water to recharge, it behooves you to become active in the ongoing allocation process. The finalization of the allocations is in progress now and authorities will soon reallocate any water that was not successfully allocated in the first allocation - some allottees have refused their allocations. You should move quickly and, be prepared to spend lots of money.

There have been questions raised as to the appropriateness or even legality of recharging C.A.P. water. Non-Indian agriculture has the lowest priority in the C.A.P. hierarchy. In years of low Colorado River flow, agriculture will be the first to be denied C.A.P. deliveries. For that and other reasons, agricultural representatives are loathe to support anything that would encourage or facilitate cities signing up for or taking delivery of maximum amounts of C.A.P. water. If, for example, a city has a C.A.P. allocation of 100,000 acre feet per year; but, in the early years of the contract, that city is only able to take delivery of 60,000 acre fee, that unclaimed 40,000 acre feet will be available for use by agriculture. This, in fact, is fairly typical as the C.A.P. allocation process in gross plans large initial deliveries to agriculture with these deliveries tapering off over the years as municipal and industrial demands grow. Agricultural representatives then view with alarm, municipal plans to recharge C.A.P. water. In the example set out above, the city would then take perhaps the whole 100,000 acre feet per year in the early years, using 60,000 directly and recharging the remaining 40,000 acre feet. The farmers are claiming that recharge is not a "beneficial use" under the C.A.P. contract and applicable law. In effect, they are saying that, so long as there are farmers willing to use C.A.P. water directly, cities should not be allowed to recharge C.A.P. water. It should be noted that, by taking larger deliveries in early years, cities are not exceeding contractual or legal limits per se. The water is theirs to order and use if they see fit. But, the cities probably would not take such large or full deliveries if they were required to use it all directly. Most damaging to the farmers' position are Sections 4.12 and 4.3(b) of the Tucson C.A.P. M.&I. Subcontract in which recharge is expressly listed as an allowable and contemplated use. This is one of the things, as noted in my previous "illusion of the law" discussion, that the cities ought to be able to depend on, at least for the 50 year life of the contract.

C.A.P. authorities appear ready to follow that language and allow C.A.P. recharge. The farmers are promising to sue. Stay tuned for later developments.

It is worth taking time to explore a side development in this same subject area. As will be discussed by Bob McCain, legislation introduced into the Arizona State Legislature this year, would have authorized the C.A.W.C.D. to recharge "excess" C.A.P. water on behalf of municipal and industrial customers in return for reimbursement of costs. As expected, agricultural interests fought this proposal. And, they have apparently won the battle. That is not to say they have won the war however. Cities will still be able to buy and recharge C.A.P. water, they simply won't be able to use C.A.W.C.D. or its available funding mechanisms to do so.

At the same time, agricultural interests seemed to have had some success in modifying the proposed legislation to authorize C.A.W.C.D. to engage in recharge for itself as opposed to the custom contract recharge originally proposed. This is a horse of a different color. Thanks to its lowest C.A.P. priority, agriculture will be the first to suffer in years of low Colorado River flow. Thus, anything, such as C.A.W.C.D. recharge, which promises to make additional water available to C.A.W.C.D. in low-flow years, will be, in effect, an agricultural relief mechanism. The cities, of course, opposed this proposal; but, their absolute bottom line was (and understandably so) that the process must be so structured and financed as to avoid the cities paying for any portion of what is viewed as an agricultural benefit. I can predict with confidence that this battle will go on for years to come in the legislature, in the courts and in the public forum.

An equally important source of rechargeable water is sewage effluent. As existing laws and circumstances force us to search out "new" sources of water, there is no better example of the maxim that one man's garbage can be another's gold.

The rather recent development of interest in effluent means that applicable law is also relatively undeveloped and unsettled in Arizona. Some legal principles regarding reuse have been established over the years in the western U.S.

Effluent derived from local surface water is probably subject to claims by downstream users -- certainly by downstream prior appropriators. Effluent derived from surface water or ground water that has been imported into the basin probably belongs to the importers. And finally, thanks to an Arizona Supreme Court declaration in <u>Town of Chino Valley v. City of Prescott</u>, 131 Ariz. 78, 638 P.2d 1324 (1981), that ground water legally reduced to possession is in the nature of personal property, effluent derived from local ground water probably belongs to the original pumper. Much of this is currently at issue in the John F. Long case. In that case, Long has sued the Valley cities, Salt River Project, Arizona Public Service and all of the utilities that own any portion of the Palo Verde Nuclear Power Plants claiming that the cities had no legal right to sell to the utilities the effluent coming from the 93rd Avenue municipal wastewater treatment plant. The basis for this claim is that under Arizona statutory ground water law, the water had to be used in the service areas of the cities. To the extent that said effluent is derived from surface water, Long claims that it must be consumptively used on the land to which it is appurtenant or, put back in the river once used. This claim is based on principles of surface water law that have been, at least in part, adopted by express legislation. In addition, A Tumbling T has sued those same defendants claiming that, to the extent that the effluent is derived from surface water, it must be placed back into the river to satisfy A Tumbling T's appropriation rights.

As this is written, final arguments have been made and the matter is under consideration by the Arizona Supreme Court. Its decision promises to have substantial impact on what effluent may be available for recharge, where it may be recharged and who may recharge and recover it.

See A.R.S. Section 45-668 regarding legal use of stored water once it is recovered. See also A.R.S. Section 45-669C.2.(c).

There are other potential sources of water which could be used for recharge. Each comes complete with a package of physical, fiscal and legal impediments to success. For example, cloud seeding. This process can be very expensive. And yet, even if you are successful in increasing rainfall, how do you control where it falls and flows? And, more to the point, how do you prove that it's your water to do with as you wish? This lack of certainty of water ownership will probably, for some years to come, limit cloud seeding to public agencies that are created and paid to benefit the public at large.

Another possible source of water for recharge is vegetation manipulation. By changing vegetative cover over large areas, losses to evapotransporation can be reduced thereby increasing runoff and/or local recharge. Vegetative manipulation shares with cloud seeding several categories of obstacles.

1. Establishing that the extra water is yours;

2. The probable need for environmental impact statements; and

3. Potential liability from flood damages due to increased runoff.

In order to produce substantial quantities of "new" water, vegetative manipulating must be done over vast areas. This means that you will probably have to work with and satisfy a variety of federal, state and local jurisdictions. And, you can bet that the prospect of removing native vegetation from thousands of acres and from miles of streamsides will bring the environmental watchdog organizations and agencies into the courts en mass.

Another potentially large source of rechargeable water is conservation savings. Money spent to level fields, line ditches, cover ponds and canals, etc. can yield significant water savings. Who does this water belong to? The answer depends on where you are and on what class of water and water use that you are dealing with. While the ground water law in this state does restrict the amount of water that can be used on each acre of historically-irrigated farmland and it does give credit and benefits to those who use less than their assigned water duty, it makes little sense here to focus on ground water because it is unlikely that anyone would want to pump ground water to produce a source for recharge. In general, in surface water law, conservation savings from non-imported surface water do not belong to the conservor and must be returned to the stream. Conversely, imported surface water generally does belong to the importer as would the savings resulting from conservation. I say "generally" because there are situations where the water law is not the only control - take for example C.A.P., which is not a water right but is instead a contract right, the use of which is governed in large part by the underlying Master Contract and Subcontracts.

There are other pervasive trends that promise to impact on the availability of water for use in recharging or otherwise. For example, regulations and regulators are pressing for more efficient uses of water and for the transfer of water to "higher and better uses". Historically, the law has frozen water uses into a place and person irrespective of subsequent developments. If your great grandfather settled your farm and first irrigated it using public water 100 years ago, you can continue to use that water for free even if thousands of urban dwellers next door are going without. Conversely, all too often, even if you want to sell that water to the urban dwellers, the law will forbid it.

More and more, both prospective sellers and prospective buyers are pressing for changes in the law that will allow water to be freely sold and traded. In fact, a water market is developing in this country faster than the law can accommodate. There are even proposals to market excess Great Lakes water now that some of those lakes are reaching flood stage. A substantial and growing portion of each issue of U.S. Water News (available from 230 Main Street, Halstead, KS 67056) is dedicated to water marketing. Another periodical has begun publication focused exclusively on water marketing -- Water Market Update can be obtained from Western Network, 1215 Paseo de Peralta, Santa Fe, N.M. 85701. See also "Water Strategist: Quarterly Analysis of Water Marketing, Finance, Legislation and Litigation", P.O. Box 963, Claremont, CA 91711, and "Proceedings of the Symposium on Water Markets and Transfers: Arizona Issues and Challenges", Arizona Section of the American Water Resources Association and the Arizona Hydrological Society, Tucson, AZ, November 7, 1986.

Unfortunately, a large portion of what such publications must report are the problems, costs, conflicts and lawsuits that are arising as a developing market runs into the tangle created by a body of law that was never intended to accommodate a free market in water. A body of law which is changing all too slowly.

The rise in the phenomena of water markets and water market publications does, on the other hand, also bode ill for those who seek sources of water for whatever use. That market and its attendant publications is developing thanks to a fierce and growing competition for water. For legal and physical reasons, many sources are not dependable or are not available year round. This is particularly true of one of the more obvious sources -- that is, flood water.

In the meantime, recharge projects can be quite expensive and economic considerations require that the facilities be in operation as much of the time as possible -- it would not do to have such expensive facilities sitting idle much of the year. One part of the solution is to have large (relative to the rate of available recharge capacity) surface storage facilities. You need then only catch a few floods and/or take a few deliveries to keep your facilities running all year. However, land is expensive, large empty mudflats are offensive and storage means losses. Another piece of the solution then is multiple sources. By seeking many different sources of rechargeable water you can be sure that your facility operates at a high load factor. And, you insure against the possibility that you may suffer a loss or failure of any one source.

Before we leave this discussion of water sources and move on to a discussion of the issues involved in transport of water, a couple thoughts are in order regarding flood waters.

One, floodwaters are not as available as they may seem. Surface water appropriations typically cover flows well above those experienced in average years. Do not plan and build a recharge project on the assumption that no one owns or wants flood waters.

Two, diversion of stream flow into recharge facilities presupposes some type of diversion works. (See, streambed ownership in the next section.) The law typically holds that when you change the direction or volume of a natural flow, you are libel <u>per se</u> for any resulting damages. In other words, the plaintiff will only have to prove causation and amount of damages. No proof of negligence will be required. Be sure then, when you design your diversion works that they will not cause high flows (which would have otherwise stayed within the banks of the river) to jump the banks or to flow onto anyone's property.

II. <u>TRANSPORT OF THE WATER TO AND FROM THE PLACE OF RECHARGE</u>

In the preceding Section I touched on the law's tendency to discourage or even outright prohibit a free market in water. Of course, a more practical and natural barrier already exists -- that is, distance and cost of transport. There are plenty of cheap sources of water that my client would dearly love to tap except for the prohibitive cost of transporting it to our place of need. But, this is likewise a two-edged sword. Distance will protect your sources from hungry and well-heeled wolves who covet your local sources. The local guy will always have the financial and physical edge attendant to proximity to the source as will any user downhill from a source. This bears mention because some commentators would lead their readers to believe that all we have to do to create a full and free water market is to get rid of those nasty laws and lawyers.

In the remainder of this section I touch upon four aspects of transportation of water. One is the impact of the law on transport or export itself--when does the law say yes or no to a proposed movement of water; two, touches upon the legal consequences that can arise from the actual movement - what liabilities and losses lie in store for he who would transport water; three, what will the law say regarding comingled water and water lost to infiltration during transport; and four, what are some of the issues involved in pipeline or ditch transport?

First of all, legal limits on transportation. If you outright own water and wish to transport it in a pipeline, you will face few if any legal issues. Otherwise, water transportation is perhaps the most complicated facet of the many faceted challenge that is recharge.

In general, surface water users are viewed by the law as borrowers -- they may use the water but they must return it to its source "undiminished in quality and quantity." This can place severe limits on a prospective recharger. However, once you satisfy all legal claims within the source watershed and export that water, it becomes tangible personal property with all of the rights, privileges and protections that attach to property.

Ground water, once reduced to possession (that is once pumped, as opposed to its legal status while it is in the ground below your property) is also in the nature of personal property. See Town of Chino Valley v. City of Prescott, 131 Ariz. 78, 638 P.2d 1324 (1981).

However, transportation of ground water is governed by a very complex code found in A.R.S. Sections 45-541 et. seq. These sections would not appear at first glance to deserve full discussion in this presentation because you are unlikely to want to pump and transport ground water for the purpose of recharging it later. However, you are likely to want to recharge effluent derived from ground water, imported or otherwise, after its first use. As noted in Section I above, the legal status and ownership of effluent is currently under formal consideration by the Arizona State Supreme Court. Whether or not effluent derived from ground water retains its legal character as ground water or becomes a separate class of property, may control whether or not ground water transportation law applies to such effluent. See also A.R.S. Section 45-668 regarding use of stored water once it is recovered.

Clearly, the direct legal limits on the transport of water are complex and changeable -- they deserve special and continuing focus. In addition, transport of water to or from your recharge site can have major liability implications if you intend to use stream beds for transport.

Clearly, streambeds may be used to transport artificial water. See A.R.S. Section 45-173. However, such transport can give rise to three types of liability.

First, anyone who has ever been sued successfully because children climbed over their wall and were hurt or drowned in their pool knows of the apparent illogic and injustice of the attractive nuisance doctrine. Despite your careful and expensive construction and maintenance of the surrounding wall, the law holds you liable because you built something you knew would be attractive to people of limited judgment -- that is to children. Imagine now miles of streams that would normally be dry but for your transportation efforts. Even fencing and patrolling those washes will not guarantee immunity from extensive and frequent liability.

Secondly, you should be aware of nuisance and tort doctrines in general. Open bodies of water that would not exist but for your transportation activities, can give rise to complaints regarding smell, appearance, insect breeding and even disease transmission.

Third, but certainly not least, is flood liability. The laws hold you liable per se if you change the direction or volume of flow of water. What the "per se" means is that while causation and amount of damages will be inquired into, the plaintiff need not prove that you were negligent -- that you breached any duty of care. Hydrologists concur that a stream that has been dry for weeks or months has more flood or high flow attenuating capacity than does a stream that is or has been recently flowing. When you use a normally-dry streambed to transport or recharge water, you are filling the subsurface and bank interstices that might have reduced a high flow or even prevented a flood. Worse yet, in at least one active case, it is alleged that continuous artificial flows in an otherwise intermittent stream (particularly flows of nutrient-rich effluent) cause choking growths of plants in the riverbed thereby causing high flows to jump the river banks. As you know, flood damages can be astronomical and juries just love to find a deep-pocketed defendant with any arguable physical and legal responsibility.

Note also that the decision to use a streambed to transport or recharge water will probably subject you to the need to obtain a surface water discharge permit and to state and federal (Clean Water Act) surface water quality protection laws, regulations and standards.

Also, you will face an uphill battle in getting A.D.W.R. to certify transmission losses as storage for which credits should be issued to you. Just for starters, where will the recovery wellfield be located? How can you hope to avoid existing wells and service areas belonging to others? How do you prove that it was your water and not natural surface flow that recharged? Etc. Etc. Even if A.D.W.R. is in a cooperative mood, their decisions in your favor can be expected to be legally challenged by those who claim that you are really "recovering" subflow of the stream or that your recovery wells are in their service area or are in violation of well-spacing regulations.

Use of streams to transport water can also give rise to possession and ownership problems. The aforementioned A.R.S. Section 45-173 does make provision for times "when the parties interested cannot agree upon the division of water turned into the natural channel from water naturally flowing therein . . ." However, rest assured that the authorities will err in the direction of protecting the surface water right holders. The burden of proof will be on the recharger and it can be a formidable burden given the tendency to presume all flow to be natural. Even if a stream would normally be dry during a particular time of year; given nature's great variability, who is to say that this is a normal year?

You can, of course, use a pipeline to transport water. Though expensive, a pipeline would limit if not eliminate losses, liabilities and contamination. However, you must first obtain a right of way for your pipeline. Much of what I am about to reveal applies also to a proposed recharge site.

Governmental entities have statutory authority of eminent domain. This means that they can buy land, or easements, by force. Cities can condemn land outside of their city limits for utility purposes. See A.R.S. Sections 9-521 et. seq. And, they can even condemn land within other cities. See City of Scottsdale v. City of Tempe, 90 Ariz. 393, 368 P.2d 637 (1962).

Cases in California have established that one municipality can even condemn easements through another municipality's property so long as the easement will not unreasonably interfere with the land-owning municipality's principal purpose. In other words, the City of Tucson could condemn a pipeline easement under the streets of the City of Marana because the pipeline, being underground, would not interfere with the use of the street to move traffic.

This is not mere abstract analysis. The City of Tucson has bought and retired many farms in Avra Valley. We are reaching out to a remote source much as you might to obtain a source of recharge water. Some, particularly those who sell us their farms, are quite pleased with our purchases. Others, for example those who sell chemicals and equipment to farmers, are less than pleased to see fewer active farms. That, combined with the perceived hegemony in water rights purchases (he who owns the water, owns the future) apparently lead the City of Marana, a few years ago, to annex enough farms and desert to quadruple their size overnight. I say apparently because it was only the grapevine that revealed to me that by the annexation, at least some of its authors hoped to stop the City of Tucson from building a pipeline from our farms in Northern Avra Valley into the City of Tucson. So the theory went, if we could not transport the water, we wouldn't buy any more farms. If my research, as reported above, is accurate, they annexed in vain.

It is worth noting that this year legislation was proposed that would, if enacted, strip cities of their power to condemn extraterritorially. That move was apparently born of two concerns. One, some hoped that it would stop farm water rights purchases. This position ignores the fact that, to date, all municipal purchases of farms have been from willing, even enthusiastic, sellers. Two, some hoped that cities could be thereby stopped from providing extraterritorial water service. The City of Phoenix's habit of charging higher rates outside of city limits no doubt added fuel to this furor. This approach ignores the fact that most cities' services to those outside of their city limits represent vital and valuable service. Without the economics of scale available to the City, many of their neighbors could not obtain healthy, reasonably-priced water. In fact, if cities are denied the ability to serve water outside of their city limits, many nonresidents who would not otherwise dream of doing so are going to fight to be annexed.

An unintended victim of such an extinguishment of our cities' extraterritorial condemnation powers would be our ability to serve within our borders. Sources, pipelines, treatment facilities, reservoirs, all too often must, by virtue of the topography and geography involved, be built outside of the city even though they are dedicated to service within that city. Just such a necessity is a pipeline from a remote source. Pipelines cross so many different properties and jurisdictions that condemnation is almost an absolute necessity. Without that power, one owner can blackmail or even block a multimillion dollar project. Depending on what our legislature does regarding power of condemnation, stream beds may actually prove to be more available or practical than pipelines for transporting water to or from your recharge site.

Another possible means of transport of rechargeable water is the C.A.P. ditch. There is ongoing discussion about how much extra capacity there might be in the ditch under various circumstances. I will leave that to the technicians to debate. Two things are clear, however. One, in those years in which there are low Colorado River flows and thus lots of extra ditch capacity, other sources of water are likely to be just as low or lower. Hence, the C.A.P. ditch is likely to be more readily available for transport from recharge site to use than for transport from source to recharge site. And, all concerned should stifle the urge to seek subsidized or special rates for their transport. The moment that you plead for less-than-cost rates for yourself, you admit that such rates are legal, ethical, reasonable, etc., but there is no way to be sure that someone else does not fall heir to your arguments thereby leaving you paying the subsidy. Likewise, I counsel against seeking exclusive access to any excess ditch capacity. Open market access or pro rata access will serve best the greatest number. And, it will preclude you being frozen out by someone else who proves more deserving of the exclusive access that you first argued was O.K.

III. ISSUES INVOLVED IN RECHARGE ITSELF

As noted in the preceding section, activities within streambeds can give rise to liability. A recharge facility in a streambed, while enjoying relatively great recharge rates thanks to subsurface permeability, does give rise to potential flood liability. Filling of subsurface and bank interstices will reduce flood attenuation capacity. Worse yet, locating physical recharge or diversion structures in a stream could well cause high flows to jump the banks. The applicable liability *per se* combined with the great damages that can result from floods should give you great concern about locating your facility in a stream bed. Note applicability of state and federal surface water quality laws if you use the stream as a recharge mechanism.

In addition, there is the whole issue of who owns the stream bed. In general, in Arizona, for the smaller washes, you can safely presume that the contiguous landowners each own out to center of the stream.

Legislation passed during the last state legislative session attempted to clarify the streambed ownership issue as to the bigger streams within the state. However, some commentators have declared H.B. 2017 to be unconstitutional for one or more reasons. And, it hardly clarifies the issue. *See* A.R.S. Sections 37-1101 *et. seq* . *Part* of the problem involves applying to intermittent streams definitions and concepts that were developed for perennial streams. "'Bed' means the land lying between the ordinary high water marks of a water course." "'Ordinary high watermark' means the line to which high water ordinarily reaches and not the line reached by unusual floods. It is the line below which the soil is unfit for vegetation or agricultural purposes."

My file on streambed ownership alone has grown to three inches thick. This latest law only adds to the questions, confusion and issues already in that file.

The nuisance and attractive nuisance doctrines discussed in the preceding section also apply here. Imagine the bug breeding potential of a flood water storage facility. Imagine the reactions of proposed neighbors when they learn that next to their home will be a "lake" to attract and drown their children 6 months of the year which will turn into a large mudflat the rest of the year? One approach is to obtain such many and varied sources as enable you to keep the lake full and usable for recreation -- a multiple use facility. However, the fact remains that any facility designed and operated to make effective use of floodwater must remain empty or near empty during certain portions of the year.

Of course, since the 1986 state legislative session, you are now required to obtain a recharge permit for artificial recharge and a storage and recovery permit if you wish to recharge and recover water so stored.

Finally, water quality issues are complex and unavoidable.

Tucson's aquifer has been declared to be a federal Sole Source Aquifer. This will only impact and impede "federally assisted projects" -- a very narrowly defined category which does not include the Central Arizona Project but which may include one of your projects if the feds help you pay for it. What the designation does do is place in the minds of the public and the regulators an extra dollop of concern -- it is officially a vital resource.

The most recent additions to the federal Safe Drinking Water Act, also in 1986, have added to the law the concept of drinking water "wellhead protection areas." The law requires in those areas extra levels of protection from and prohibition on "anthropogenic" sources of contamination. By definition, if you are recharging for purposes of later recovery for drinking water use, your recharge facility will be at least part of the wellhead protection area for your recovery well field. You would be well advised to read, understand and follow the developments in this subject area.

In a very parallel move, the 1986 Arizona Environmental Quality Act establishes a presumption that all aquifers are or will be used for drinking water and, for purposes of calculating what may be discharged to those aquifers, the applicable use-based standards are to be applied in situ. Per A.R.S. Section 36-541, recharge projects must obtain an aquifer protection permit from the Department of Environmental Quality. See also A.R.S. Sections 45-652B6 and 45-664B5 which set out a D.E.Q. discharge permit as a precondition to a recharge or storage and recovery permit. See also A.R.S. Section 36-3544C in which applicable ground water standards are mandated upon recharge projects. While this does raise the specter of mandatory treatment of water sources before recharge, that eventuality is remote, at least for relatively pure sources. After all, in some places recharge is used as a treatment process thanks to the attenuative capacity of the subsurface strata and some people in Tucson are even pressing for the City to use recharge as our only means of C.A.P. water treatment -- they are that convinced of the ability of recharge to cleanse water.

This subject is certainly not closed and you should keep a careful eye on it. In particular, you must be vigilant that the in situ standards are solidly health-based and do not impose impractical and unnecessary burdens.

It is also worth noting that point of compliance (the point at which measurements are to be made to determine compliance with standards) under the law applicable to discharge permits is a moveable negotiable point at least for non-toxics. A.D.W.R. has noted that they do not care if you recover the actual water you stored by recharge. I submit that A.D.E.Q. may. If you can convince A.D.E.Q. that you have designed your project so as to assure total recovery of the actual water recharged, you can probably negotiate a rather far-flung point of compliance and be allowed to discharge some relatively nasty contaminants -- after all, they (the contaminants) are not going anywhere because you are going to recover that water before it reaches anyone else's well.

IV. MAINTAINING CONTROL OF AND PROTECTING THE STORED WATER

Once you have your water safely recharged, one of your major new concerns must be protection of its quality.

One way to protect quality is to choose a remote undeveloped area in which to store your water. Lack of activity (urban, industrial or agricultural) usually also equates to lack of sources of contamination.

Another means by which to protect both water quality and water quality is the purchase of the overlying land. If you own the land, then you can control absolutely what takes place on that land.

You can also gain control of surface activities by obtaining leases, easements or other rights short of full fee simple ownership. Many communities have achieved control of land by management agreements with state land departments, U.S. Forest Service, U.S. Bureau of Land Management, etc. Below is a partial list of communities that have created enclaves for the purpose of protection of surface water quality. Some, by a combination of ownership, lease, management agreement, etc., have gained control over tens of thousands of acres. In some cases, no activities are allowed on the lands. In others, limited activities, such as hunting, are allowed; but, in no case are the allowed activities inconsistent with the goal of water quality protection.

LAND CONTROLLED/OWNED BY CITIES FOR WATER RIGHTS

Location	# of Acres Owned* or Controlled**	Uses Allowed
Seattle, WA	74,860* 29,025**	Timber harvesting, research, education, archaeology, wildlife sanctuary
Los Angeles, CA	320,000*	Grazing, wildlife preserve, agriculture
San Diego, CA	25,271*	Agriculture, grazing
Tacoma, WA	13,487* 147,840**	Logging, recreational
Everett, WA	6,400*	None
New York, NY	90,000*	Utility easements, school playgrounds/ athletic fields, fire stations, and other public facilities
Boston, MA	96,000*	Recreational, timber harvesting
Salt Lake City, UT	119,040**	Recreational

Fort Collins, CO	1,040*	Recreational, grazing
Colorado Springs, CO	15,000*	Recreational

Source -- "Avra Valley Land Use Study" -- August, 1984 -- published by City of Tucson Planning Department.

All of the preceding examples are communities that have obtained control of land to protect surface water quality. In its simplest sense, the land control is used in order to avoid the cost of building and operating drinking water treatment plants. However, the same principle would apply to protecting ground water quality and quantity. You can protect the quality now, by whatever means available, or later suffer the costs and consequences of contamination.

Note also that the State of Rhode Island is currently proposing to spend over $35 million to buy land adjacent to municipal water supply sources in order to protect water quality. See the March 13th, 1987 issue of the Bureau of National Affairs' Environmental Reporter.

It is important to emphasize the value attendant to the protective function described above. All too often there is a tendency to say "we own the land, it's just sitting there idle, we should do something to make it earn a return on its cost." This can be a serious mistake. If you buy the land in order to protect the quality of the underlying water, you should be very careful about which activities, if any, that you allow on that land. Most human activities carry with them the threat of ground water contamination.

As discussed in Section III, above, ground water quality protection laws and regulations can limit, prohibit or increase the costs of recharge activities. Those same mechanisms, however, have another edge. You can use them to your advantage. Once you have water in storage underground, those same laws and regulations can be your sword and shield in your battle to protect that water from contamination. Apprise yourself of any activities that threaten your water, educate yourself as to what laws and regulations may be used to control those activities and then see to it that the proper authorities do their job.

Also, in reviewing applicable laws and regulations, note those areas of inadequacy and take such action as is necessary to correct the situation. For example, as often as not, agencies charged with environmental monitoring and enforcement are underfunded. Use whatever influence you have on the appropriate process to see that adequate funds are provided. The 1986 Arizona Environmental Quality Act calls for 17 different rule making processes related to water quality protection to take place within the first two and one-half to three years after its adoption. The rules will add detail and practicality to the law. The regulations will range from agricultural controls to hazardous wastes disposal. Contact the Arizona Department of Health Services or, after July 1st, the new Department of Environmental Quality and obtain a regulatory calendar. Determine those bodies of proposed regulations that will impact on your interests (including the quality of your recharged water) and then involve yourself in the extensive public hearing and input process that is by law attendant to each rule's promulgation.

Of course, all of the above discussion of the presence or development of environmental regulations also applies to the use of streams for water transport as discussed in Section II above. You can use and depend on those regulations and laws to protect the quality of your water as it moves through the streams of this state. All dischargers to the stream must obtain and obey National Pollution Discharge Elimination System Permits. However, the standards that must be obeyed do vary depending on the uses for which that segment of stream is certified. If you are going to transport drinking water in a stream, be sure that all involved segments are officially protected to drinking water standards.

The other major item involved in protection of your stored water involves quantity protection -- keeping others from pumping and using your stored water. Our moderator asked if recharge legislation passed by last year's Arizona State Legislature has impacted our clients' operations. The short answer, at least as regards protection from others, is "no." That new legislation, A.R.S. Sections 45-651 <u>et</u>. <u>seq</u>. and Sections 45-661 <u>et</u>. <u>seq</u>., along with preexisting law, did little to assist a recharger in protecting stored water from competing pumpers. The principal protections provided appear in A.R.S. Section 45-672 and involve prohibitions on certifications of assured water supply and on construction of new wells and replacement wells "within the area of hydrologic impact of an underground storage and recovery project" to persons other than the recharger. Also that section limits issuance of various types of special ground water withdrawal permits such as dewatering, mineral extraction, general industrial, poor quality water, etc. Clearly, such prohibitions can be quite valuable to you if your stored water is threatened by a new use, particularly new uses falling within the above-cited special withdrawal permit categories. However, the law does little to protect your stored water from existing uses and users. For that reason, you would still do well to recharge or store your water in an area which you control (such as the center of your service area) or some remote isolated area in which you face no existing or projected competition.

V. RECOVERY OF THE STORED WATER

There is not too much left to say because much of the preceding discussion also impacts at least indirectly on recovery issues.

Here is where our moderator's questions elicits a positive answer. The 1986 recharge legislation does indeed have significant impact on recovery. For the first time you can recharge confident that you will be able to recover the water even from areas outside of your actual service area. This is one of the incentives I alluded to in my title.

Note that permit conditions may be later modified and that in doing so, D.E.Q. may not ". . . consider land uses and water uses in the area of hydrologic input of the project which were not in existence when the permit was issued."

Note also that there are two types of permit -- a "recharge" permit and a "storage and recovery" permit. If you intend to later recover it, legal precision dictates that you call it storage, not recharge. In many places in this presentation I have used "recharge" to mean recharge and/or storage and recovery where this would not mislead or confuse. It is worth noting that recharge within an area you control and in which you may legally pump is much like storage and recovery except that you cannot obtain the benefits that flow from storage credits.

Note also that well-spacing regulations will apply to your recovery wells. See A.R.S. Sections 45-664B.4. and 45-667B.1. Here again I submit that A.D.W.R. may well be interested in your recapture of the actual water you recharged. If you can convince A.D.W.R. that your project is so designed, you should, by definition, automatically comply with well-spacing performance standards.

It is also worth noting that the 1986 additions and changes to the federal Safe Drinking Water Act would appear to establish traditional drinking water treatment technology as a presumptive mandate. In other words, all drinking water will have to be treated unless you can prove that the quality is such that treatment is unnecessary or that your proposed alternative treatment technology is the equivalent of traditional treatment methods. This means that you must approach the concept of recharge as a treatment process with great care -- you may well be required to traditionally treat your recovered water at least until a few years operations prove to the authorities that recharge will adequately treat. Under any reading of the federal act, there is no way that an all-recharge treatment process will be allowed in the short term -- you will be required to build a treatment plant and operate same until recharge proves itself as a treatment process.

Finally, I note that in A.R.S. Section 45-669 there is an attempt to force direct use of C.A.P. water in preference to continued pumping of groundwater while the user recharges C.A.P. water. Such a principle is, of course, anathema to any concept of recharge as a treatment process for C.A.P. water -- it certainly obviates any all-recharge C.A.P. "treatment" strategy. The statutory section under discussion came into being because certain influential parties feel that it is inappropriate for anyone to be recharging C.A.P. water while anyone else is still pumping and consuming ground water. This philosophy ignores the very real need to match quality with use -- they ought to be at least as upset that some users will have to treat C.A.P. water to meet drinking water standards while at that same time pure sweet ground water is being used on surplus crops. More to point perhaps, so long as Pinal County refuses to accept safe yield as a statutory mandate, why should we allow them to export the negative impacts of their profligate ways. That is in effect what happens when we are told we may not recharge any or all of our C.A.P. water so long as others are overdrafting.

Groundwater Recharge in Arizona
State Health Department Perspective

Norman L. Weiss
Manager, Planning and Program Development
Arizona Department of Health Services

With the enactment of new laws, there can be understandable confusion regarding the procedures which may need to be followed to obtain a recharge permit. It's important to understand that under the Environmental Quality Act, under the Recharge Act, we have a very complex law that requires very clearly defined procedures. Just for the record, the Department of Environmental Quality or Department of Health supports recharge, but recharge is considered a discharging activity which is required to get a permit. The permit isn't a right, but a license or privilege subject to certain conditions. Under the Environmental Quality Act, the aquifers are protected for drinking water use. Water conservation augmentation and water quality protection certainly can be compatible goals. I think these are reinforced in both the Groundwater Management Act and the Environmental Quality Act. However, there are some basic environmental concerns regarding recharge which primarily pertain to the issues of land use and location. Historically, riverbeds in Arizona have constituted cheap land from a real estate perspective. We've dumped our garbage, hazardous wastes or sewage in these areas. Riverbeds are also considered prime location for recharge activities. Environmental concerns become pronounced when you have a situation where recharge activity may increase the water level perforating the base of older existing land fills or impoundments contributing to leachate percolation.

Environmental concerns also become pronounced when you have a recharge project that alters the flow of the goundwater and affects nearby pumping or remedial action projects. Under the Environmental Quality Act, facilities like impoundments, pits, pounds, lagoons and landfills are required to get aquifer protection permits. We are currently in the process of developing rules governing this process. In order to be issued a permit, an applicant must demonstrate that the best available demonstrated control technology is being used to reduce the discharge. They're also supposed to ensure that they are in compliance with the aquifer water quality standards.

Recharge projects must go through that permit process. There are some distinctions as Bill Chase indicated. First is that the BADCT demonstration does not apply to recharge projects or underground storage projects. BADCT does, however, apply to waste water treatment plants and we're going to need to consider the use of effluent and water conservation when we're developing that BADCT for the waste water treatment plant. The highest technology for a waste water treatment plant may not be the best technology for recharge particularly if you're concerned with some of the issues of chlorination and the generation of trihalamethanes.

In terms of the aquifer water quality standards, all facilities that discharge are going to be required to comply with those standards. Aquifer water quality standards currently constitute about twenty-one EPA primary drinking water Maximum Contaminate Levels (MCL's). We will be adopting some new ones in June, but those that might be of interest for a recharge project, I believe, would be nitrates, trihalamethanes, selenium and arsenic. Currently, we are evaluating the literature regarding development of a health based standard for TDS or its constituents. I think it's going to be important to try to come up with a health based number. By doing so we can avoid debating what constitutes a health based standard and what does not as each recharge project situation occurs. That is one issue we are trying to evaluate. The other, pertaining to aquifer water quality standards, is that the Department is pursuing the adoption of a narrative health based aquifer water quality standard. We have been trying to discuss this through a variety of mechanisms. In fact, the Water Quality Advisory Council has been dealing with this issue and, at the last meeting, there was unanimous support for a narrative health based standard.

In order to get a recharge facility through the process, there are a number of permit processes one will need to go through. One is the aquifer protection permit process under the Department of Environmental Quality. Obviously, the other one is through the Department of Water Resources for recharge. Dredge and fill permits under the Corps of Engineers may be required. Also, the concern of local zoning and land ownership, I believe, is going to be more pronounced.

There have been a couple of recent events in the legislature of interest. One is House Bill 2017 which deals with the ownership of streambeds. As I understand it, if somebody owns the land or has paid taxes on land on the Salt, Gila or Verde Rivers, they should pursue a quick-claim deed with the State Land Department to clarify the land ownership. Under our proposed aquifer protection permit rules, an applicant will need to hold free title to the land or provide some documentation so that the owner is aware that a discharge is occurring on the property.

Also, House Bill 2335, commonly called the DEQ omnibus bill, has some provisions dealing with the zoning issue and the issuance of aquifer protection permits. Under that law, the Director cannot issue a permit unless it appears that evidence submitted from the applicant shows that it's in compliance with local zoning. These are some of the provisions that people should be aware of as they're going through the aquifer protection permit process.

I believe that there are numerous opportunities for both the Department of Water Resources and DEQ to coordinate in the permit process. There is no reason to reinvent the wheel. I think there are some common information bases as one goes through the aquifer protection permit and recharge permit processes. Some of these might be in the hydrologic investigations that are required. Other opportunities, as someone mentioned, are reporting requirements. Certainly, we can anticipate that some possibilities of joint public hearings will arise in the future. Also, in financial and technical competency testing, opportunities exist for a common base of information.

As Frank indicated, we are further pursuing a joint permitting scoping process. I think it's also important to note that some of the requirements under the Environmental Quality Act, in terms of penalties and who can sue, are somewhat different. Under the Environmental Quality Act, there are civil penalties up to $25,000. There are criminal penalties if someone knowingly fails to monitor a sample or knowingly violates standards. Further, there are citizen suits authorized which is a rather significant development. This is the first time that action suits can be initiated under environmental law in Arizona.

(Postscript)

Based in part as a result of the dialogue established at the symposium, DEQ is proposing a permit by rule (general Permit) for Recharge demonstration projects which use C.A.P. aqueduct water or water which meets a drinking water quality criteria.

Question

How many applications do you have for permitting at this time and what is your specific process?

Answer

We're currently in the process of developing the rules. We have over 900 facilities that have notices of disposal or groundwater permits. Under the Environmental Quality Act, if you currently have been issued a Groundwater Protection Permit or if you have been issued a Notice of Disposal and you are meeting the aquifer water quality standards, you will be deemed in compliance until your permit is called in. And we'll be concentrating on the new facilities first.

Comment

My personal research file on streambed ownership has grown to over three inches and has not produced clear answers. House Bill 2017 is argued by some people to be unconstitutional and, therefore, may not be effective. Even if it is effective, I don't feel that it necessarily clarifies things. In some cases, it confuses things. If you're planning on building a recharge project particularly on spending a significant amount of time in a streambed, I would suggest that you get a good lawyer on your planning team early on.

Question

What may be a zoning or local land use law that would conflict?

Answer

Each city often has their own zoning ordinances, their own local controls. All that is required under this law is that the applicant demonstrate that they are in compliance with the local zoning. That might require documentation from the local Planning and Zoning office or something else.

Question

I'm hearing that you're holding in this permitting process into something ongoing in the Department now. It is not a new permitting process that you're instituting, particularly for recharge. Is that correct?

Answer

We do have the groundwater protection permit program on line and, if a facility is discharging, they would need to comply with the standards.

INSTITUTIONAL ASPECTS OF WATER RECHARGE

William B. Lord
Director, Water Resources Research Center
University of Arizona

Many of you may have read a little essay by Garrett Hardin called "The Tragedy of the Commons". In his essay Hardin used the example of the English grazing commons. In every village there was an area not owned by individual farmers but owned by the village in common. He pointed to the fact that the incentive was to overgraze the commons; to deplete it. No single grazer could prevent others from overusing it, and therefore there was a race to get as much as you could before the utility of the resource disappeared from overuse. This led to a collective tragedy which he called the tragedy of the commons. The utility of the paradigm of the commons isn't confined to talking about grazing. There are many other examples of a commons, such as the ocean fishery, where there is a constant tendency to overfishing because nobody can be excluded, and to the oil field where the same situation pertains. In this latter case we've developed a set of institutions called unitizing which controls and prevents overuse of that particular common property resource. Groundwater is yet another common property resource, and we can expect to find overutilization of groundwater as well as fisheries and petroleum fields. This has occurred in Arizona, which is why we have the Groundwater Management Act of 1980. Whether or not groundwater overdraft can be reversed is problematic, but at least it should be arrested. This is the goal of safe yield.

There are generally held to be two ways of addressing the problem of the tragedy of the commons. One of those ways is the regulatory approach. To go back to the metaphor of the common grazing area, this approach is akin to asking the Bureau of Land Management or the Forest Service to issue grazing permits so that no individual has property rights but each individual's use is controlled through this regulatory issuance of permits.

The other solution is to subdivide the commons and make it a matter of individual property - to issue title to a portion of the commons to each particular grazer. Then, if the individual grazer can fence his own particular portion of the commons and exclude all others, he's able to confine his own use and manage the resource. Either way, overuse can be controlled, either through administrative fiat or through creating the preconditions for socially responsible individual behavior.

It's hard to build a fence around groundwater, and we have not succeeded with groundwater in general. But as Gray Wilson told us this morning, the new recharge law of last year does succeed in building a fence at least around recovery water, if not the rest of the water in that aquifer. And, of course, with that law we have taken a private market approach, in a sense. We've created property rights to a portion of the water in the aquifer. I'll come back to that a little bit later but now I want to draw your attention to the fact that that fence is not 100 percent effective.

Returning once again to the grazing metaphor, if it's cattle that I'm grazing and I use a barbed wire fence, the fence is very effective. However, if somebody is grazing animals which can jump over such fences, then those animals will not be deterred by barbed wire fences and you'd be back in the problem of the commons again, because you couldn't have effective exclusion of others.

To what extent does the recharge law provide effective exclusion and protect the rights of the recharger in this case? It does pretty well in protecting the quantity of water to which the recharger is entitled, but there are two gaps in the fence. First the value of recharged water may decline after recharge because other users of the aquifer may have drawn it down. It costs more to pump back out than it would have had when you first recharged and when water levels where higher. So there is a possible loss to the recharger through the actions of others. Theoretically, that won't occur when we attain safe yield, at least in the urban AMA's, but it will occur everywhere until then and it will occur outside those AMA's even after 2035. The other gap in the fence, as it were, is the one we heard quite a bit about already this afternoon, and that has to do with quality changes. If you recharge high quality water into an aquifer the quality of that water may indeed be degraded before you can recover it, if through the actions of others or through the mixing of lower quality water in the aquifer itself.

We could go further into these considerations but the point is that we haven't solved the problem. I thought this was going to be a revolutionary statement before hearing all the rest of the panelists. Now I realize that it's something of an anticlimax. We haven't solved all of the problems and these are at least two that we have not solved. There are fundamental reasons for this failure. I think that our struggles to eliminate the institutional barriers to recharge and our general stream adjudication of the Gila River system both are leading us in the same direction. We are finally going to have to achieve what many people have been calling for for thirty years, which is integrated water quality--water quantity management, together with conjuctive management of ground and surface water resources. None of you will be surprised to hear that this isn't going to be easy. It will be very difficult because we regulate our surface waters, our groundwater, and the quality of both, in fundamentally different ways. Surface water use is controlled by the prior appropriation system, which is basically a free market approach. Groundwater use is controlled by the Groundwater Management Act, which is basically a regulatory approach with a few free market features thrown in. Additionally, any shortages in surface water availability are borne entirely by junior appropriators, while groundwater shortages are shared by all users, following the principle of proportional sacrifice. We regulate water quality with our Environmental Quality Act, which is almost entirely a regulatory approach. How we can succeed in melding those sets of insitutions that rely on totally different principles I think is the real challenge ahead of us in the years to come.

PROBLEMS AND FUTURE PROSPECTS OF GROUND WATER RECHARGE IN CALIFORNIA

Donald J. Finlayson
Principal Engineer
California Department of Water Resources
Sacramento, California

Abstract

The California Department of Water Resources (Department) has recently completed an engineering report on ground water recharge in Kern County, California. The report concludes that conjunctive operation of the State Water Project (SWP) surface water facilities with ground water storage is feasible. The Department proposes to use one-million acre-feet of storage space underlying Kern County as a "water bank." Water from the SWP California Aqueduct would be conveyed through new canals to spreading basins and later withdrawn through wells for return to the State system. Capital costs are about $78 million; financial costs to the State water contractors are about $70 per acre-foot. Full feasibility studies will begin soon, as will studies to expand the areal extent and storage capacity of the Kern Water Bank.

Evaluation of the Kern Water Bank Program

We have recently completed a report on a prefeasibility study of adding ground water storage to the California State Water Project (SWP) and operating the ground water basin as off-stream storage. The objective of the study was to evaluate the desirability of purchasing all, or a portion of, lands offered for sale by TWI (Figure 1) for the purpose of a direct recharge, storage, and extraction program. This program is designated the first element of the Kern Water Bank. We call this operation water banking, rather than conjunctive use, because our use of a locally controlled ground water basin is limited to a determined amount of storage. The property offered was of interest to us because it was on an alluvial fan adjacent to the principal aqueduct of the SWP.

A program Environmental Impact Report (EIR) was finalized and filed in December 1986. The concept of the Kern Water Bank (KWB) was discussed with both local and statewide interests during 1986. The concept has evolved to a coordinated program between the SWP and local agencies, which would consider a mix of both direct and in-lieu recharge of local and imported water. In-lieu recharge is being considered in several areas overlying the Kern County Basin. The program, as envisioned by the Department of Water Resources (DWR) and

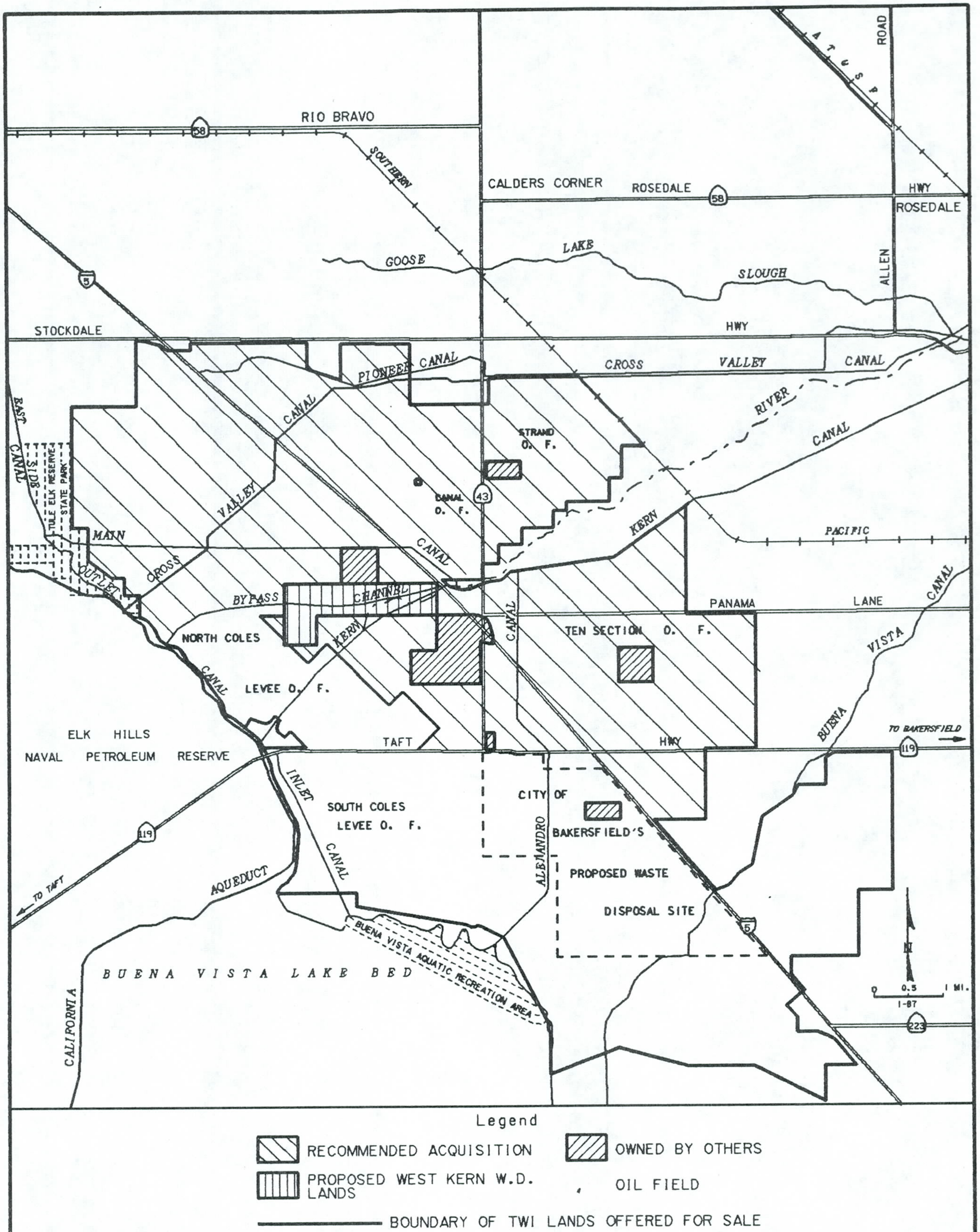


Figure 1. PROJECT AREA

the Kern County Water Agency (KCWA) requires the cooperation of present diverters and will provide a sound basis for a workable conjunctive use program.

Study Area Description

The Kern River alluvial fan area comprises about 800 square miles near the southern end of the San Joaquin Valley. Mountains on the northeast, south and west form a U-shaped ring around the Valley, with the open end to the northwest. The City of Bakersfield, the largest urban center in the area—population 403,089 (1980 census)—lies at the head of the modern alluvial fan. Although the present location of the Kern River extends to the west from Bakersfield, in geologic time it has been in various locations, ranging from extending to he north and extending to the south from Bakersfield.

The economy of the area is based mainly on the production and processing of agricultural products and petroleum. Because of the semiarid climate, agriculture must be supported by irrigation. Sources of water are surface streams (principally the Kern River), ground water pumping, and water imported through the SWP and the Federal Central Valley Project (CVP).

The mountains surrounding the southern end of the San Joaquin Valley have major effects on the climate of the area. The coast range to the west shields the valley from moist Pacific Ocean air, thus contributing to a mild semiarid climate. Runoff from the east side of the coast range, which lies in a rain shadow, is intermittent and flashy, whereas runoff from the western side of the Sierra Nevada provides a perennial source of water. The snowpack on the Sierra Nevada begins melting in March or April, contributing to Kern River flows, which reach a maximum in May but decrease rapidly in June or July. Isabella Dam, about 40 miles upstream of Bakersfield, with a 570,000 AF storage capacity, regulates the flow of the river. The period of low precipitation from April to October coincides with the period of maximum high temperatures and accelerated rate of plant growth.

Ground Water Geology

In the southern San Joaquin Valley, the rocks of the Sierra Nevada and Coast Range underlie the valley. These rocks play no significant role in the ground water basin. Overlying those two broad units and filling the valley trough is a thick mass of consolidated and semiconsolidated continental deposits composed of alluvial and lake sediments derived from the surrounding highlands and deposited by tributary streams, mainly the Kern River. The continental sediments, which overlie faulted marine rocks of the Coast Range and crystalline basement rocks of the Sierra Nevada, constitute the primary ground water basin and are several thousand feet thick in the project area. However, the usable portion of this sediment accumulation is limited to the portion above the base of fresh water, which varies from an elevation of about -2,800 in the east to about -800 feet near Elk Hills on the west. Ground water development is limited to the upper portion of the fresh water system.

The present course of the Kern River from its emergence from the foothills at Bakersfield is southwesterly across the valley to a point of intersection with the Elk Hills. This channel has been in this location only since 1867-68, and the river is artificially maintained in this channel. Before that time, the historic main course at the Kern River was southward from the point of emergence into the valley, through the present site of the City of Bakersfield and terminating in Kern Lake. A series of lesser distributary channels carried flows and at times were the main river courses. These channels radiate down the fan from near Bakersfield, and their locations are often followed by modern canals.

Specific capacity data (the amount of drawdown per unit rate of pumping) provides an indication of the relative permeability of the materials from which the well is extracting water. The wells in the study area tend to be concentrated north of Panama Lane with only a few wells located in southwest. The wells in the area tend to be composite in that they (1) are perforated above and below the Corcoran Clay (a major confining layer) and (2) are generally not perforated in the upper 150 to 250 feet or so of the aquifer system.

Specific capacity data are based on pumping tests of wells perforated mainly between 200 and 700 feet. The data suggests that during much of the time that the more recent alluvial fan deposits were being deposited, the ancestral Kern River flowed along the northern portion of the Tenneco property approximately along the alignment of the Pioneer Canal and Goose Lake Slough systems. At other times, the main course of the river was southwestward, approximately along the present alignment of the Buena Vista and Stine Canals. Between these areas, materials are finer grained (silty sand to clay) with interbedded sands and probably represent mainly flood basin deposits.

The upper fan deposits are underlain by the Corcoran Clay at depths of 300 to 400 feet. The Corcoran Clay is thought to exist under the western two-thirds of the property. The Corcoran Clay is a thick deposit of lakebed clay and silt with very low permeability. It forms a regional confining layer separating the overlying semi- and unconfined aquifers from a deep confined system. In the northeastern portion of the study area, the Corcoran Clay is thought to be absent, with the area serving as a forebay for recharge of the confined aquifer system.

The geologic analysis suggests that both recharge and extraction facilities should be located primarily in the area north of the Kern River and east of Interstate 5. A smaller concentration of facilities could be located west of Interstate 5. Limited facilities can be located between the Kern River and Taft Highway. Substantial subsurface exploration will be necessary during the feasibility investigations to adequately characterize the hydrogeologic properties of the aquifer system.

Recharge Capability

A detailed soil map for this project was developed by tracing field maps of the U. S. Department of Agriculture's Soil Conservation Service's (SCS) recent (years) soil survey for a portion of Kern County. From the detailed soils map used to help locate percolation ponds, a more generalized map was produced to differentiate areas of relatively similar recharge potential. The estimated recharge rates for the upper 5 feet of soil are 10 to 20 feet/day for high, 1 to 10 feet/day for moderate, and less than 1 foot/day for slow permeability classifications. The soils with higher rates are in the eastern and northern areas. Percolation ponds were not located on soils with the slow rates.

Water Quality

Ground water quality in the Kern County Basin is extremely variable. In general, ground water from the west side of the valley has high mineral concentrations and is categorized as sodium sulfate or sodium chloride types. These chemical characteristics reflect the movement of ground water into the basin from marine sediments and limited fresh water recharge. In large parts of the west side of Kern County, the total dissolved solids (TDS) concentration of native ground water is above 1,000 milligrams per liter (mg/l), limiting its use for irrigation or domestic purposes. In the project area, this poor quality water type is largely restricted to a narrow band adjacent to the Elk Hills.

The eastside water quality is generally good and generally of the bicarbonate type, either sodium bicarbonate or calcium bicarbonate. Its quality reflects the quality of its primary historical recharge source, the Kern River. The eastside ground water is generally of somewhat lower quality than the Kern River water, but in chemical characteristics it is similar. In coarse gravel deposits close to the river, the quality of the eastside ground water is very good, frequently less then 200 ppm total dissolved solids. Its quality drops off in areas farther from the river due to limited recharge in the less permeable deposits. Overall, the eastside ground water is very usable; this is the predominant water type in the project area. The area between the east side and west side has a more variable water quality.

The Kern County Basin as a whole is a closed basin with no natural outlet for surface or ground waters. Salts are brought into the basin by the surface water supply sources—Kern River, Friant-Kern Canal, SWP, and minor streams—but are not removed. This condition of adverse salt balance is compounded by the impacts of leaching soluble salts from the soil into the ground water. These two processes inevitably increase overall salt content in the ground water basin. Historically, water quality degradation has been noticed in many wells in Kern County.

Concentrations of boron in the project are generally less than 0.5 mg/l with some areas to the west of Interstate 5 having concentrations exceeding 0.75 mg/l. However, it is expected that the water extracted and delivered from the project area will be of suitable quality for agricultural use.

The area in which arsenic concentrations in the unconfined aquifer have exceeded the water quality standard of 0.05 mg/l designed to protect public health is generally south of Taft Highway, straddles Interstate 5, and coincides somewhat to the area to be used as a sewage farm by the City of Bakersfield. No project facilities would be located in the problem area.

A portion of the Tenneco Property will be used as a sewer farm. Treated effluent at the City of Bakersfield's Waste Water Treatment Plant will be used for irrigation on a 4,700-acre site southwest of Interstate 5 and Taft Highway. This reclamation site will be operated by Tenneco West, Inc. The treated effluent will be used to irrigate orchards, vineyards, and fodder, fiber, and seed crops at the site. The reclaimed waste water used for the spray irrigation of orchards and vineyards will be adequately disinfected, oxidized, coagulated, clarified, and filtered. The project should not have a significant effect on local ground water quality.

All or parts of five oil fields are found in the project area. In the vicinity of the oil fields, over 130,000 tons of salt has been disposed in unlined sumps. The water produced with the oil is a sodium-chloride type almost as concentrated as sea water. The sumps were the only means of disposal between the 1950s and 1960s.

Due to the extensive oil field operations the potential for contamination by toxic organic chemicals exists. Although no contamination has been identified, the Department has hired a consultant to identify and evaluate potential problems.

The quality of water historically available for recharge in facilities on the project property has been of acceptable quality for both agricultural and municipal and industrial uses. SWP water is compatible with existing ground water, however, its total dissolved solids content is slightly higher than that of ground water present in most of the project area.

Water Supply

Three sources of surface water have historically been used in Kern County: Kern River, Friant-Kern Canal, and SWP. There are numerous lined and unlined canals which deliver these supplies for use or recharge.

Kern River

To date, the Kern River has been the only source of surface water to the project site, and historically it has been the primary source of surface water to Kern County as a whole. The river drains a 2,420-square mile area of the southern Sierra Nevada. From the head of its drainage area, the river's main stem flows south to its confluence with the South Fork at Isabella Reservoir. Downstream of Isabella Reservoir, the river flows generally southwest, entering the valley northeast of Bakersfield. Flows near Bakersfield (First Point of Measurement) averaged 746,000 acre-feet annually between 1894 and 1986. In most years, all Kern River flow is diverted just downstream from its entrance to the valley floor, and the river channel through the project site is dry. In extremely wet years, surplus Kern River flows have been diverted into the California Aqueduct to prevent downstream flooding.

Friant-Kern Canal

Historically, no Friant-Kern imports have been used in the project site, but they have supplied adjacent agencies and contributed flow to the Kern River. The Friant-Kern Canal diverts San Joaquin River flows at Friant Dam northeast of Fresno. From there, the canal flows south, supplying surface water to several agencies in Fresno, Kings, Tulare, and Kern Counties. The Friant-Kern Canal terminates at the Kern River near Bakersfield. In extremely wet years, flows from the Kaweah and Tule Rivers also are diverted into the Friant-Kern Canal and eventually into the Kern River to alleviate flooding in the Tulare lakebed.

State Water Project

Historically, the project site has not used surface water from the SWP. However, the SWP does constitute a large source of supply for Kern County lands adjacent to the site. The California Aqueduct would be the primary source of recharge water for the proposed ground water storage program. The source of SWP water consists of releases from Oroville Dam on the Feather River and surplus flows in the Sacramento-San Joaquin Delta. South of the Delta Pumping Plant, the California Aqueduct flows along the west side of the San Joaquin Valley to Kern County and ultimately to Southern California.

Ground Water Conditions

The project area overlies a portion of the Kern County Ground Water Basin (Cal. DWR, 1980) which is defined by DWR as the portion of San Joaquin Valley alluvial material lying in Kern County. The eastern, southern, and western boundaries of this basin lie at the edge of the consolidated rocks of the Sierra Nevada, the San Emigdio Mountains, and Coast Range. Flow into or from the basin across these boundaries is negligible due to the extremely low permeabilities of the consolidated boundary material. Flows of small quantities of ground water across the northern boundary are possible but not probable.

Beginning about 1900 to 1910, ground water pumps came into widespread use and by the 1920s, pumpage exceeded the natural recharge of the basin (Cal. DWR, 1931). This condition of overdraft caused ground water levels in the Kern County Basin to decline, with locally severe declines in areas of heavy ground water pumpage and no surface water supplies. The land surface subsided in some parts of the basin.

The Friant-Kern Canal was built in the 1950's, and the canal delivers surface water to former ground water users in portions of Kern County. In the early 1970s, the SWP also began deliveries of surface water to former ground water pumpers in the Kern County Basin. These supplemental surface water supplies reduced existing overdraft but increased basinwide development of irrigated agriculture and prevented the complete elimination of overdraft conditions. At present, the demand for water exceeds supplies in Kern County as a whole by about 250,000 acre-feet per year.

Computer Simulation Model Studies

The potential delivery capabilities of the SWP were evaluated by interaction of three computer simulation models—two of the ground water basin and the other of the SWP basin. The sequence of studies follows:

1. Expected conditions in base years 1990 and 2000 were assumed and operation studies conducted under the operation mode of maintaining the classical firm yields for the two development conditions.

2. The studies in 1 (above) are rerun with the addition of the ground-water-reservoir project, with a set maximum storage space and maximum monthly recharge and extraction rates. The results of these studies provide annual recharge and extraction amounts.

3. The annual recharge and extraction amounts from 2 (above) and quantities of local water available for recharge are used for inputs to the ground-water-reservoir model and predicted ground-water-level responses are reviewed.

4. If the responses in 3 (above) are unacceptable, new maximum recharge and extraction amounts are assumed for 2 (above), followed by a rerun of 3 (above) until the balance of recharge, extraction, and land-surface area and water-level responses are adequate to permit preliminary design.

State Water Project System Operation Analysis

The added delivery capability of the Kern Water Bank (KWB) to the SWP is determined by modeling the operation of the system with and without the KWB. The difference between the two capabilities is assigned to the KWB.

SWP yields have historically been developed on a "firm-yield" basis, i.e., the sustained delivery of an amount of water over the 7-year drought period with allowances for agricultural deficiencies totaling 100 percent (of one year) but not exceeding 50 percent in any one year. For planning studies, these deficiencies have usually been set at 33-1/3 percent per year. When a new facility is added and the project is operated in this manner, the objective is to develop the maximum increase in firm yield. In recent years, the project has been operated by taking some risk of shortage to develop higher average deliveries. This procedure uses the relationship between the forecasted Four (Northern California River) Basin Index for the remainder of the year and the SWP water delivery capability for the entire year. Annual target storages for conservation reservoirs are set for each of the years in a 7-year drought period along with a minimum storage for the system.

SWP Operation Studies - Year 1990 and Year 2000

The purpose of the SWP operation studies is to obtain the delivery capabilities, under the prescribed operational criteria, during the historical hydrologic (1922-1978) period. The operation studies described in the following sections were conducted similarly to those prepared for other SWP conservation facilities so that results may be compared. Under actual operating conditions, Initial ground water levels and weather conditions could differ from those assumed but would have minor effects on yields. Additional studies may be required to reflect (1) agreements with KCWA and other local agencies and (2) physical restrictions developed in the technical studies.

As a first step in identifying the potential accomplishments of a Kern Water Bank (KWB) storage program, several preliminary studies of the SWP system were performed at both the 1990 and 2000 levels of demand and development. These studies were the *Base Study* and the *Base Plus Ground Water Study* with different operational modes. Both were conducted to determine (a) the amount of increased SWP delivery that would be available through conjunctive operation, (b) the times and amounts of water that could be made available for storage, and (c) the times when extraction from storage would be required and the amount of the extraction.

Proposed Plan

The facilities required for implementation of the first element of the Kern Water Bank are shown on Figure 2. For the purpose of evaluating the cost of the Kern River Fan Element, an independent canal (State Canal) serving only this element has been developed. In addition, connections between the State Canal and recharge basins were assumed to be new facilities, although agreements with local districts may permit use of existing facilities.

A 10-mile-long State Canal would connect the California Aqueduct to the City of Bakersfield's existing Kern River recharge area. Its location roughly bisects the new recharge area. The canal would be concrete-lined.

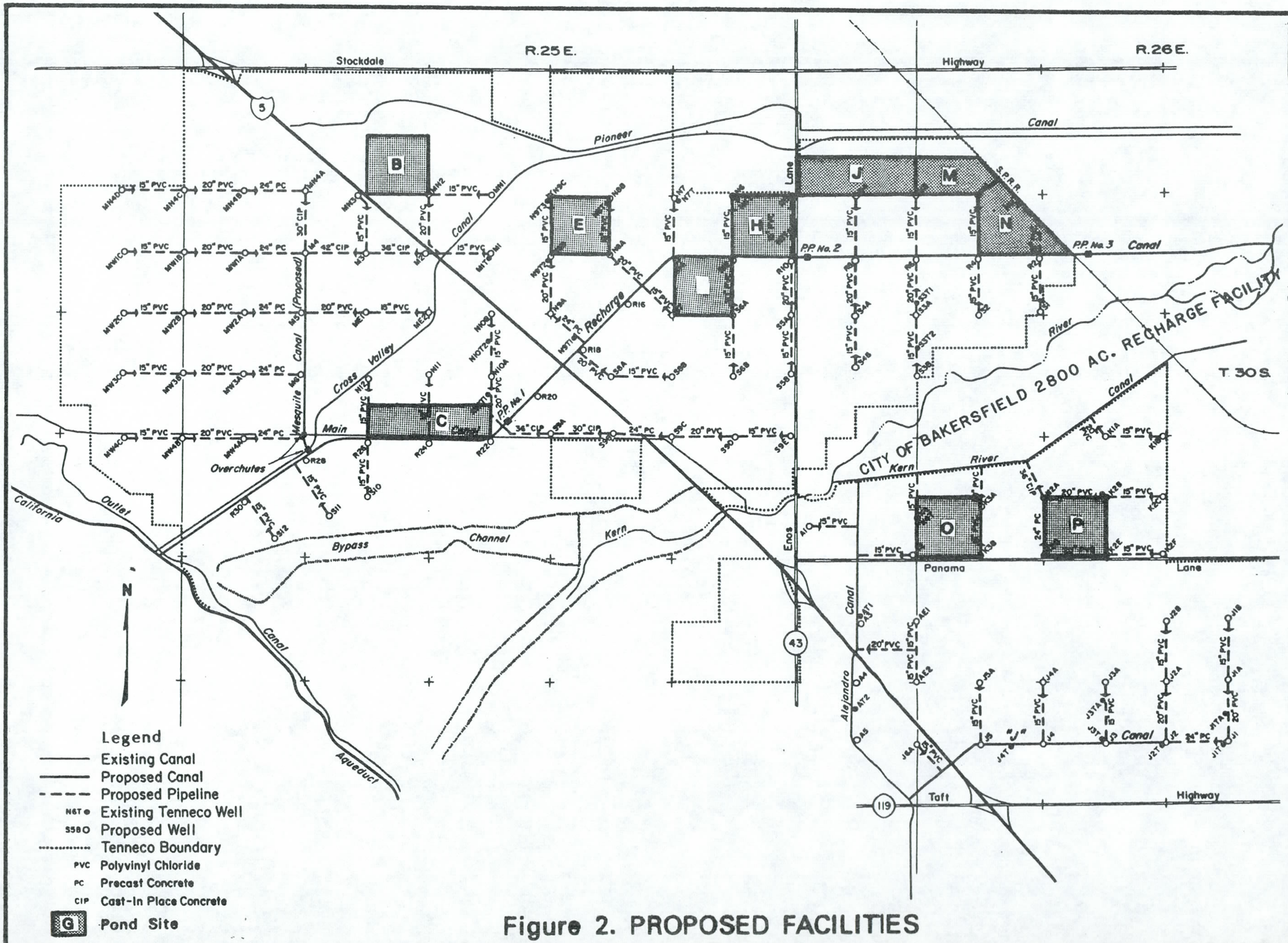


Figure 2. PROPOSED FACILITIES

The gradient of the canal invert would be essentially flat with three pumping plants providing head to move the water eastward. The canal would be lined to increase flow efficiency and to permit its use in an extraction operation. Five siphons are used to bypass obstructions at existing canals, highways, and railroads. The canal capacity for recharge operation varies from 500 cfs at the California Aqueduct to 200 cfs at the Kern River. This would permit a maximum monthly recharge rate of 30,000 acre-feet per month for SWP water. Maximum capacity for withdrawal operation is about 400 cfs.

Conveyance of water from the State Canal to recharge basins would be by gravity and earth channels. Recharge basins south of the Kern River would be fed by discharge to the city's 2,800-acre site at McClung Weir. Recharge water would be directed by gravity from behind the McClung Weir into the existing James-Pioneer I. D. laterals that feed the basins south of the river. Service to potential additional basins between Panama Lane and Taft Highway could also be made through existing James-Pioneer laterals. Recharge basins in the City of Bakersfield recharge area would also be fed by discharge from the end of the State Canal.

During periods when local water is being recharged, the State Canal would be operated to move local water diverted from the river to the west to State percolation ponds.

Recharge Basin Design

Evaluation of ground water model results lead to the use of values of 30,000 AF for the first nine months, followed by 25,000 AF per month, have been used as the allowable sustained recharge rate for the area, including both the property to be acquired as well as the existing City of Bakersfield recharge facilities. During some periods the large flows in the Kern River would make it difficult to also recharge imported water. Recharge of SWP water was adjusted for this effect.

The ponds in the City area are downstream of the end of the State Canal and would be available for recharge of State water subject to the terms of a MOU with the City of Bakersfield. These City ponds would have a monthly recharge capacity of 12,500 acre-feet per month. To allow for a peak 30,000 acre-feet per month total recharge, the area required for recharge basins to be located on State property would be that necessary to recharge the remaining 12,500 AF per month.

The basins were sized on the basis of a recharge rate of 4 inches per day and an operational water depth of 1 foot. Basins and interbasin conveyance facilities were sized to accommodate the 6-inch-per-day recharge rate that is believed possible under optimum management procedures. An additional 25 percent was added for effective movement of water into one basin or successive basins. For maintenance requirements, a basin was expected to be out of service one-third of the time.

The total recharge basin area required is 1600 acres; the typical basin design consists of 160 acres divided into four equal segments of 40 acres. The exterior and interior levees are substantial and capable of supporting vehicle traffic under all weather conditions. Short, low sections of low berms are provided within each 40-acre segment for wave control.

The majority of the feeder canals connecting the State and Kern River canals to recharge basins would flow by gravity as would flows within and between recharge basins. Feeder canals would be unlined. Where connection distances are short, corrugated metal pipe would be used. Control structures would be simple and portable. Each recharge basin would have a concrete weir to provide for escape of excess inflows or extreme rainfall.

Extraction Facility Design

Sixty wells, ranging from 600- to 700-feet deep, exist on the property to be acquired. Although the wells are not designed to operate through a wide range of lifts, they could be used to supplement extractions from new wells. Thirty-three of the wells are planned to be used by modifying the pump discharge pipe. In a more detailed analysis it may be possible to use more of the existing wells by installation of new pumping plants. An additional 107 wells 350 to 700 feet deep would be needed to extract the 30,000 acre-feet per month required for operation of the Kern River Fan Element. Most of the wells would be connected by pipe to the State Canal and then to the California Aqueduct. Wells south of the Kern River Canal would be connected to the Kern River Canal and then to the Alejandro Canal. Later studies will determine how much additional extracted water would be delivered through local canal systems. As noted in an earlier section, the State Canal is designed for both recharge and extraction operation.

In general, wells are spaced at about half-mile intervals. New wells were located to reduce or avoid adverse impacts of the project on pumping in adjacent areas.

Project Yield and Costs

An analysis of yields shows that this project is capable of increasing the annual firm yield of the SWP by 145,000 acre-feet. Average annual deliveries would increase about 76,000 acre-feet. If the SWP were operated less conservatively, average annual deliveries would increase and drought-period (firm) yield would decrease, although not in direct proportion. The costs of the project are still being finalized but will be less than $100 per acre-foot.

The Future

A decision on purchase of property will be made soon. If the land is purchased, subsurface exploration, a full feasibility study, and design and construction will follow. Parallel to these activities, a prefeasibility study of the ground water basin will be conducted to ensure a coordinated program. The SWP will also pursue an interim recharge program, using the City of Bakerfield's facilities.

GROUND WATER IN SOUTHERN CALIFORNIA

By Neil M. Cline, Vice President

Camp Dresser & McKee Inc.
2302 Martin Street, Suite 275
Irvine, California 92715

Introduction

Early settlers of southern California found ample surface water supplies, however, as the demand for water increased, the local streams were soon fully utilized and a dependence upon ground water emerged which prevails to this day. To protect and perpetuate ground water resources, southern California has developed a variety of water management programs, including basin management, surface water storage programs, and water quality protection projects. Currently, over 80 percent of all local supplies are produced from ground water basins, which amounts to about 1,200,000 acre-feet of ground water production in southern California.

Ground Water Management

As early as 1925 it became apparent that unless some form of restraint on ground water production was established, sea water intrusion would destroy this natural resource. Typically in the early days, rather than organize and develop management practices, the various parties would engage lawyers and pursue their interests in court. What has emerged after years of litigation is a series of management processes that are designed to maintain ground water utilization, minimize or prevent overdraft, and optimize their conjunctive use with available imported surface supplies.

The major basins in southern California are listed in Table 1.

TABLE 1

Basin	Average Annual Production Acre Feet
Ventura County	25,000
Upper Los Angeles Basin (San Fernando)	100,000
Central/West (L.A. County)	255,000
San Gabriel	200,000
Orange County	260,000
Chino	150,000
Bunker Hill (San Bernardino Co.)	120,000
Riverside County	60,000

In the highly urbanized areas of the coastal plain, generally the basins have either been adjudicated and operate under a court order with continuing jurisdiction, or the overlying agency is authorized to manage the basin under formally authorized provisions.

Management Techniques

To maintain supply, provide carry-over storage for drought conditions, provide low cost distribution, minimize treatment costs, and in the case of coastal basins, prevent sea water intrusion, there have emerged a variety of management techniques.

In most basins, long-term safe yields are established as a function of local ground water recharge. These safe yields are computed, based upon natural recharge from precipitation and return flow, less losses. The management agencies subsequently provide (1) formal withdrawal limitation based upon safe yield, (2) impose replenishment assessments which are used to purchase imported supply for artificial recharge, (3) maintain an orderly market for pumping rights between parties, and (4) maintain spreading operation to facilitate recharge with both local and imported supplies.

The San Gabriel Basin is an example of an adjudicated basin management, representative of much of southern California ground water operations.

The Basin is situated in the eastern portion of Los Angeles County, serving a number of communities including Alhambra, Covina, Baldwin Park, and San Gabriel. In 1986, 200,000 acre-feet were pumped, supplying about 70 percent of water demand in the area. The stipulated judgment directs that a watermaster be established, composed of nine members appointed by the court. The watermaster is responsible for determining the operating safe yield of the basin each year. The safe yield is defined as the quantity of water which may be pumped from the basin in a particular year without imposing a replacement water assessment fee. Should pumpers exceed the operating safe yield, assessments are imposed, collected, and used to purchase water from the Metropolitan Water District for replenishment.

Additional watermaster authority includes the power to levy assessments and to purchase supplemental water for basin recharge. The watermaster has the authority to regulate the use of basin storage through "cyclic storage agreements" which provide capacity for ground water storage for cyclic or regulatory storage of imported supplies. The stipulated judgment provides that the watermaster has "sole custody and control of all ground water storage rights in the basin pursuant to the physical solution, and subject to the review of the court." The stipulated adjudication in summary, directs the local and competing producers to work together to establish the most economic, long-term conjunctive utilization of surface and ground water, imported water supplies, and ground water storage capacity to meet the needs and requirements of the basin's overlying water users.

These kinds of court structured management procedures are utilized with minor modifications in most of the southern California basins.

The Orange County ground water basin is not adjudicated. In that area, the Orange County Water District, formed by a special act of the State Legislature in 1933, is managed by a combination of seven elected directors and three appointed directors. The directors annually determine ground water conditions and then establish a replenishment assessment sufficient to purchase supplemental water from Metropolitan Water District and to operate the agency. The average annual production is about 260,000 acre-feet. In 1987 the replenishment assessment was $32 per acre-foot for municipal and industrial use and $16 per acre-foot for agricultural uses.

To assure equal access to lower cost ground water, the District annually establishes a basin pumping percentage which limits the amount of water an agency may produce without penalty. In 1987 the Basin Pumping Percentage was 70 percent. OCWD requests is pumpers to refrain from producing more than the established percentage. If an agency exceeds the limitations, it is assessed a penalty equal to the theoretical difference between the cost of ground water and the cost of imported supply.

Some pumpers habitually opt to pay the penalty and over-produce. To offset this activity, the District requests other pumpers to produce less than the basin production percentage. Since ground water is considerably less expensive than imported supplies, using more water from MWD places an increase in costs on the agency being restricted. In 1987 the cost for imported water was $225 per acre-foot. Ground water production costs were about $90 per acre-foot, therefore the Basin Equity assessment was $145 per acre-foot and limited agencies were accordingly reimbursed $145 per acre-foot for the costs they incurred to accommodate the basin's safe operations.

Conjunctive Use Management

The conjunctive management of ground water with imported supply is the cornerstone of water resources operations in southern California. Conjunctive use includes both the storage of local runoff in the basins, supplemented by artificial recharge, and increased extractions in order to create storage capacity. The ground water basins are artificially replenished to store water in wet years to provide assured supplies in dry years. The flexibility thus provided by conjunctive management, not only extends water supply utility, but reduces the capital investment that would otherwise be required to meet the demand.

In Los Angeles and Orange Counties it is estimated that 90 percent of local runoff is captured in water consumption and flood control facilities for ground water replenishment.

Los Angeles County agencies maintain over 3,000 acres of spreading grounds that can accommodate an estimated combined 2,000 cfs capacity. In recent years Los Angeles County agencies have recharged an average of 240,000 acre-feet per year of local supply, 50,000 acre-feet of imported water from the Colorado river or Northern California, and 24,000 acre-feet of reclaimed water.

Orange County owns about 1,000 acres of replenishment facilities with an estimated percolation rate capacity of 450 cfs. During the period from 1949 through 1987, over 2,000,000 acre-feet of Santa Ana River flow has been recharged and more than 2,000,000 acre-feet of imported supply have been placed in the basins.

Similar recharge operations are maintained on a lesser scale in Ventura, San Bernardino and Riverside Counties.

Cyclic Storage Arrangement

To further utilize the advantages of actively managed ground water basins, Metropolitan Water District has developed local cyclic storage agreements.

Thus far MWD has the right to store up to 142,000 acre-feet in the San Gabriel Basin and up to 100,000 acre-feet in the Chino Basin. The Chino storage program is planned to be expanded to over 1,000,000 acre-feet. Under these arrangements, northern California water is delivered for storage when available and in excess of Metropolitan's demands. The water accumulated in storage is sold to the overlying member agency when replenishment water is not available for direct surface deliveries or when direct deliveries from MWD are not possible. When the cyclic storage deliveries are made, MWD recovers its costs amassed in storing the water.

Additional cyclic storage arrangements have been made for desert water agencies to impound Colorado River water. Under this management, during times of shortage, the desert agencies would use MWD stored water in exchange for MWD's access to the desert agencies' northern California supply. To date, MWD will place over 550,000 acre-feet in its desert storage operations.

Water Quality Considerations

Traditionally ground water quality, with the exception of sea water intrusion, was considered to be scarce. Recent events and current analysis of changing conditions have revealed that ground water is vulnerable to the activities of man, and must be protected if they are to be perpetuated.

Extensive monitoring of ground water quality has been conducted in southern California. To date, significant losses due to quality conditions has not occurred, despite media coverage that would suggest otherwise. Unfortunately, there have been some wells that have had to be taken out of production, due to either excessive mineralization or the presence of organic chemicals in trace amounts. Table 2 compares total production with the amount of losses due to quality factors.

The chief culprits in mineralization have been excessive TDS and nitrates which account for 43,000 acre-feet of the 78,000 acre-feet lost to poor quality. The organics detected have been mainly TCE, PCE and DBCP in trace amounts.

TABLE 2

Basin	Total Production AF/Year	Losses Due to Minerals AF/YR	Losses Due to Organics AF/YR
Ventura	25,000	3,000	–
San Fernando	100,000	3,000	3,000
Central/West	255,000	6,000	1,000
San Gabriel	200,000	1,000	500
Orange County	260,000	12,000	2,000
Chino	150,000	–	–
Bunker Hill	120,000	5,000	2,000
Riverside	60,000	12,000	–

Depending upon the stringency of future drinking water standards and the additional constituents that may be added to the Safe Drinking Water Act, the impact of water quality regulations in local water supplies could increase significantly. Currently, local water managers employ blending acceptable water with imported supply to maintain constituent considerations in water below federal MCL and California action levels.

Because of the essential nature of ground water operations, extensive protection plans are being formulated to minimize quality losses. These programs range from well head treatment, planned by local agencies, to comprehensive basin-wide, formally adopted, water quality control plans. These basin plans are formulated, adopted, and enforced by the State of California in each major drainage area of the state. The cooperative effort of local, state and federal agencies are, in general, containing quality degradation in southern California, but at significant expense and effort to assure no further diminution of ground water resources occur.

A Recommendation

Based upon the California experience, it has been demonstrated that ground water basins, conjunctively used with imported water supplies, will provide optional use of limited resources. It has worked successfully in California. It will work in Arizona.

THE RILLITO RECHARGE PROJECT: AN EXPERIENCE IN COOPERATIVE WATER MANAGEMENT

by
Craig O'Hare
Arizona Department of Water Resources
Tucson Active Management Area

THE PROJECT IN PERSPECTIVE

The growth of industrialized society has generated a need for greater sophistication in water management. Early civilized communites were comparatively small and spread out from one another. The demands on the water resource were also small allowing the mere magnitude of the hydrologic cycle to mitigate any society-induced stresses placed on it. A town's wastewater, for example, discharged to a stream, was sufficiently aerated and diluted to render potable water to a downstream community miles away. The little water management that was needed could ignore the interrelated nature of the hydrologic cycle and treat water problems as discrete issues.

The expansion and coalescing of metropolitan areas that has accompanied the population boom has placed an enormous stress on the hydrologic cycle. We no longer have the liberty of dealing with each water issue independently from others. Water management has responded by recognizing the interrelationship of water problems and developing more comprehensive responses to them. Addressing the surface/groundwater interface and responding to quality/quantity interactions are examples of this relatively new concept of "conjunctive" water management.

The Rillito Recharge Project is one of southern Arizona's contributions to this progressive trend in water management. The project integrates flood control and water supply objectives in a single facility.

Historic flood control practices focused on channelizing, widening, and straightening drainages to rout flows out of the metropolitan area as quickly as possible. More recent flood control techniques emphasize retention/detention strategies that encourage runoff to infiltrate into the subsurface and contribute to the regional groundwater supply.

In arid and semi-arid areas, past water supply efforts concentrated on groundwater withdrawal by drilling more and deeper wells. Recently, great emphasis has been placed on groundwater replenishment as a means to help stabilize the resource and bring long-term certainty to the water supply.

PROJECT DESCRIPTION AND AGENCY INVOLVEMENT

The proposed Rillito project is a stormwater runoff/alternative source artificial groundwater recharge facility that combines the concepts of retention/detention and groundwater replenishment. The project is a cooperative effort between Tucson Water, Pima County Flood Control District, and the Arizona Department of Water Resources. The project, located along Rillito Creek between Craycroft and Swan Roads (see Figure 1), is Arizona's first large-scale demonstration recharge facility proposal. The primary purpose of the project is to evaluate the opportunities for integrating increased flood storage and enhanced recharge of runoff waters along the Rillito Creek channel. The potential for recharging other source waters such as treated effluent and Central Arizona Project (CAP) water will also be evaluated. The project will be a water spreading operation using detention/infiltration basins.

This paper, focuses on the unique aspect of the project: primarily the bringing together of city, county and state water management agencies to work cooperatively towards a common project. Lacking a regionally oriented "water district" with widespread authorities, conjunctive management projects can be implemented by creatively linking water management agencies having specific authorities and expertise: hence the term "cooperative water management."

Before outlining the methods used to effect interagency coordination, a discussion of each agency, their role in water management, and their particular interest in the Rillito Project follows.

Arizona Department of Water Resources/Tucson AMA

The goal of the Tucson AMA is to ensure that safe-yield of the region's groundwater supplies is reached by the year 2025. As part of this program, the 1980 Groundwater* Code requires the AMA to develop a water supply enhancement or "augmentation" program. Augmentation may include such techniques as importing additional surface waters (CAP), increasing surface water yields (watershed management)and making better use of existing resources

* (The Groundwater Code presents "groundwater" as one word. While the NWWA insists that "ground water" should always be typed as two words, the author has chosen to follow the Code's precedent in the interest of consistency.)

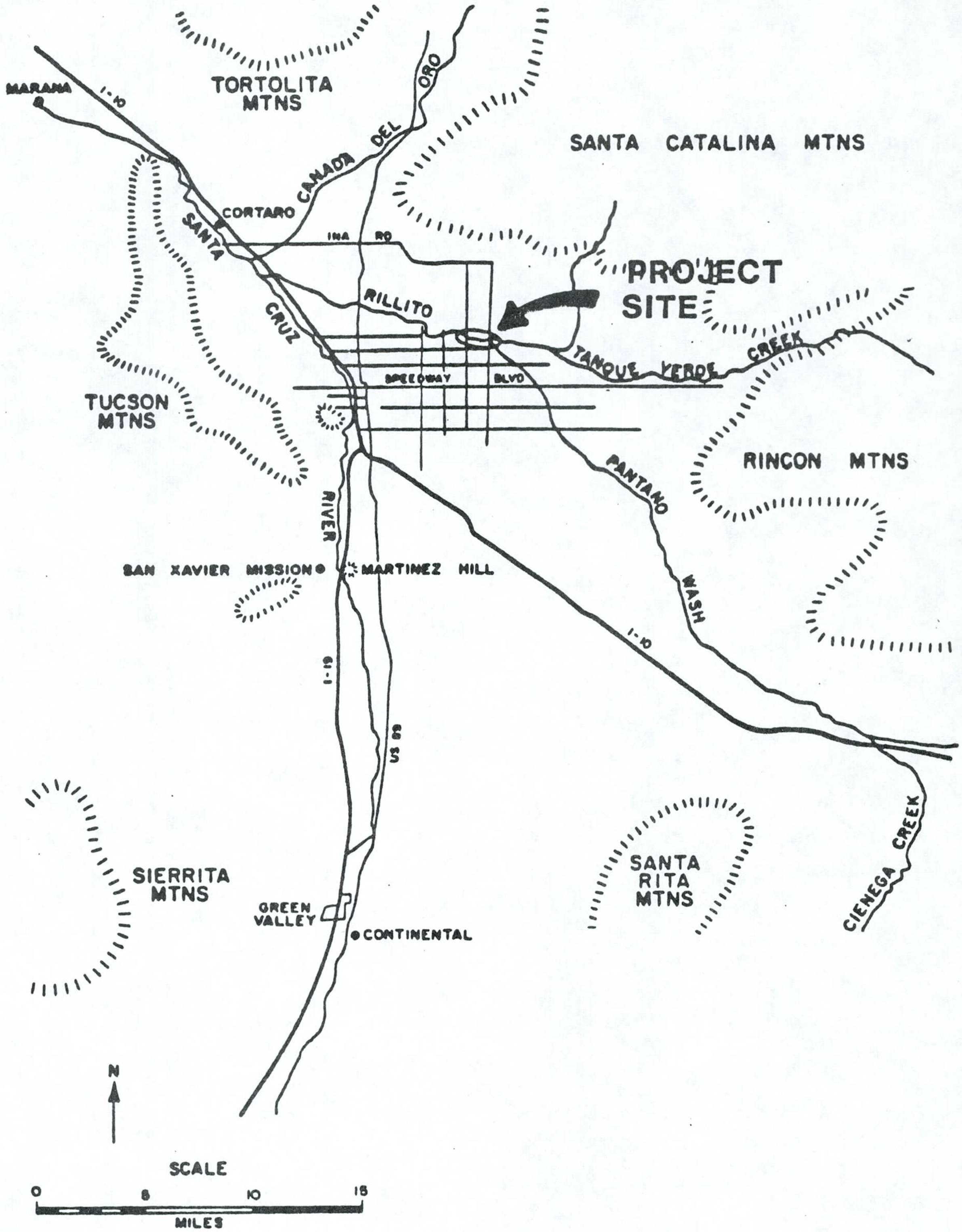


FIGURE 1

TUCSON BASIN VICINITY MAP

(effluent). Artificial groundwater recharge, not itself an augmentation method, allows these augmented supplies to be stored when direct use is either impractical or too costly.

The AMA adopted an augmentation program in August 1985 which identified a storm runoff groundwater recharge facility for Alamo Wash at Rillito Creek (just east of Swan Rd.). The site area was later expanded to include the main channel of the Rillito Creek because of the County's interest in a large-scale facility. One of the AMA's primary objectives for the Rillito project is to generate information that can be used to evaluate and develop future recharge proposals.

Tucson Water

Tucson Water, a department of the City of Tucson, is the greater Tucson area's municipal water utility. The utility is charged with providing the public with a safe, dependable, and economical water supply. Tucson Water has two source waters available for groundwater recharge: treated effluent and CAP water beginning in 1991. The utility's primary recharge objective is short and long-term water storage. Secondary objectives include minimizing pumping depths and improving the quality of the source of water. Tucson Water is currently operating a small-scale effluent recharge facility and conducting a comprehensive recharge feasibility assessment for the greater Tucson area. The Rillito project complements Tucson Water's on-going studies in artificial recharge. Data and conclusions from current studies will help assess the feasibility of the Rillito project. The Rillito project, in turn, will help direct future Tucson Water recharge efforts. Background monitoring for the project will provide Tucson Water with useful data on the quality of runoff waters and its potential impact on groundwater quality.

Pima County Flood Control District

The Pima County Flood Control District's primary mission is the protection of life and property from flood hazards. The Rillito project is an extension of the District's emphasis on retention / detention measures to reduce flood damage. The District adopted a retention/detention ordinance in 1984 requiring most new developments or subdivisions to incorporate retention/detention structures into their development plans.

The Rillito project is a large-scale version of the retention/detention concept. The District hopes that a successful Rillito demonstration project will lead to a more extensive flood control/recharge plan for the Tucson area. Similar projects may eventually be implemented both up and downstream from the project area creating effective flood and erosion control for a large range of Rillito Creek flow events.

The District is also interested in the nonwater-related benefits of the project. By acquiring land in this rapidly urbanizing area, the County hopes to: 1) preserve natural open space, 2) provide recreational areas for hiking, picnicking, and equestrian activities, and 3) protect flora and fauna by maintaining natural flood plain habitats.

INTERAGENCY PROJECT MANAGEMENT

Key to the success of the project is the ability of the three agencies to cooperate effectively. Each agency's particular water management responsibilities results in each having a slightly different set of objectives in collectively pursuing the Rillito project. Creating a formal interagency project management structure is critical to ensure that each agency's objectives are met. The structure must include a smooth decision-making process to resolve the many problems and issues typical of a complex project.

A number of vehicles are being used to create an effective project management process. These vehicles include a comprehensive intergovernmental agreement, an interagency technical advisory committee, and delegating certain responsibilities to outside services.

The Intergovernmental Agreement

The intergovernmental agreement (IGA) signed in July 1987 is the foundation of the cooperative effort. The IGA sets up a central project fund, clarifies each agency's role and responsibilities, and provides the legal structure necessary for each agency's participation.

Project objectives are an integral part of the agreement. Table 1, which is part of the IGA, describes the overall project objectives and details the objectives for the two major preproject activities: background monitoring and the project feasibility study. Establishing an early consensus on objectives helps minimize the potential for misunderstandings between agencies as the project proceeds.

The IGA also delegates specific tasks to each agency based on their expertise. For instance, constructing monitoring wells is delegated to the agency most familiar with constructing and operating wells: Tucson Water. The Department of Water Resources' groundwater data collection field crew is assigned to record groundwater levels and collect groundwater quality samples. Pima County Flood Control District has the most experience in surface water hydraulics and engineering, and will be the eventual owner/operator of the facility. The District will administrate the consultant contract for the project feasibility study.

TABLE 1: RILLITO RECHARGE PROGRAM OBJECTIVES

OVERALL PROJECT OBJECTIVES	BACKGROUND MONITORING OBJECTIVES	PROJECT FEASIBILITY STUDY OBJECTIVES
1. Demonstrate interagency cooperation	1.Establish intergovern-agreement to conduct back-ground monitoring.	1. Establish intergovernmental agreement to conduct project feasibility study.
2. Develop a methodology for facility development that can be applied to future projects.		2. Generate nonproject specific discussion of procedures used to develop, screen, and rank facility options including: - data needs - generating alternatives - choosing selection criteria - incorporating environmental and land use considerations, etc.
3. Pursue feasibility of recharging multiple sources of water.	3. Assess existing surface water and groundwater qualities to determine possible impacts of alternative source water recharge.	3. a. Incorporate alternative source water considerations in most design/operation scenarios. b. Assess impact of recharging alternative source waters on groundwater quality and recharge efficiency.
4. Demonstrate low cost recharge technology and document recharge costs and benefits.	4. Assess and quantify natural runoff/recharge relationships as a pre-condition to quantifying the impacts of project once operational.	4. a. Limit development of design options to spreading operations (basins or pits, in-channel and off-channel) or infiltration galleries. b. Develop preliminary level capital and operational costs for each design option.

OVERALL PROJECT OBJECTIVES	BACKGROUND MONITORING OBJECTIVES	PROJECT FEASIBILITY STUDY OBJECTIVES
		c. Estimate quantity of water recharged and additional benefits and costs (including environmental impacts) for each design concept.
5. Determine urban runoff water quality parameters	5. Include comprehensive sampling and analyses of run-off from Alamo Wash, an urban watershed.	5. Incorporate design and operational measures to mitigate impacts of urban runoff, if warranted.
6. Integrate facility design and operation into County's real time flood warning system		6. a. Select impoundment gates or diversion structures which are compatible with County's automated network. b. Determine best location for additional automated precipitation and stream gages based on evaluation of contributing watershed.
7. Assess water quality impacts of recharge	7. a. Generate comprehensive assessment of pre-project water quality conditions. b. Document historic landfill locations.	7. a. Develop conceptual or numerical prediction model for each design concept to assess groundwater quality impacts. b. Propose mitigative strategies where necessary - including those related to historic landfills.
8. Promote compatibility with surrounding land uses including: - provision of recreational amenities - habitat enhancement - vector control - visual amenities		8. a. Incorporate public access component to each design concept (landscaping, pedestrian and equestrian trails, signing, fencing "natural looking" detention basins, etc.) b. Develop operational plans (e.g. detention holding times) that inhibit vector propagation.

Rillito Project Management Committee

The Rillito Project Management Committee (RPMC) is the formal decision-making body for project activities. The Committee includes a representative from each of the three cooperating agencies and additional members with expertise in areas such as groundwater recharge, surface water hydrology and structural engineering. The Committee serves both project development and project review functions. Major responsibilities of the Committee are to: 1) develop and oversee the background monitoring program, including data interpretation, 2) generate a scope of work for the project feasibility study, 3) serve as the consultant selection committee for the project feasibility study, and 4) oversee feasibility study progress and refine the scope of the study, if necessary.

Outside Services

The IGA specifies that outside parties may be used to complete tasks outside the expertise or staff availability of the cooperating agencies. For example, the U.S. Geological Survey is conducting surface water gaging and sampling, and all water quality analyses. A private consultant will be hired to complete the project feasibility study. Other outside services may be needed as the project proceeds. To pay for these services, each agency contributes to a DWR-managed "Rillito Project Fund".

An overview of the project structure and decision making process is provided by Figure 2 "Rillito Project Organization Flow Chart"

PROGRESS TO DATE

1986

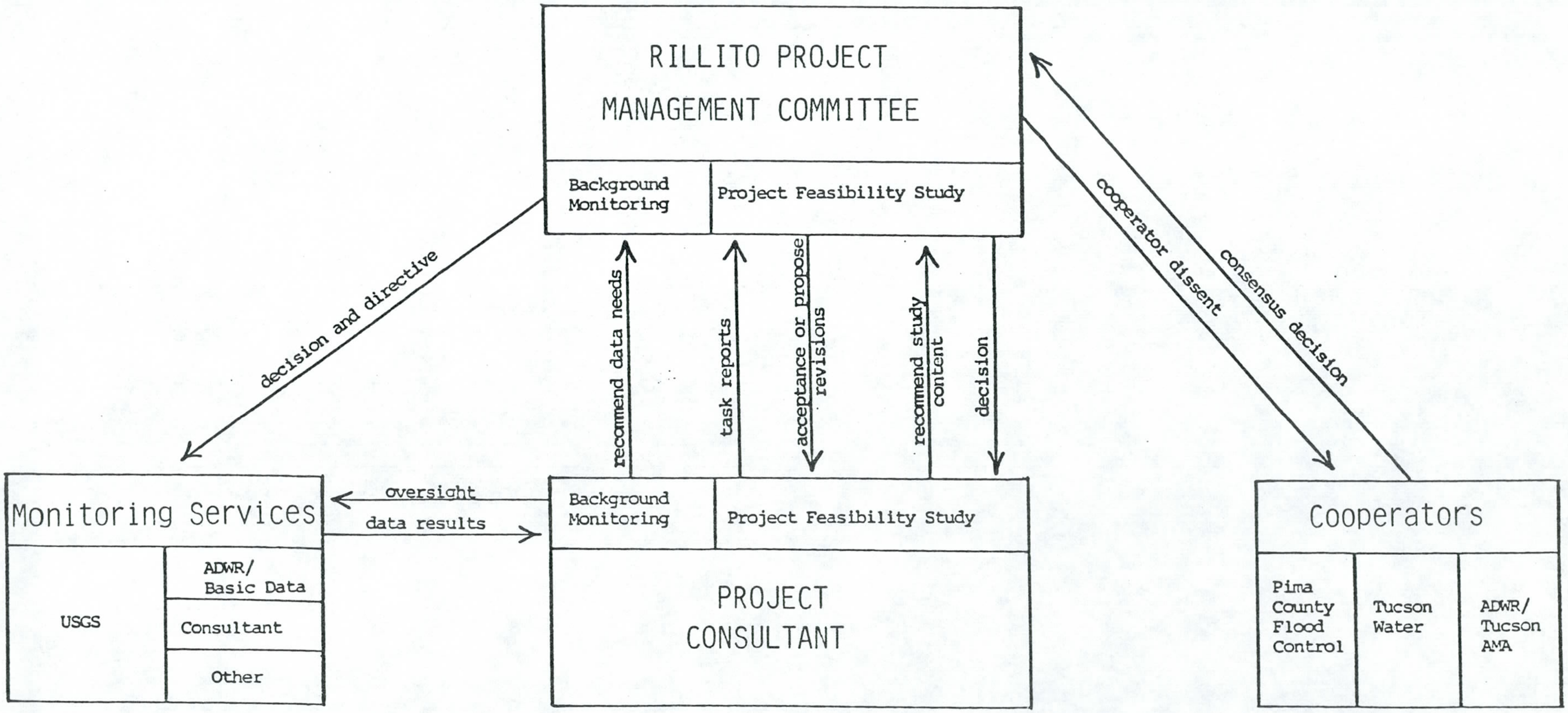
January	Tucson AMA augmentation fee becomes effective, creating the AMA's funding source for Rillito Project participation. Represents Arizona's first state augmentation fund.
May	Pima County voters approve Flood Prone Land Acquisition bond issue, including funds for Rillito land acquisition.
June	Governor Babbitt recommends Rillito Project to Bureau of Reclamation for High Plains States Groundwater Demonstration Program Act funding.
December	IGA concept paper drafted and agreed upon by cooperating agency staff.

1987

February	ADWR signs $180,000 contract with USGS to conduct background monitoring services.

FIGURE 2

RILLITO PROJECT ORGANIZATION FLOWCHART



May	Pima County Flood Control District advertises "Notice to Consultants", beginning consultant selection process for feasibility study. Bureau of Reclamation publishes "High Plains States Groundwater Demonstration Program Phase I Report" recommending Rillito Project to Congress for funding.
June	USGS surface water gaging and sampling installations completed.
July/ August	City of Tucson City Council, Pima County Flood Control District Board, and ADWR Director sign Rillito IGA.

FUTURE ACTIVITES

In addition to interagency project management, the Rillito Project is unique for another reason: runoff and other source waters will be recharged in an unregulated drainage subject to flash flooding. Multi-source recharge projects have been operating for over 30 years in California but only on drainages where flows are regulated by upstream dams or detention structures. An abundance of feasibility and operational data does not exist for a project such as the Rillito. This unique character of the project therefore necessitates a comprehensive planning and evaluation stage.

The Rillito drainage is an excellent area of natural recharge, but many technical and public health concerns need to be addressed prior to project design and implementation. Most of the project development effort through 1988 will address these concerns. During the next year and a half, efforts will focus on continued background monitoring and completion of the project feasibility study.

Background Monitoring Program

The background monitoring program will assess physical and chemical conditions in the site area. Because the project involves both surface water and groundwater, extensive data collection is necessary. Water quantity monitoring includes 1) precipitation gaging and estimating, 2) surface water gaging up and downstream from site area, and 3) recording of groundwater level responses to streamflow events. As part of the project feasibility phase, additional data collection may include soil borings, nuetron logging, and constructing and evaluating pilot infiltration basins.

Surface and groundwater quality samples will be collected and analyzed for common ions, trace metals, EPA priority pollutants, radionuclides and microorganisms. A subobjective of the monitoring program is to conduct a fate of contaminants study on urban runoff. Alamo Wash is a nine square mile urban watershed that discharges directly into the Rillito at the project site area. Sampling of Alamo runoff, bed materials. and the underlying groundwater will help identify contaminants in urban runoff and determine their mobility during the natural recharge process.

Data collected during background monitoring will be used during the feasibility study to help develop and evaluate alternative project design concepts. For example, the timing (with respect to the storm hydrograph) and concentration of suspended sediment in Rillito Creek runoff may dictate certain design and operational measures to mitigate basin clogging.

Project Feasibility Study

Two major goals of the project feasibility study are 1) develop data and methodologies that can be used in future recharge project development, and 2) develop alternative recharge project design concepts and evaluate them with respect to recharge efficiency, flood storage benefit, water quality impacts, and recreational amenities.

A few of the design concepts that may be considered include: 1) in-channel impoundment behind Swan Road bridge and slow release downstream. 2) off-channel diversion of flows to a sedimentation basin and then to a recharge basin. 3) off-channel diversion to a detention basin and then slow release back on-channel. 4) use of infiltration galleries. The Rillito Project Management Committee will work closely with the engineering consultant in developing the project design concepts. The Committee will then recommend a preferred design to the cooperating agencies.

Implementation Schedule

November 1987	Project Feasibility Study begins
November 1988	Completion of Project Feasibility Study. RPMC selects preferred design concept. Cooperating agencies reassess their role in project.
December 1988	Conduct public hearing on project proposal.
1989	Development of detailed plans, specifications, and operational manual for selected design.
1990	Construction.
1991	Operation and monitoring begin.

Project Significance

Southern Arizona, like most other regions, historically dealt with water resource management problems as independent issues. Flood control districts dealt solely with floods. Water providers, water utilities and irrigation districts, simply pumped groundwater to meet demand. No agency was responsible for basinwide groundwater management. At times, institutional or structural solutions to one water management problem created a different kind of water problem.

Recently, however, greater emphasis has been placed on the need to address water management as a whole. The Rillito recharge project, linking groundwater recharge and flood control objectives, is an example of this recent trend in water management. An experience that may pave the way for future interagency water management efforts.

CITY OF TUCSON GROUNDWATER RECHARGE PROGRAMS

R. Bruce Johnson*

Introduction

The water resource concerns in the Tucson area have been the subject of much discussion and publicity in recent years. Tucson's local problems as well as statewide concerns over water resource development and utilization, together with the implied withholding of Federal funds to complete the Central Arizona Project (CAP) led the Arizona State Legislature to adopt the Groundwater Management Act of June 12, 1980.

This new law created a strong state agency called the Arizona Department of Water Resources (ADWR) to deal with the growing problems of water management within the state. In addition, Active Management Areas (AMA's) were created to solve the problems of local groundwater overdraft. These are the Phoenix, Tucson, Pinal and Prescott active management areas.

The primary management goal of the ADWR in managing the Tucson AMA is to realize a safe-yield condition (long-term balance between withdrawals and total recharge) by 2025. The basic tools which are available to the ADWR to achieve this goal are water conservation, supply augmentation and wastewater reuse programs. Fundamental to the achievement of this goal is that reuse of wastewater and importation of Colorado River water through the CAP aqueduct system should be maximized to the greatest extent feasible (ADWR, 1984).

Tucson Water Recharge Programs

Tucson Water is presently implementing several programs which bring to reality specific policies adopted by the Mayor and Council with respect to groundwater recharge. In general, these policies state that recharge will be utilized as a strategy for augmenting the local groundwater supplies and to provide long term operational flexibility to Tucson Water's water resource management programs and utilization of local floodwaters.

*Chief Hydrologist, Tucson Water, P.O. Box 27210, Tucson, AZ 85726

Additionally, these policies provide for regional assessments for recharge of CAP waters and a cooperative, inter-agency approach toward implementing groundwater recharge programs throughout the Tucson Active Management Area. Our programs, which support these concepts, are briefly discussed in the following text.

Reclaimed Water Recharge Project

In full recognition of the increasingly important role effluent would play in future water resource management efforts, the Tucson Mayor and Council adopted generalized effluent reuse policies in July, 1982. In November, 1982, Tucson Water retained the professional services of the joint venture consultant team of CH2M Hill/Rubel and Hager to conduct the Tucson Metropolitan Reuse Assessment.

The reuse assessment included a comparison of supplying reclaimed water from regional treatment plants versus upstream subregional wastewater reclamation facilities. It also identified benefits and constraints of groundwater recharge, evaluated impacts of the future use of CAP water, discussed probable water rights questions and institutional concerns, and evaluated public health impacts and overall acceptability of the program.

Identified potential users for effluent in the metropolitan area included turf irrigation for landscaping, industrial use and groundwater recharge.

The assessment specifically recommended the construction elements of the first phase of a 10-year development program and provided estimates for future effluent demand as shown in Table 1 (Smith & Guild, 1984).

TABLE 1

PROJECTED POTENTIAL DEMAND FOR RECLAIMED WATER
FOR LANDSCAPE IRRIGATION
WITHIN THE METROPOLITAN AREA

Year	Annual Demand Acre-Feet/Year
1983	18,800
1990	23,000
2000	28,000
2010	33,000
2020	38,000
2030	43,000

One of the major conclusions of the reuse assessment conducted by the joint venture of CH2M Hill/Rubel and Hager was that recharge of treated effluent would be a key factor in optimizing Tucson's wastewater reuse system (Smith and Guild, 1984).

Reclaimed water could be allowed to percolate into the subsurface at controlled spreading grounds during the fall and winter and recovered through the use of wells during the spring and summer to meet peak landscape irrigation demands. The additional treatment achieved as this water moves through the vadoze zone enhances the overall quality of the reclaimed water and may provide for some degree of nitrogen removal as well.

Underground storage of reclaimed water would significantly reduce the size and cost of conventional treatment facilities and reservoirs. Aquifer storage would enable these facilities to be sized and operated to meet average irrigation demands instead of peak demands.

Following a site selection process, it was decided to locate the City's 0.5 to 1.0 million gallon per day reclaimed water recharge project on the west side of the Santa Cruz River channel immediately opposite from the Roger Road Wastewater Treatment Facility.

Presently, the system consists of an 8.2 million gallons per day (mgd) pressure filtration plant (expandable to 25 mgd), a 3 million gallon reservoir, a 12 mgd booster facility, and a significant network of large capacity distribution lines which supply major turf irrigation uses throughout the community. The pivotal element of the system is the 1.0 mgd aquifer recharge facility which provides cost effective seasonal storage of reclaimed water for subsequent recovery and use during the peak demand season. A schematic view of the recharge facility is shown on Figure 1.

As depicted on Figure 1, the primary features of the demonstration recharge facility are the four 3/4 acre infiltration basins. These basins are centrally located to the main distribution facility and are designed to be relatively shallow and readily expandable. Inundation depths vary from 6 to 18 inches with optimal depth of inundation being one of the primary operational testing goals during facility operation.

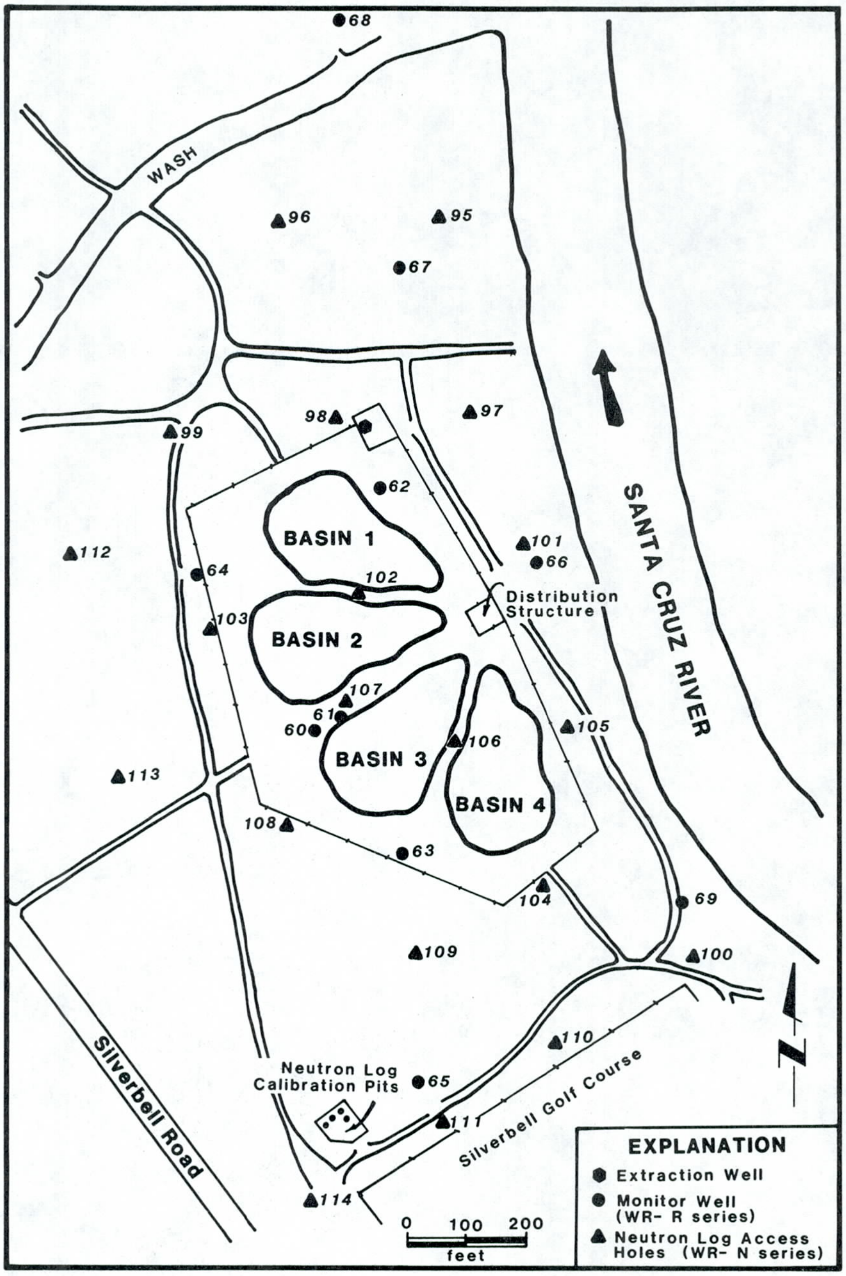


Figure 1.
Schematic View of Recharge Facility

Filtered, disinfected effluent (reclaimed water) is delivered to the recharge facility from the reclaimed water plant at Roger Road through a pipeline interconnect crossing the Santa Cruz River channel. The same channel crossing contains parallel piping to conduct the recharged water recovered with the extraction well to the booster plant for distribution to the various delivery points on the effluent delivery system.

Ten monitor wells have been constructed on the recharge site to provide monitoring and sampling capability throughout the operation of the project. These wells are identified on Figure 1 and allow the collection of water level information as well as chemical quality data for analysis.

Recovery of the recharged effluent will be accomplished through pumpage of the extraction well as located on Figure 1. After a period of recharge has concluded (such as during fall and winter) the recovery well is activated to recover the water recharged to meet peak demands. Seasonal aquifer storage as an operational element of the reclaimed water delivery system achieves a significant savings in the capital costs associated with peak demand storage.

Expansion of the recharge element is programmed to begin during fiscal year 1987-88 consistent with the expansion of the Roger Road reclaimed water treatment plant from 8.2 mgd to 25 mgd. These efforts will ensure the cost effective expansion of the reclaimed water delivery and reuse system.

The reclaimed water delivery program has reduced peak demands on the potable water system and represents a major step toward the efficient management of the water resources available to our growing community.

Recharge Feasibility Assessment Project

The Recharge Feasibility Assessment project is a significant step toward defining the overall role which groundwater recharge activities will play in future water resource management plans for the City of Tucson. Artificial groundwater recharge has historically represented a potential viable technique through which seasonal and long-term storage of available water resources could be accomplished for the benefit of the community. Tucson Water, in particular, has been a proponent of this concept and through this project is assessing the technical, economic and institutional feasibility of groundwater recharge as an effective resource management tool within the Tucson Active Management Area.

Delivery of water through the Central Arizona Project aqueduct system represents an additional major water resource available to the City beginning in 1991. Approximately three years ago, a significant change in the pricing structure and delivery opportunities for CAP water made the concept of recharging excess CAP supplies a potentially feasible addition to our resource management plans. To respond to future needs, the recharge assessment was begun. A product of this assessment will be an evaluation of our present plans to take those quantities of CAP water over and above our direct service needs and recharge that water throughout the early years of the project for future utilization. Should additional quantities of CAP water in excess of our annual allocation become available, they could be recharged in a similar fashion. The study is also evaluating recharge of other alternative water supply sources such as reclaimed water and local surface runoff.

The Recharge Feasibility Assessment program is divided into three separate phases. Phase A of the assessment is scheduled to be completed in May 1987. Included in this study are detailed evaluations of water quality considerations or constraints pertaining to groundwater recharge methodologies, in-situ ground- water quality and the matrix materials of the vadose zone. Detailed evaluations of the geohydrologic conditions existing in the Tucson Active Management Area are being conducted as well as an evaluation of our ability to use the existing network of distribution system pipelines and wells to move treated CAP water to areas conducive for recharge. Additionally, the contract contains elements which define the institutional and legal framework for recharge activities and evaluate the economic viability of incorporating groundwater recharge techniques into the City of Tucson water resources management programs.

Phase B of the program will include the collection of additional data found necessary in Phase A work and the design, construction, and operation of appropriate pilot projects to evaluate selected recharge methodologies in our local environment. Phase C will portray the overall evaluation of all data, pilot project results and recommendations for formulation of a comprehensive program of groundwater recharge activities to be implemented by the City.

Cooperative Recharge Programs

Since August, 1985, Tucson Water has been an active cooperator in the Rillito Creek Recharge Project sponsored by the Arizona Department of Water Resources. Along with ADWR and the Pima County Flood Control District, Tucson Water is contributing staff support and funding to implement a demonstration project to evaluate the opportunities for enhanced recharge of natural flood runoff waters along the Rillito Creek channel. This three-party program represents a significant step toward inter-agency cooperation and is, in fact, the first recharge augmentation program authorized by the State in any of the active management areas. The results of this particular demonstration project will be of value to the Tucson Active Management Area to guide future enhanced utilization of naturally occurring flood flows in local watersheds.

Summary

Tucson Water has demonstrated a progressive attitude with regard to implementing groundwater recharge activities into its operational programs. Groundwater recharge elements are currently playing a vital role in managing reclaimed water to take maximum advantage of that resource. The Recharge Feasibility Assessment will provide a much needed overview of the role recharge will play in the future.

In developing a long range groundwater recharge program for the City, Tucson Water is presently evaluating other opportunities for groundwater recharge which are found to be consistent with the adopted policies of our Mayor and Council.

The recharge programs being implemented by Tucson Water are designed to maximize the availability and use of all potential recharge water sources in the most cost effective manner and to provide the greatest degree of flexibility for future water resource management for the community.

Acknowledgements

The assistance rendered by co-workers of Tucson Water during the preparation of this paper is gratefully acknowledged.

References

Arizona Department of Water Resources, 1984. Proposed Management Plan - First Management Period 1980-1990. Arizona Department of Water Resources.

Smith, Stanley A., and K. Guild, 1984. Development of Tucson Metropolitan Reuse Program. In: Proceedings of Water Reuse Symposium III, American Water Works Association.

GROUND WATER RECHARGE ACTIVITIES OF THE SALT RIVER PROJECT

GARY G. SMALL

Salt River Project
P. O. Box 52025
Phoenix, Arizona 85072

The Salt River Project (SRP) at this point in time does not have an operational recharge project. However, they have been working very hard to get one going. To understand where SRP is headed, you must understand where it's been. The following is a review of some of the activities that SRP has been involved with up to this date.

The SRP was involved early on with the Flushing Meadows project. This project had several other sponsors back in the mid 60's and was in an operational mode until it was terminated in 1978 by water releases in the river. SRP has been involved in three ground water recharge symposiums. SRP has completed the Salt River Infiltration Study and is presently involved in a joint recharge project with the AMWUA cities called the Granite Reef Storage and Recovery Project.

The Flushing Meadows project lasted a little over ten years. It was located within the Salt River bed and utilized sewage effluent as its water source. The first five years of operation were involved in doing studies for the optimization of hydraulic loading and determining what were the optimum infiltration rates, plus determining the length of the drying, and wetting cycles. In the last five years of operation, studies concentrated on nitrate removals through the aquifer treatment process which has become known as the Bouwer Process. In 1978, a flood producing flows as high as 180,000 cubic feet per second in the Salt River bed washed out the Flushing Meadows facilities.

The SRP organized the first ground water recharge symposium in 1978 and was a co-sponsor in 1985 and 1987. The theme of the first symposium was "A technical, economic and legal overview." The second one was "A current Arizona perspective." The theme this year is "Let's get moving."

The Salt River Infiltration Study started back in 1985 to locate areas within the Salt River bed that has the highest infiltration rates. This study focused on finding those stretches within the Salt River bed that could actually support a recharge project with infiltration rates higher than one to two feet per day. The Infiltration Study was conducted from Granite Reef to the 48th St. bridge.

The results of the study highlighted high transmissivity reaches within the 17 mile study area, but the overall infiltration rate matched the historic values of one to two feet per day. This study influenced SRP's selection of the recharge site between Granite Reef Dam and Gilbert Road for the Granite Reef Storage and Recovery Project.

Salt River Project established a goal to permit and operate a storage and recovery project by May of 1988. To date, SRP has completed the following activities: 1) a preapplication meeting, 2) a joint project overview with the Salt River Pima Maricopa Indian community, 3) the recharge impact assessment study, and 4) the identification of all of the environmental and the associated permits required.

The following are the milestones that remain to be accomplished: 1) a participation agreement among the participants 2) a lease on the land where the recharge facility is to be located. 3) the approval of the storage and recovery application, 4) the approval of environmental and associated permits, 5) the design and construction of the facility, 6) a secure water supply, and 7) an operational recharge facility by May, 1988.

RECHARGE IN SCOTTSDALE, ARIZONA:

AN OVERVIEW

Leonard L. Dueker, Executive Assistant to City Manager 1/
Floyd L. Marsh, Water Resources Director
City of Scottsdale
3939 Civic Center Plaza
Scottsdale, AZ 85251

Introduction

The City of Scottsdale has made a strong, long-term commitment to groundwater recharge and storage as an integral component of its water resources management master planning. Such commitment will help Scottsdale meet future management goals of the Phoenix AMA and continue its reputation for creative municipal water planning.

Profound changes in municipal water management will occur as Scottsdale and other major Arizona municipalities shift from groundwater dependence of the past to utilization of CAP supplies and other water sources in the future. The 1980 Groundwater Management Act mandates significant changes to the water production activity of Scottsdale. Historically, the City provided additional water for its population growth needs by placing additional wells in production and pumping groundwater into the City water system. The Act requires that the City achieve "safe yield" by 2025. The water needs of the current population can be provided from groundwater, Salt River Project (SRP) and Central Arizona Project (CAP) surface water sources. However, new water supply sources must be acquired, or otherwise developed, to meet needs of future growth and diminish our dependence on groundwater to safe yield. In short, one apparent solution is the conjunctive management of available surface and groundwater supplies including recharge and storage of temporary excesses and treated municipal effluent in the groundwater basin underlying the City to accommodate variations in water supply and future municipal demands.

1/Presentation by Leonard L. Dueker.

Water Supply versus Future Demand

In 1986, the City of Scottsdale, which overlies about 40% of the Paradise Valley groundwater basin as depicted in Figure 1, produced approximately 24,800 acre feet of groundwater to meet municipal demands compared to the estimated safe yield for the entire basin of 6,600 to 7,000 acre feet per year. A proportional percentage of this estimated total natural recharge (2,600 to 2,900 acre feet) combined with the City's annual 20,488 acre feet CAP allocation yields about 5 percent less than the City's 1986 production. Hence, in order to achieve safe yield, all future water demands resulting from projected growth must be met with the acquisition of additional renewable water supplies and the reclamation of advanced treated municipal effluent, both involving recharge and subsurface storage.

At ultimate buildout, Scottsdale will have an estimated annual water demand of approximately 140,000 acre feet per year. The multiple sources of supply to meet this projected demand are illustrated by Figure 2. As noted in this figure, reclaimed effluent and the supply from other sources comprise approximately one-half of the required supply to meet future demands. Reclaimed effluent alone represents slightly more than one-third of the City's future supply. That quantity will need to be used either for direct irrigation of turf and landscape or converted to potable water with advanced treatment, recharged and then recovered and delivered to the municipal system.

Not only does effluent comprise the most significant future source in relation to the other supply components, but there are great variations in when the supply is available and the demand for its direct use exist. In a simple supply-demand relationship, the greatest effluent demand is during summer months; whereas, the greatest supply is during the winter months creating a seasonal supply-demand imbalance. Figures 3 and 4 vividly illustrate the seasonal demand-supply variability and large block of effluent excess to direct irrigation and contractural obligations (Palo Verde) which must be reclaimed through advanced treatment, recharged and recovered for subsequent delivery to the potable system. Master planning studies project a total of 17,400 acre feet of effluent available in the area generally north of the CAP aqueduct at buildout with an estimated 8,600 acre feet per year allocated for direct golf course and turf irrigation and 8,600 acre feet per year remaining for indirect use through advanced treatment, subsurface storage and recovery. Additional effluent becomes available for advanced treatment and recharge as wastewater flows increase in other areas between now and ultimate buildout. Overall, with buildout treated municipal effluent will become a significant component of the City's water supply budget and likewise an integral source for reclamation through direct irrigation use or recharge and subsurface storage.

Recharge Planning Activities

In early 1987, the City of Scottsdale retained a specialized three-member consulting team to develop an integrated water resources master plan. Recharge, subsurface storage and recovery was a major component of this ongoing water system planning process along with water supply and distribution and wastewater collection and reclamation. Reports on this comprehensive, computer-based master planning process will be available in July, 1987. Being dynamic in nature, the coordinated master plans resulting from this process are capable of future refinement and periodic update.

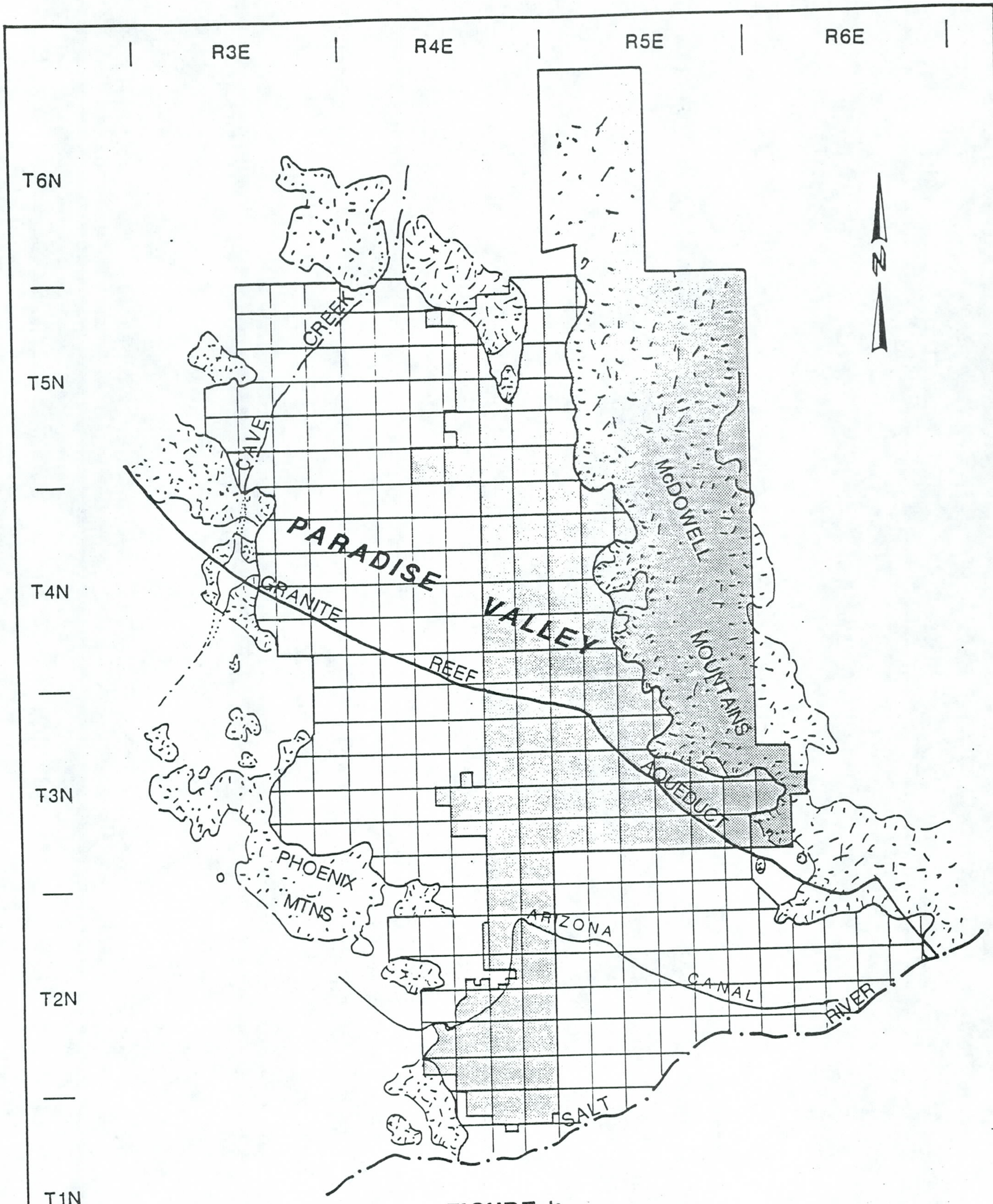


FIGURE I

PARADISE VALLEY AQUIFER

Scale
0 1 2 3
Miles

City of Scottsdale
Water Resources Management
Master Planning
June 1987

Boyle Engineering Corporation
consulting engineers / architects

SUPPLY
ACRE FEET PER YEAR

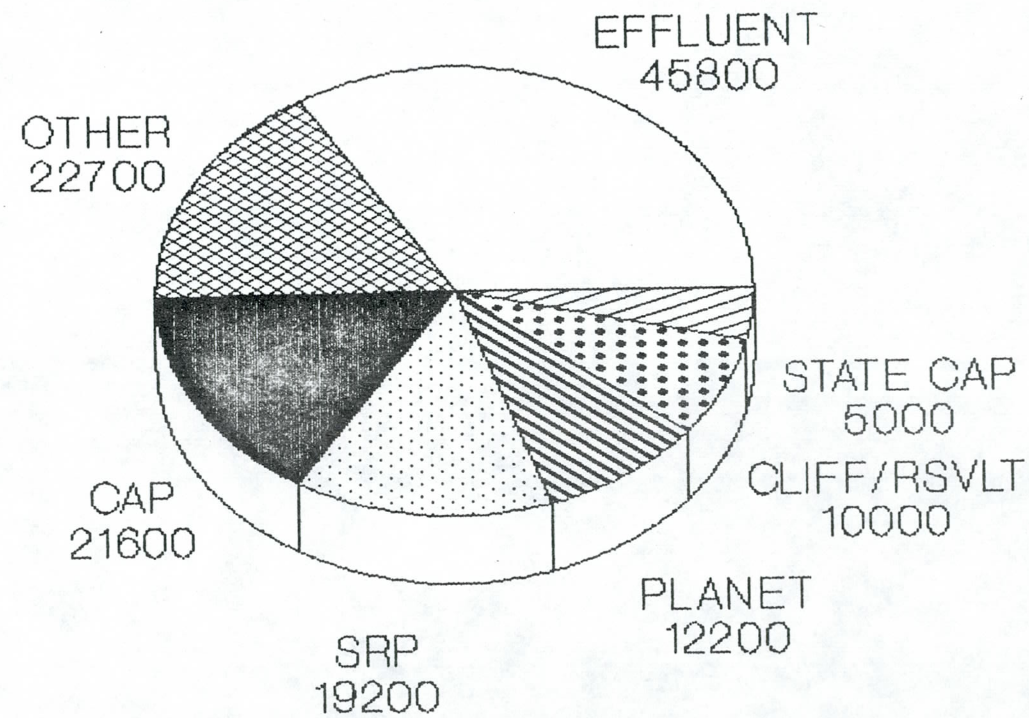


FIGURE 2

EFFLUENT
SUPPLY VS DEMAND

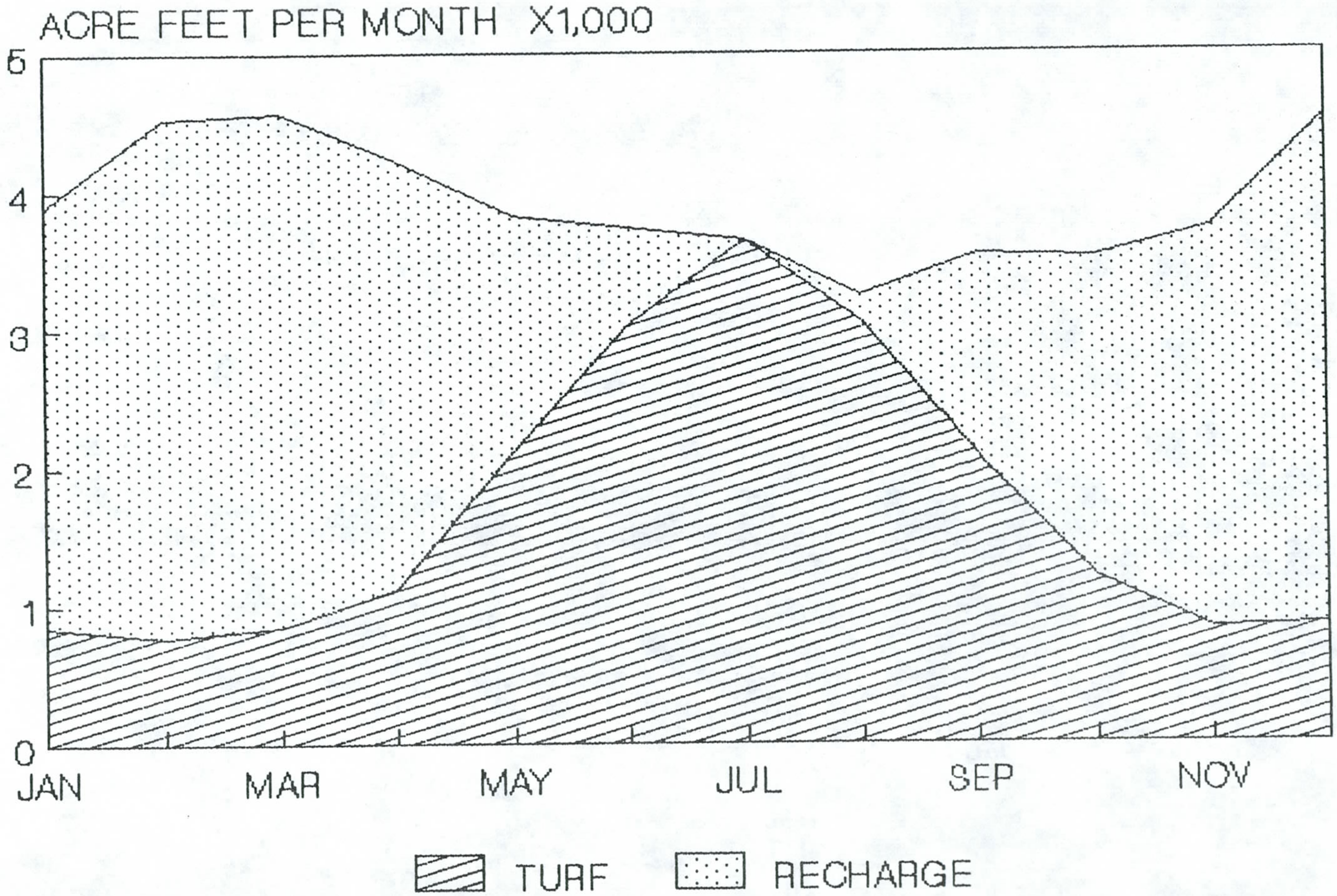


FIGURE 3

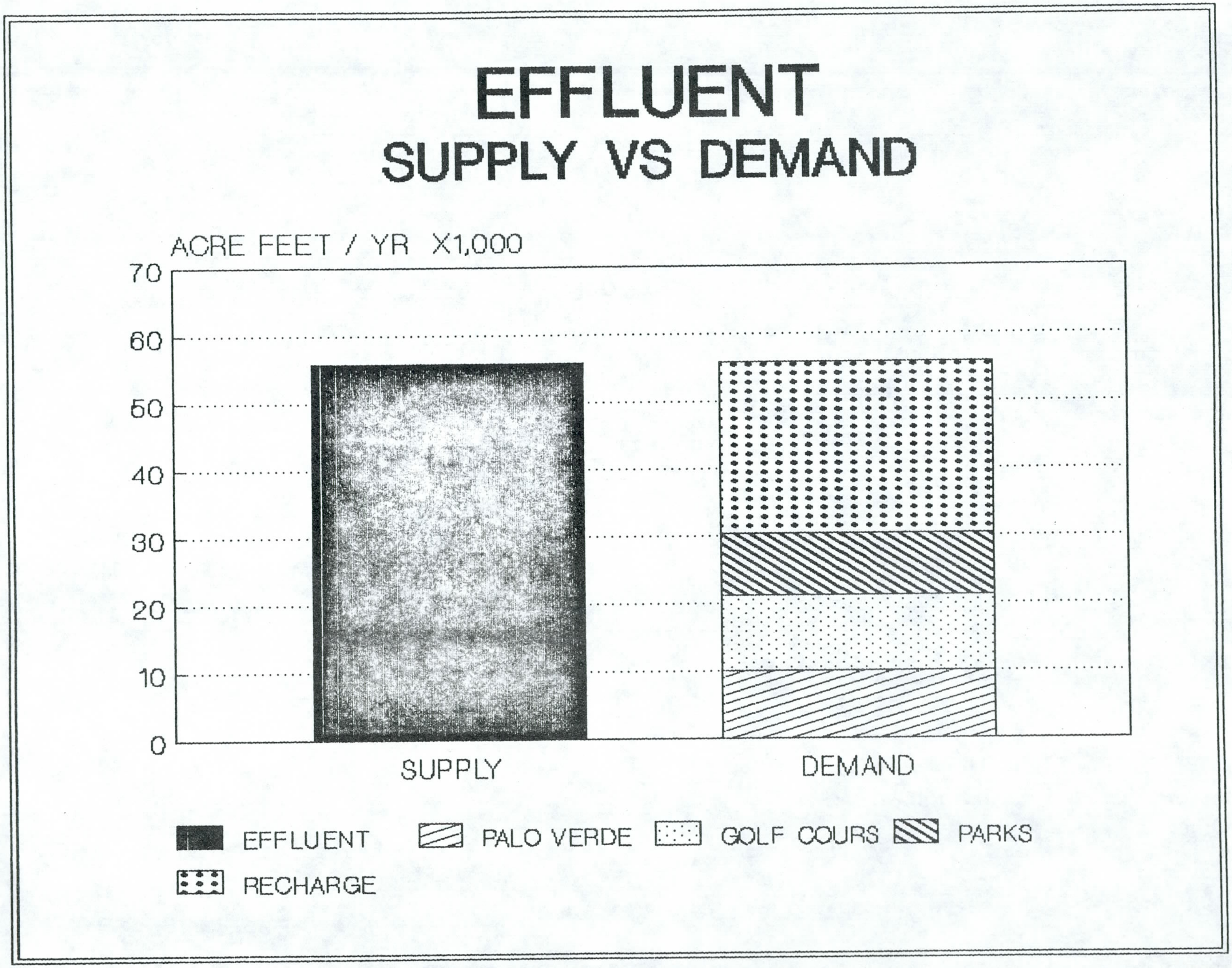

EFFLUENT
SUPPLY VS DEMAND
ACRE FEET / YR X1,000
70
60
50
40
30
20
10
0
SUPPLY
DEMAND
EFFLUENT
PALO VERDE
GOLF COURS
PARKS
RECHARGE

FIGURE 4

Prior to this more recent master planning effort, in early 1986 the City contracted to conduct a feasibility investigation of groundwater recharge within its municipal corporate boundaries. As a provision of this investigation, in May 1986 an application was submitted for federal cost-share under the 1983 High Plains States Groundwater Demonstration Program Act for a demonstration groundwater recharge project at a site north of the CAP Granite Reef Aqueduct on the City's new Tournament Players Club (TPC) municipal golf course.

In the City-wide feasibility study leading up to and supporting the High Plains funding application, the City was divided into five general recharge zones based upon a number of technical considerations. Each zone was rated based on its potential for recharge and four sites, including the site noted previously, were selected from three of the five zones. Completed in December 1986, the study concluded that the subsurface geology and groundwater aquifers underlying the City would permit artificial groundwater recharge and storage utilizing several different methods singly or in various combinations. The study report recommend that the City begin with a pilot recharge program to verify technical characteristics and demonstrate the effectiveness of recharge leading into a full-scale project.

The City of Scottsdale's recharge-recovery program is evolving in a multi-dimensional direction. That is, it includes multiple water sources comprising both raw and treated CAP water, advanced treated municipal effluent and storm runoff at multiple locations with multiple objectives. Functionally, the program is developing as a dual-faceted approach including provisions for both future operational peaking capacity and reserve subsurface storage capacity for drought periods or other unforeseen emergencies. Recharge-recovery locations include proposed projects both inside City boundaries and outside City limits. For strategic reasons, we are evaluating the AMWUA-proposed Agua Fria recharge facility west of the Phoenix metropolitan area and two prime recharge-recovery locations within the City corporate boundaries for use as system peaking facilities. Whereas, we are considering the AMWUA-proposed Salt River site as reserve subsurface capacity for meeting emergency needs over the long term. Each of these proposed facilities are conceptual plans moving toward project design.

Within Scottsdale Boundaries

From the feasibility study to select a High Plains States Groundwater Demonstration project site, two prime recharge-recovery locations emerged - one in north Scottsdale and one in south Scottsdale. Both locations overlay an excellent aquifer stratigraphy for recharge-recovery projects.

The northern project location was selected for initial detailed investigation largely because of its prime recharge potential and geographic location. This area is bisected by the CAP aqueduct and includes the Scottsdale CAP water treatment plant and numerous existing production wells. It also encompasses the proposed High Plains demonstration site A on the Scottsdale TPC municipal golf course and several large existing flood detention basins behind the Paradise Valley Detention Dike. In addition, another potential site identified in the feasibility study (site D) is located immediately north of this site which also includes a number of existing production wells. By combining the existing features of this 16 square mile area with proposed facilities as noted in Figure 5, it provides

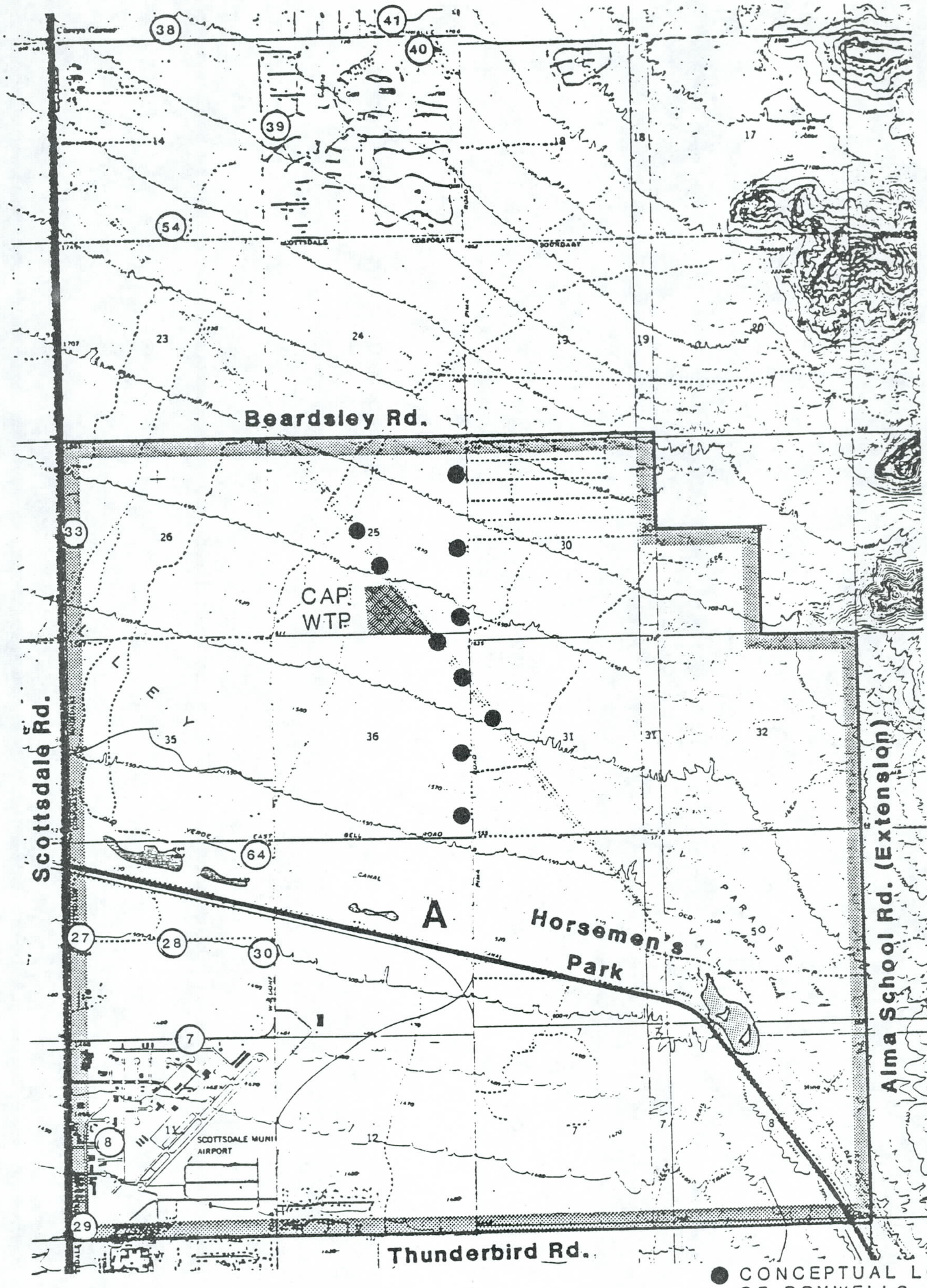


FIGURE 5
CONCEPTUAL LOCATION
INITIAL RECHARGE DRYWELLS

City of Scottsdale
Water Resources Management
Master Planning
June 1987

Boyle Engineering Corporation
consulting engineers / architects

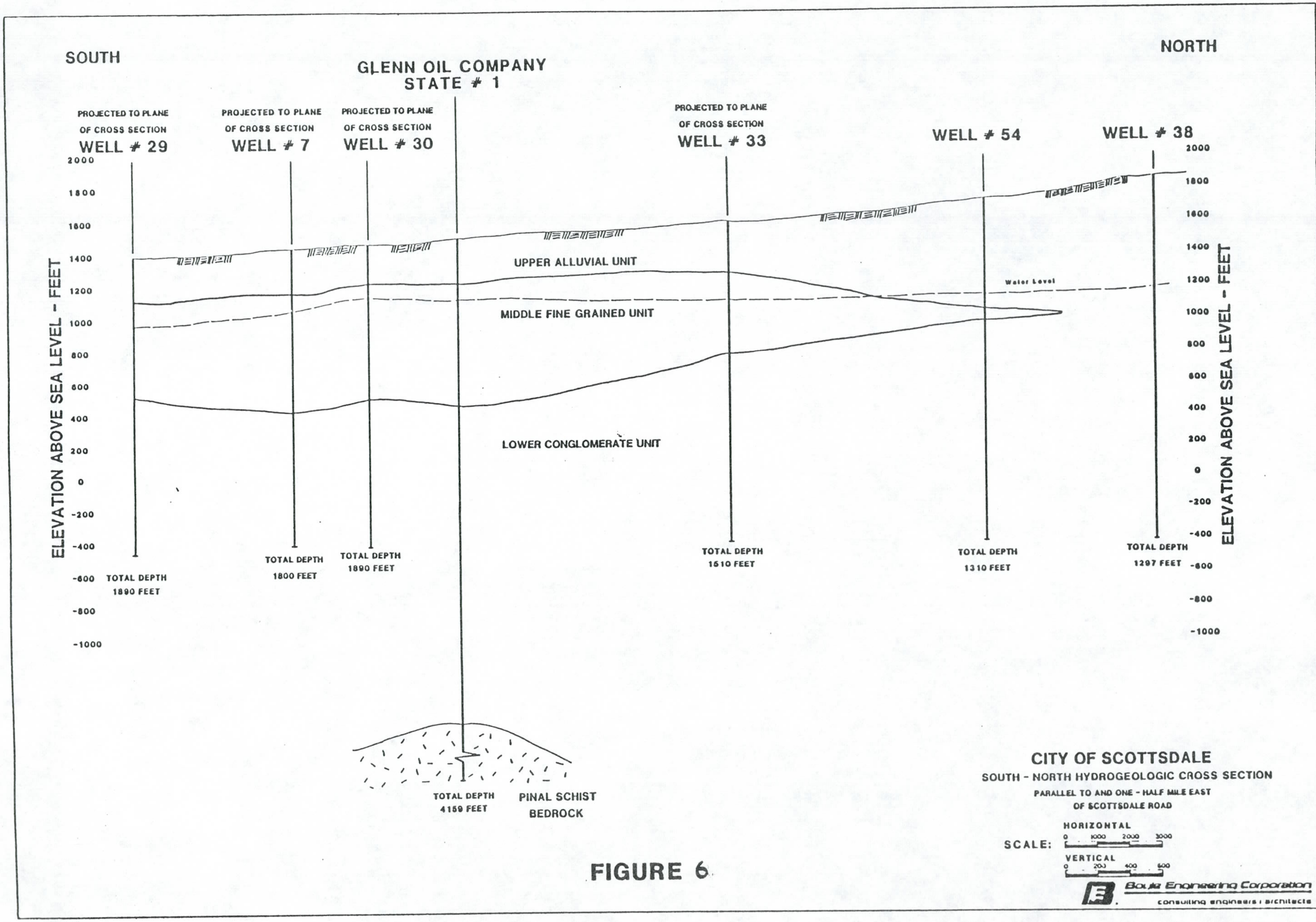
an ad hoc plan to start up quickly with a pilot recharge-recovery program and eventually could become an integral component of permanent facilities. The required permitting process will be initiated soon for this proposed facility.

Figure 6 illustrates a north-south hydrogeologic cross-section of the aquifer stratigraphy underlying this location. The basin stratigraphy is comprised of three geologic units: an upper alluvial unit which has been virtually dewatered by previous pumping, a middle fine-grained unit and the lower conglomorate unit which is the location of current well production. The upper alluvial unit is estimated to be capable of recharging 23,000 acre feet of water through a combination of recharge basins and dry wells; whereas, within the lower conglomerate unit it is estimated that 13,000 acre feet of water could be recharged through deep injection-recharge wells for a total of 36,000 acre feet of recharge capacity.

The conceptual plan of recharge-recovery for this location utilizes several different recharge methods singly or in combination. Conceptual design of the proposed demonstration site located at the TPC golf course lake is a unique combination of reverse drainage-spreading basin system supplemented with shallow and deep wells as illustrated in Figure 7, allowing the use of both surface and subsurface recharge methods. A detention basin will provide both a lateral drain collector system and spreading basin for surface infiltration into a combination of shallow and deep recharge wells, at a lake incorporated into the municipal golf course. Using a dual water source comprised of untreated CAP water and storm runoff when available, preliminary studies estimate that 1,600 acre feet per year can be recharged on a demonstration basis with the design flexibility to possibly expand the capacity of a permanent operational facility to 5,000 acre feet per year.

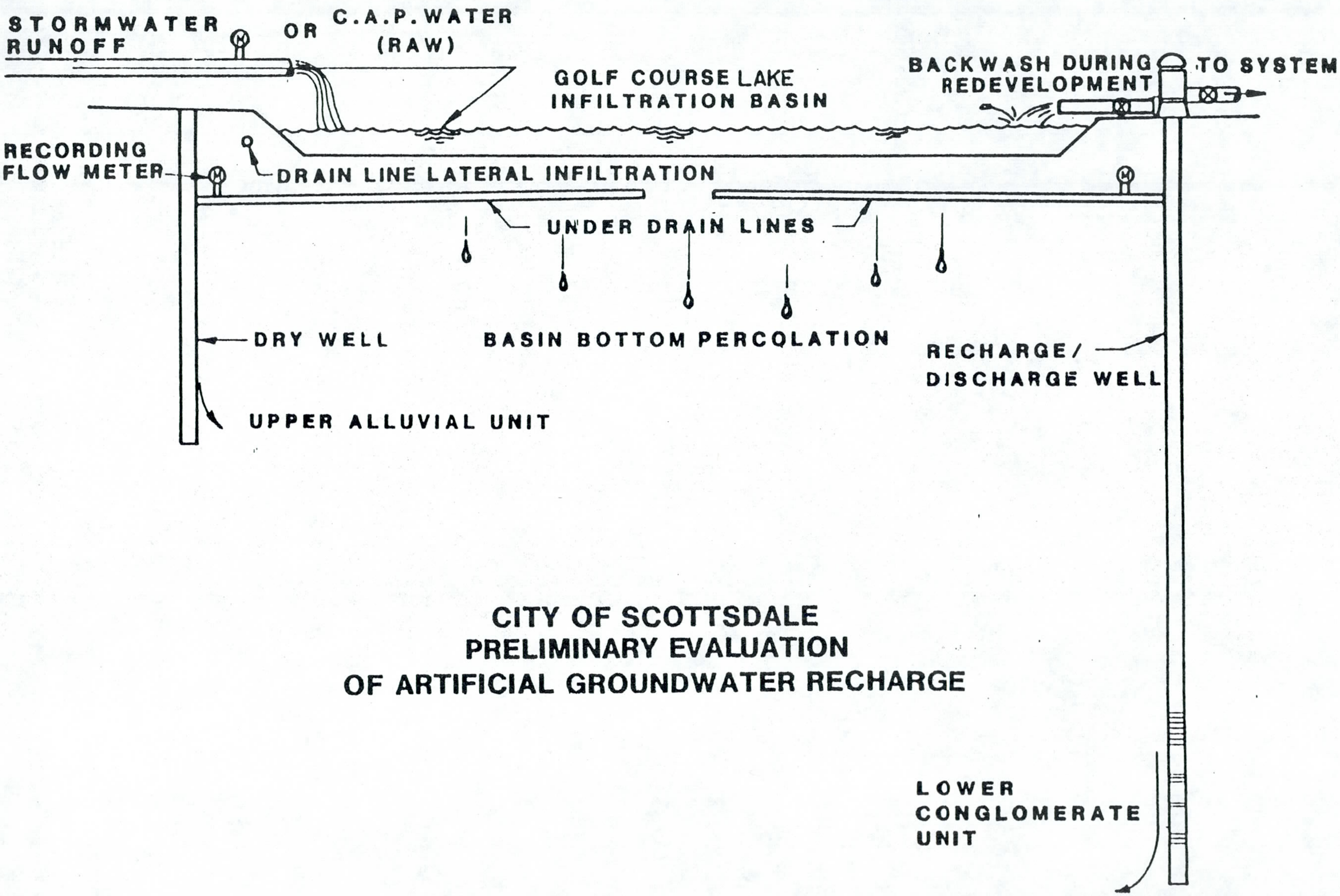
Within this area, a series of existing flood detention basins located in the lower (downstream) end of the City's Horsemen's Park provide significant recharge capacity. Excavated to construct the Paradise Valley Detention Dike above the CAP aqueduct, material in the sides and bottoms of these basins is quite course indicating highly permeable materials beneath. Three existing basins, with a combined surface area of 25 acres, are estimated to have a storage capacity of 120 acre feet of water. Their estimated annual recharge capacity is 7,500 acre feet using recharge of nearby CAP water and storm runoff when available.

A schematic configuration of dry wells and deep recharge wells is also proposed for additional recharge capacity in this location as noted in Figure 5. These wells would be located near the Scottsdale CAP water treatment plant on or adjacent to existing right-of-way corridors including the Pima Road and Arizona Public Service rights-of-way. Treated CAP water would be recharged through these wells into the upper alluvial and lower conglomerate units of the aquifer, beginning with the upper unit as the recharge zone of choice because of its high hydraulic conductivity and relatively shallow depth for recovery pumping. Existing municipal production wells, which pump from the lower conglomerate unit but are perforated in the other alluvial units, are effectively located for capture of recharged water before it migrates outside the City boundary to the west These wells will be supplemented as necessary with future wells for purposes of extraction from subsurface storage.



SOUTH
NORTH
GLENN OIL COMPANY
STATE # 1
PROJECTED TO PLANE OF CROSS SECTION
WELL # 29
PROJECTED TO PLANE OF CROSS SECTION
WELL # 7
PROJECTED TO PLANE OF CROSS SECTION
WELL # 30
PROJECTED TO PLANE OF CROSS SECTION
WELL # 33
WELL # 54
WELL # 38
ELEVATION ABOVE SEA LEVEL - FEET
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
UPPER ALLUVIAL UNIT
Water Level
MIDDLE FINE GRAINED UNIT
LOWER CONGLOMERATE UNIT
TOTAL DEPTH 1890 FEET
TOTAL DEPTH 1800 FEET
TOTAL DEPTH 1890 FEET
TOTAL DEPTH 1510 FEET
TOTAL DEPTH 1310 FEET
TOTAL DEPTH 1297 FEET
TOTAL DEPTH 4159 FEET
PINAL SCHIST BEDROCK
CITY OF SCOTTSDALE
SOUTH - NORTH HYDROGEOLOGIC CROSS SECTION
PARALLEL TO AND ONE - HALF MILE EAST OF SCOTTSDALE ROAD
SCALE: HORIZONTAL 0 1000 2000 3000
VERTICAL 0 200 400 600
Boyle Engineering Corporation
consulting engineers / architects

FIGURE 6



ARTIFICIAL GROUNDWATER RECHARGE THROUGH COMBINATION SYSTEMS

FIGURE 7

Numerical models of both groundwater flow and solute transport systems have been developed in the northern recharge location to simulate and predict aquifer response to recharge-recovery activities in terms of water quantity and quality considerations. As noted in Figure 8, these models link with the ADWR Indian Bend Wash Remedial Investigation model to the south being used to model the TCE-contaminated region in the extreme southern portion of Scottsdale.

In addition to the northern Scottsdale location, significant recharge-recovery potential also exists in portions of southern Scottsdale. Although parts of this area have been identified in previous feasibility studies as an excellent aquifer system for recharge, storage and recovery, a significant portion of it, particularly in the lower reach of the Indian Bend Wash drainage in south Scottsdale, has been contaminated with volatile organic compounds and since designated a federal TCE Superfund site. Remedial investigation of the site is ongoing. Current plans are to incorporate this area into a future phase of recharge-aquifer management activities to restore the integrity of the system as a recharge-recovery medium and also as an integral component of final remedial cleanup or containment plans. The area would be used for injection and recovery of advanced treated municipal effluent through the Water Factory 21 concept. Additional recharge capacity in a four to five mile reach of Indian Bend Wash upstream from the Superfund site is also being considered. These plans involve surface infiltration of 15,000 to 20,000 acre feet per year through the streambed and percolation basins with recovery by the same recovery well field used for the TCE site.

Outside of Scottsdale Boundaries

Scottsdale's comprehensive recharge-recovery planning also includes use of the Agua Fria and Salt River streambed recharge sites located outside the City. These locations, noted in Figure 9, were investigated and selected for their recharge potential in the 1986 AMWUA riverbed recharge feasibility study report. Total combined recharge capacity at these sites for Scottsdale is anticipated to be 35,000 to 40,000 acre feet annually.

Scottsdale's use of capacity in the proposed Agua Fria recharge-recovery facility is anticipated to provide operational peaking capacity in meeting future water system demands in conjunction with the recharge-recovery facilities located within the City. Plans at the proposed Agua Fria location involve purchase or participation in infiltration capacity in the upper Agua Fria riverbed to recharge and store excess CAP supplies during early-year deliveries, miscellaneous CAP water and Planet Ranch water. Stored water would be extracted through recovery wells located near the CAP aqueduct and delivered through a transmission pipeline along the Carefree Highway alignment to the City's municipal distribution system in north Scottsdale. Joint use of this transmission line with the cities of Phoenix and Glendale to deliver supplies to their northern areas is also a possibility.

The Salt River recharge and recovery facility would involve joint use of capacity in the proposed facility to recharge and store Plan 6 Roosevelt conservation storage water, "other" alternative Plan 6 conservation storage water and excess SRP "spill" water. This stored water would be designated as reserve storage capacity for drought periods or other unforeseen emergencies over the long term. When needed under such conditions, the water would be recovered from this reserve storage for diversion into the Arizona Canal for conveyance to Scottsdale treatment and supply points.

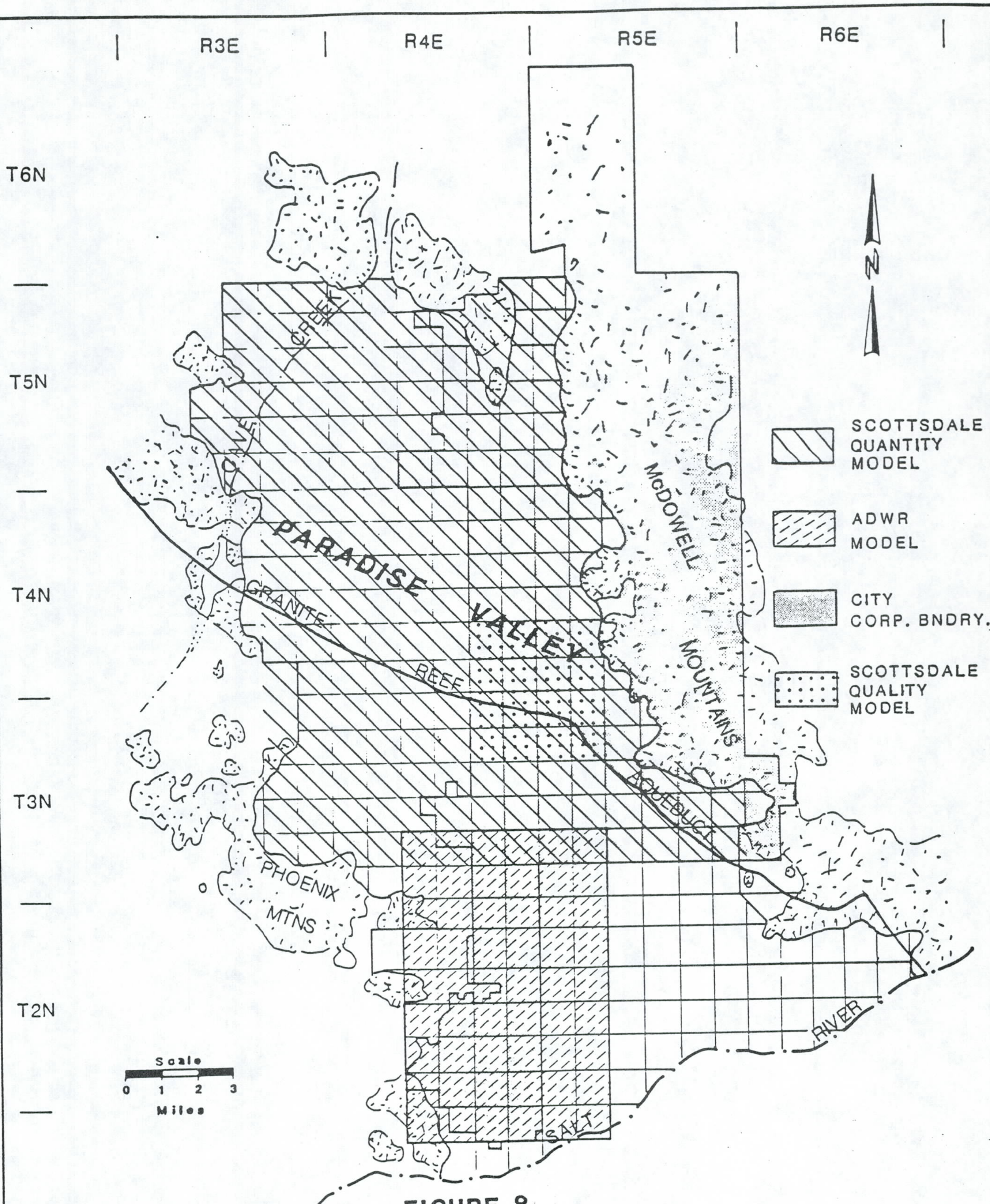


FIGURE 8
COMPUTER MODELED AREAS
PARADISE VALLEY AQUIFER

City of Scottsdale
Water Resources Management
Master Planning
June 1987

Boyle Engineering Corporation
consulting engineers / architects

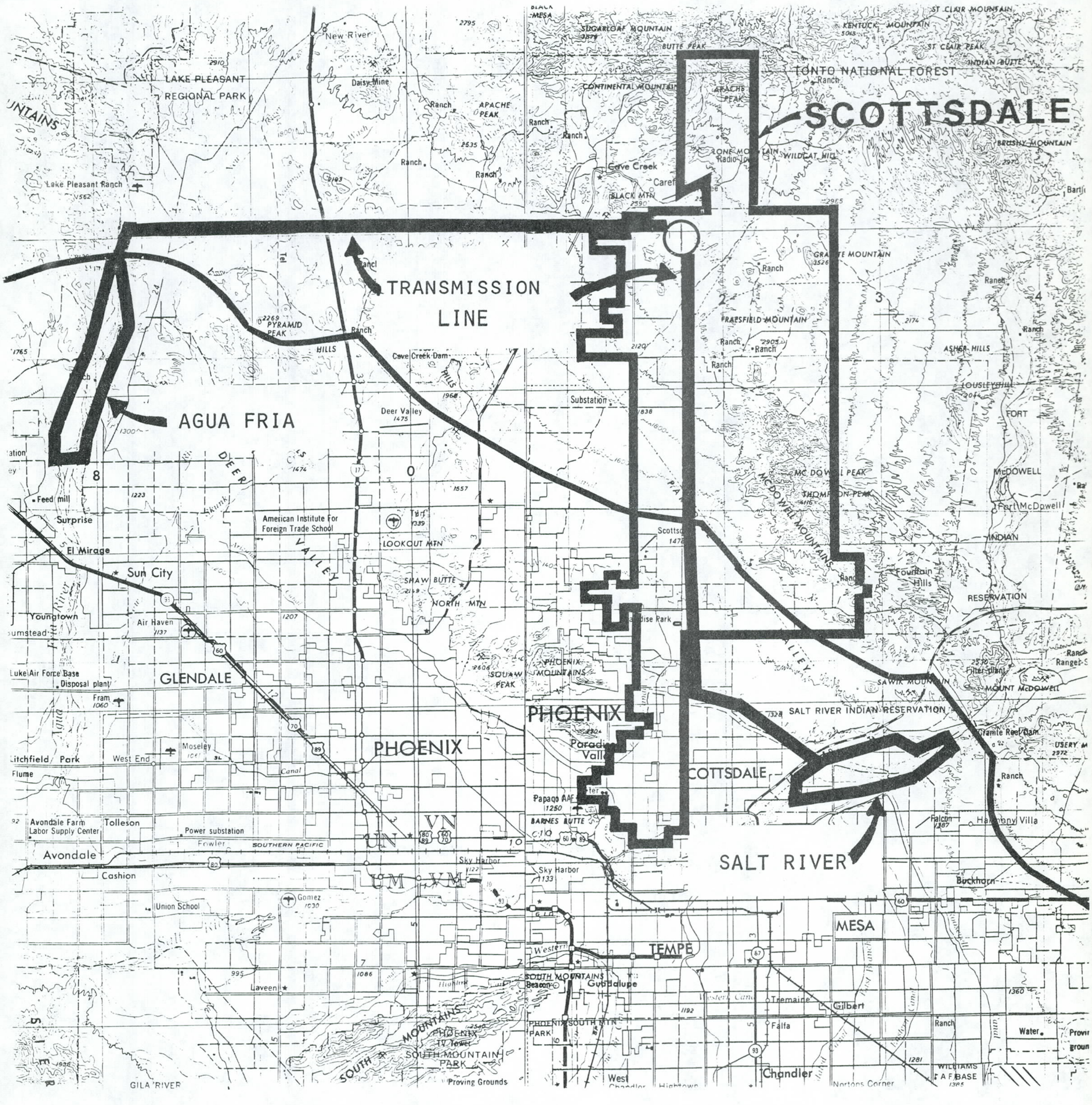


FIGURE 9 PROPOSED AGUA FRIA AND SALT RIVER RECHARGE FACILITIES

Summary

Recharge, subsurface storage and recovery is a major component of the City of Scottsdale's ongoing water system-water supply master planning. Scottsdale's long-term commitment to groundwater recharge-recovery involves a multi-dimensional program and development of a coordinated aquifer management system. A shift from groundwater dependence to reliance on renewable water sources including CAP water, SRP water, imported ranch water and reclaimed municipal effluent requires a comprehensive recharge-recovery program at multiple locations inside and outside City of Scottsdale corporate boundaries. The proposed multi-faceted approach provides many operational options for municipal water system management to accommodate changes in water customer demand and variations in water supply.

References

Arizona Municipal Water Users Association. 1986. Feasibility Study Report for Riverbed Recharge Project, prepared by Camp Dresser and McKee, Inc. and W.R. Mills and Associates, August 1986.

City of Scottsdale. 1986. Applications for High Plains States Groundwater Recharge Demonstration Program, prepared by Boyle Engineering Corporation, May 1986.

City of Scottsdale. 1986. Preliminary Evaluation of Artificial Groundwater Recharge, prepared by Boyle Engineering Corporation, December 1986.

City of Scottsdale. 1987. Water Resources Management Plan-Utilization of Groundwater Reservoir Under City of Scottsdale, prepared by Boyle Engineering Corporation, June 1987.

City of Scottsdale. 1987. Water Resources Management Plan: Wastewater Collection-Water Reclamation Master Plan, prepared by Greeley and Hansen Engineers, June 1987.

ARTIFICIAL RECHARGE OF GROUND WATER PLANS OF THE FLOOD CONTROL DISTRICT OF MARICOPA COUNTY, ARIZONA

Stanley L. Smith, Jr., P.E.
Deputy Chief Engineer

ABSTRACT: A brief summary of the authority and history of the involvement and rationale for Flood Control District of Maricopa County, Arizona in artifical ground water recharge, including the lobbying efforts and decisions leading to legislative changes in authority during 1987. Also, a discussion of the scope of work for an engineering study to determine which of the District's existing flood control facilities have the potential feasibility for ground water recharge using flood water or a supplementary water source.

TEXT

The Flood Control District of Maricopa County was formed in August of 1959 as the first and only Special Flood Control District in the State of Arizona. The District is supported by a flood control tax levy on real property in the County. The current tax rate is 50 cents per $100 of assessed valuation, which will produce approximately $48 million in fiscal year 87/88.

Among the powers and duties of the District are the construction, maintenance and operation of flood control and drainage facilities, floodplain management, and the construction, operation and maintenance of artificial ground water recharge facilities, if they have flood control benefits.

Over the past several years, District staff, the citizen's Flood Control Advisory Board, and members of the Board of Directors have been lobbied extensively to support a new role for the District in gound water recharge. The rationale being, that it is logical for the District to to follow the example of flood control districts in California which are now and have for years been involved in ground water recharge. Another reason given, but not publicized, was that the District is well established, has a competent technical and maintenance staff with equipment already in place, and has an accepted revenue source spread over the entire county which could be utilized to "purchase some Colorado River water which is now being wasted to the Gulf of

California, and to get some water into the ground to help assure the future of Maricopa County and Arizona".

The lobbying efforts were successful to the point that the District proposed changes to its enabling legislation which would allow the District to participate with other agencies in artificial ground water recharge and recovery operations without regard to flood control benefits, and to purchase water for recharge purposes if necessary. After a few steps forward, and some retreat, the proposed changes as contained in HB 2401 passed the legislative hurdles as follows:

In the general paragraph concerning:
48-3603. <u>Powers, duties and immunities of district and board; exemptions</u>:
...
C. A district organized under this article, acting through its board of directors, may:
...
17. Construct, operate and maintain artificial groundwater recharge facilities, AND IF ORGANIZED IN A COUNTY HAVING A POPULATION OF MORE THAN ONE MILLION, FIVE HUNDRED THOUSAND PERSONS, ACCORDING TO THE MOST RECENT U.S. DECENNIAL CENSUS, UNDERGROUND STORAGE AND RECOVERY FACILITIES, if they have flood control benefits, and contract and join with the United States, this state and other governmental units for the purpose of constructing, operating and maintaining multipurpose groundwater recharge, UNDERGROUND STORAGE AND RECOVERY, and flood control facilities, EXCEPT THAT A DISTRICT SHALL NOT EXPEND DISTRICT FUNDS FOR ANY UNDERGROUND STORAGE AND RECOVERY FACILITY THAT DOES NOT HAVE FLOOD CONTROL BENEFITS.

At this time the District staff has not had the opportunity to fully discuss the implication of this language in the enabling legislation with legal counsel. However, on the surface it looks like the District now has the authority to conduct artificial ground water recharge, and underground storage and recovery activities utilizing flood control tax revenues, if flood control benefits can be identified. We would also have authority to contract with other government units for such purposes. If no flood control tax benefits can be identified, then such operations would need to be wholly supported from another revenue source, such as a state appropriation or a contract with another governmental unit.

In preparation for this new role, the District has recently negotiated a contract with the engineering consulting firm of CH2M-Hill to determine which of the District's facilities are potentially feasible for ground water recharge projects using flood waters and supplementary water supplies. The contract requires the work to be completed within six (6) months of the Notice to Proceed, exclusive of review time.

A "fatal flaw" approach will be used to identify facilities not feasible for a recharge project consideration. We expect that the consultant will use available data and some preliminary criteria to evaluate 15-20 sites where existing facilities might be modified for recharge purposes. The second round of evaluation will probably involve up to seven (7) sites using more stringent criteria. The final round will get us down to three (3) or fewer sites having real potential for recharging both flood waters and a supplemental source.

Among the criteria to be used in the evaluation and elimination of District facilities could be insufficient water supply, shallow depth to ground water, presence of landfills or hazardous waste sites or dumps, known contamination problems in the existing ground water, inadequate land available, contractual constraints on land use, or other environmental problems. Second round criteria might include soil characteristics, estimated percolation rates, aquifer characteristics such as permeability and transmissivity, storage capacity, perched water table conditions, risk of flood damages to recharge facilities, and availability of surface or supplemental water for recharge.

The Consultant is responsible for the evaluation and ranking of no more than three (3) sites which are the most suitable for recharge projects. For each of the sites, he will identify the recharge method best suited and also identify and evaluate flood control benefits which could result from a recharge project at that site.

Once the three (3) sites have been presented, reviewed, and accepted by the District the Consultant will prepare conceptual facility plans for each of the sites. Estimated costs for the construction, maintenance, and operations for each of the recharge facility plans are also to be provided.

Finally, we are asking the Consultant to determine what additional data and appropriate gathering technique will be required for final design, permitting, construction, and operations of a ground water recharge facility at each of the selected sites.

From an operational view point, we are also requiring the Consultant to look at our current and planned activities including existing programs such as floodplain management, area drainage studies, channelization of streams, and maintenance of open space for the purpose of recommending changes in the management or design of these projects which could promote an incidental, beneficial recharge of ground water.

By the time of the next symposium, the District will have some positive results to report.

BIOGRAPHICAL SKETCH

Stanley L. Smith Jr., P.E. is the Deputy Chief Engineer of the Flood Control District of Maricopa County, which is located at 3335 W. Durango Street, Phoenix, AZ 85009. He is a registered Professional Engineer (Civil) in the states of Washington and Arizona. He has a Bachelor of Science Degree in Civil Engineering from Drexel University in Philadelphia, Pa and a Masters of Science in Civil Engineering from Purdue University in West Layafette, Indiana. He has been with the Flood Control District for the past eight years. He is a retired military officer from the U.S. Army Corps of Engineers.

RECHARGE ACTIVITIES BY THE CENTRAL ARIZONA WATER CONSERVATION DISTRICT

For Presentation at The Third Symposium on Artificial Recharge of Groundwater in Arizona

by Larry R. Dozier
Assistant General Manager

May 21, 1987

About six months ago when I agreed to make a presentation to this group, I hoped to have some specific plans to report. I think there are still more questions than there are answers in planning for groundwater recharge activities. I think those crucial questions are the same ones that many of you here will have to address. They are questions such as how much water will be available for underground storage in the recharge projects, how should one size those projects, and how are you going to pay for those projects. I suspect we will all be dealing with those specific questions for some time.

Today, I will try to bring you up to date on what the Central Arizona Water Conservation District has done, what we are currently in the process of doing, and some ideas on our future plans. In January of 1987, the Board of Directors adopted a policy that addressed District involvement in underground storage and recharge activities. Specifically, this policy says, "Based on the assumption that not all of the available water will be purchased and used by other entities, the District should recharge excess water at appropriate locations to augment the amount of water available during future water shortage periods. CAWCD will proceed as necessary to conduct District recharge projects using surplus Colorado River waters as soon as it is possible. However, it is doubtful that the District will be ready to do any significant recharge in 1987. The District will: 1) Pursue the necessary actions to collect and use tax funds for the construction and operation of recharge projects, 2) Concurrently conduct site specific studies to identify site characteristics, facilities needed, economics, etc. of potential recharge sites, and 3) Evaluate requests for recharge projects for others." The Board policy further stated that they would adopt a "price for any water used for groundwater augmentation or storage projects. This price will be the cost of energy plus $2/acre foot. The $2/acre foot is added to the energy component to cover administrative and record keeping costs of this category of water. This water will have a lower priority than any other water delivered. By making water for recharge purposes available at the lowest cost over the interim period, users will be encouraged to take advantage of the current surplus water conditions. Most of the water sold in this category probably would not be purchased if the price were higher." This lower price is for the interim period until such time that the Project is declared complete and the water sales become subject to the terms of the long term subcontracts. It is, of course, subject to review from year to year. Obviously, the policy could be updated if conditions change.

The District actively sought broad legislative authority to become involved in underground storage and recovery projects, and augmentation projects.

Our initial request would have permitted CAWCD to recharge water in the name of the District by using contracts with others or by using our own forces. It would have permitted recharge of water for other entities. The source of water could have been any water permitted for underground storage and recharge under state law. We sought additional taxing authority of $.05 on $100 of assessed evaluation to help finance these projects. The recharge legislation recently passed is more complex and restrictive. It permits the District to undertake underground storage and recovery projects using surplus CAP water, that is, water that has first been offered to our subcontractors for other direct uses. These projects shall be for the benefit of CAP subcontractors. Water purchased by CAWCD for these projects shall not be priced less than the full agricultural water price. We could do underground storage for others using any water supply they might have, including their CAP water supply with certain limitations. When recharging for others, we can do so 1) only when it does not interfere with deliveries for direct use, 2) only with water that would not otherwise be delivered for direct use when the Colorado River supply is 1.5 MAF or less and 3) only with water which would not otherwise be delivered for direct use in the same AMA (this limitation goes into effect after December 31, 1993). Water withdrawn from such projects must be assessed charges sufficient to recover all development, operational, and maintenance costs. We did not get any additional taxing authority, but did get the clarification of the right to use our existing tax authority of $.10. We are currently taxing at the $.07 rate. We may also issue revenue bonds to finance such projects.

At Butler Valley, we have a feasibility study underway by Engineering Enterprises Inc. from Norman, Oklahoma. This study is scheduled for completion in September, 1987. Engineering Enterprises has drilled about 12 additional holes at the site and is doing computer modeling of alternative project configurations. Preliminary indications are that the underground storage project can be accomplished in Butler Valley. It would require lifting the water from the canal elevation of approximately 1300 ft. through pumps and canals to about 1800 ft. elevation. Previously we had thought it would only be lifted to 1600 ft. elevation. There is a confining clay layer at the lower end of the valley which causes some artisian pressure within the aquifer. This made it necessary to go somewhat higher in the valley. At these higher elevations, there is a layer of fine material, but it is permeable. It may slow the infiltration rate and may increase the losses; however, there is sufficient storage space for 2 million acre feet or more of recharged water. Some of the remaining significant questions deal with how to size the project. How much water will be available for recharge after our customers get their water for direct use and for recharge in their own projects? How do you size the inflow pumping rate? What annual volume of water do you plan to put in the site? What demands will be made on the water and what recovery rates will be needed? What is a reasonable price for recharged water and how do you finance the project?

We currently have another study effort underway. Ungerman Engineering is conducting a study to identify the many other potential recharge sites along the Central Arizona Project aqueduct and to identify what level of study has already been done on these sites. We are also trying to determine what other potential rechargers are doing about developing some of these sites. This information should be of value to all of our potential customers. It should help us coordinate our efforts with theirs to avoid overlap and duplication. It may result in identifying other sites for additional specific studies. In recent budget discussions, the Board budgeted money for the 1987-1988 budget year to do additional site specific studies at sites that are yet to be identified.

We have been participating in discussions with valley cities, Salt River Project, and others in their efforts to evaluate the potential of projects on the Salt River and on the Agua Fria. We also respond to questions and discuss issues with many other groups that are considering recharge projects in the vicinity of the CAP aqueduct. Again, some of their primary questions are just how much water will be available, what will it cost, what priority will it have, can I use the CAP canal to get water there, and can I use the canal to get water out of the recharge site and delivered to potential users.

In summary, I do not have any firm plans to present to you today. However, the activities of the Central Arizona Water Conservation District in the past year indicate that we will be making our best efforts to ensure that available water supplies are recharged for future use. Our role is, as yet, not completely identified, but it is intended to compliment and supplement the efforts of the water users in our service area to maximize the available future water supplies.

THE HIGH PLAINS GROUNDWATER RECHARGE DEMONSTRATION PROGRAM

CAROL ERWIN

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
23636 NORTH SEVENTH STREET
PHOENIX, ARIZONA 85068

All three Arizona proposals for the High Plains Program have already been directly or indirectly talked about today, so I'm not going to outline the Arizona proposals. I would like to outline the status of the High Plains Program as we see it now and describe what the future activities are expected to be. The theme of this Symposium is "let's get moving" and, in terms of the High Plains Program, we are moving. The High Plains States Groundwater Demonstration Program Act was passed in 1983. It required that the Bureau of Reclamation (Reclamation) establish - not study, but establish - a minimum of 21 demonstration sites in the 17 Reclamation states. At least 12 of the sites had to be in the 8 High Plains states. We felt that perhaps Congress saw the need to stop studying and start doing (but then the program wasn't funded for 2 years).

The program is to be accomplished in two phases. Phase 1 has been a two-year planning and site selection effort. We are now nearing the completion of that Phase 1 effort. Phase 2 will be a 5-year effort which will involve the design, construction, operation, monitoring, and evaluation of the selected sites.

We will also be required to work with the states to develop information on the economic feasibility of recharge. Finally, Reclamation is required to take a look at the recharge work and determine if recharge projects have the potential to be incorporated into existing Reclamation projects.

The Program was initiated in December 1985. Meetings were held with state representatives to describe the program, based on what we knew and what we interpreted from the Act. We then met with representatives of the various Reclamation regions, U.S. Geological Survey (USGS), and the Environmental Protection Agency (EPA) to develop criteria for ranking locally proposed recharge projects.

The USGS is a funded participant in the Program. EPA also has a role as a coordinating agency. Together we developed the set of criteria, then asked the various participating states to submit their proposals. By June 1986 we had received a total of 41 proposals, including three proposals from the State of Arizona. Between June and December, Reclamation, EPA, and USGS evaluated and ranked those proposals.

Three sets of criteria were used in evaluating the proposals. The first set, actually specified in the Act itself, required the project be in an area that has a declining water table, an available surface water supply, and local interest in cost sharing at least 20 percent of the project costs with the Federal Government.

The second set of criteria was essentially related to a site's technical capabilities. The most important were the monitoring program and some evidence of engineering and hydrologic feasibility. Both the monitoring program and hydrologic feasibility were the primary areas where USGS reviewed the proposals for Reclamation.

The third set of criteria involved possible environmental problems, and potential legal and institutional problems. The uniqueness of the proposals and the amount a state was willing to contribute were also considered in ranking the proposals. If a state was willing to cost share more than the required 20 percent, that was good. The overall project cost was also considered a criteria in ranking the proposals. The more money the Federal Government had to contribute, the lower the proposal was rated.

After ranking the proposals, the regional representatives met to discuss their rankings. Since the rankings were done for the various Reclamation regions by different people, efforts were concentrated on trying to normalize the rankings. We tried to be as fair as we could, making sure that we all similarly viewed the criteria while ranking the proposals.

Preliminary recommendations have been made and we are now preparing the report that Congress required at the end of our 2-year planning process. That report should be available for review by the states in about 2 weeks, or around the first week in June. So we really are nearing the end of Phase 1. We will next ask the states to be responsible for a coordinated state agency review of the proposals. [The Report was transmitted to Arizona for review on June 23, 1987].

The results of the program are as follows. We received 41 proposals from 16 of the 17 states, North Dakota did not submit a proposal. The proposals covered about every aspect of recharge imaginable. Primarily, they were augmentation proposals that took advantage of either base surface flow or seasonal runoff. We also had proposals for seasonal treatment of stored effluent. We received one proposal to use recharge to investigate conjunctive use operations. There were proposals to recharge high quality surface water in order to improve aquifer water quality, and proposals that looked at using recharge as a method to accomplish water transfers. The city of Phoenix proposal included examining subsidence problems and the ability to use a recharge program to control or help eliminate that problem. One of the California proposals discussed power recovery as part of their recharge program. The Montana proposal utilized snowmelt management to develop a runoff source with recharge as the mechanism for capturing that additional runoff. In Oregon they proposed the use of geothermal resources, taking hot water out and putting cool water back through recharge. We had a program in California that would create a physical barrier at the edge of the ocean, where the salt water would be pumped out and fresh water stored. The demonstration program would determine the technical feasibility of recharging that fresh water. We received at least one state program with the stated objectives of developing public awareness and support of recharge.

The reasons for our programs ranged from wanting to take advantage of long-term opportunities for augmentation to much more immediate needs where recharge was intended to keep existing well fields in production.

The costs of our programs range from programs much smaller than we originally anticipated (in the order of $70,000) to as much as $2 million for the Federal share. The methodology ranged from the very simple to the very complex.

In areas where recharge is fairly new and just now being investigated, I think Dr. Bower is correct in what success was expected to be. If we could put any water in the ground at all at some sort of a decent rate, we would be successful--but in the more sophisticated areas, areas where there is already a legal framework available and they are doing recharge (as in California), the objectives of the programs were much more complex.

Optimization of operation and other technical areas were discussed as objectives of the proposals. Although Reclamation did not specify that research was required as an objective, I think we'll find that there is going to be a great deal of data available from these projects on which we can build.

Yesterday someone asked how much data was needed to put a pilot program in operation? The answer appears to be "enough to get the government permits". But because there is going to be a great deal of data required, you will have an opportunity to use your recharge programs to build a data base. It won't simply be a matter of putting the water on the ground, and if it disappears then we're okay.

I think you'll probably be interested in the recommendations resulting from the program. The criteria used for the sites selection included the criteria stipulated in the Act, plus the fact that at least 12 sites of the 21 sites had to be in the High Plains states.

We looked at technical merit. We took into account those ranking factors I mentioned. We were asked to specifically take into account a mix of technologies. We did not want 21 injection projects. We did not want 21 infiltration basins either. As a Federal agency we were required to look at environmental constraints, which is one area we are still attempting to deal with. And, of course, there were still the dollar constraints that were part of the original legislation. There was $20 million to be allocated for the 5-year process of operating and evaluating sites.

We were somewhat surprised to find that $20 million is going to go a bit further than expected. There were two sets of recommendations developed. The State's recommendations and the Bureau's recommendations are slightly different, but in Arizona they are identical.

There are 26 proposed projects. Thirteen in the High Plains states and 13 in the other states. This automatically means that some states could get more than one project, which I believe is going to be the case here in Arizona. Of the remaining proposals, there are seven that have technical merit, but we simply do not have the money to fund. If money becomes available, there are seven more proposals we would like initiate. We felt that five of the proposals were deficient. Only three of the 41 proposals were found to be technically unacceptable.

Arizona's three proposals rated, in a technical sense, within the top third of the 41 proposals. Presently both the Rillito project and the Cave Creek project are recommended for inclusion in the list of 26 projects that go forward. The Scottsdale project is on the list of seven projects that we would like to carry forward if money could be made available.

Right now the proposals are under review by the Assistant Secretary's Office. I don't think we'll see any particular reason for our recommendations change. [Subsequent to this writing and the review by the Assistant Secretary's Office, 21 proposals were selected, one of which, the Rillito project, is in Arizona]. The Program is presently scheduled to start in October 1988. I think we have the Rillito project starting then and the Cave Creek project starting the following year. We found that it was just not feasible in terms of Reclamation's staff time to start all of the proposals the same year. As we see it now, the projects will all run a total of 5 years before the Federal involvement in the Program ends.

I think the recommended 26, though, may be subject to a little bit of change. I'll tell you about that. Thirteen proposals were recommended in the High Plains states. Five have some moderate-to-significant environmental problems or potential environmental problems. Most involve an endangered species. Just going through the process of identifying the problem (even if it might not have turned out to be serious) may become such a large and arduous task that we simply cannot implement some of those proposals as part of the High Plains Program. In that case, you may see a shift in which projects are recommended.

There is one thing that I have heard during the last two days that concerns me. We may find that the legal and institutional path we need to follow becomes just as arduous. I am concerned that if in any state, Arizona included, we get to the point where obtaining the required regulatory permits takes a year or a year and a half, you may see changes in Reclamation's involvement and recommendations for the High Plains Program. That has not happened yet, and we hope it doesn't.

I think we were naive in the beginning. We thought that if we got water into the ground at some decent rate, we were successful. We are beginning to see now that if we can get through the red tape to get any water near the ground, we may be successful. I think that this is typical of government projects today, where the environmental and legal restrictions are becoming much harder to deal with than the technical feasibility.

In a more positive vein, I think that we will develop some technical data that people can build on in the High Plains Program. I think that in all the states, and in particular, Arizona, we are going to develop some institutional information that will be of value to people too. In fact, if the Arizona proposal is initiated in 1989, we may be among the first rechargers in Arizona to go through the permit process and determine just how you do get through it, how long it takes, what the pitfalls are, and perhaps what some of the solutions to the pitfalls might be.

The institutional hurdles are of concern to us, but we feel pretty positive about it for a couple of reasons. Both the Department of Water Resources and the Department of Health Services agreed to informally review the three Arizona proposals. This is not something that they typically do before being asked for a permit. We have asked them to do that in part because we were a little uncomfortable about recommending something to Congress that might have an obvious flaw. But the reviews came back stating there are no obvious flaws. So we have initiated a partnership there that we feel pretty positive about. I think we are moving. I think that is how I'd like to conclude -- we are moving. I would very much like to be able to come back in 2 years and be able to say we've made progress on at least two of the proposals. Let's hope that that's what happens.

RECHARGE SITE SELECTION

R. BRUCE MACK, SUPERVISOR, GEOHYDROLOGY DIVISION

SALT RIVER PROJECT, PHOENIX, ARIZONA

TECHNICAL CONSIDERATIONS

The selection process for siting an artificial recharge facility should seek to define key technical and design considerations which are generic to many recharge methods. Some important items to consider are: the proximity of the facility to the source water and the end use operation and the land costs and use constraints. Other items include geohydrologic feasibility and the water quality of the source and receiving waters.

Proximity to Water Source and End Use Facility

It is apparent that the total cost of many recharge projects can be significantly impacted by the capital and operating costs associated with delivery of the source water to the facility and transfer of the recovered water to an end use operation. It is, therefore, reasonable to evaluate sites which require short transmissions of either source or recovered waters and/or have established transmission systems in place. For example, many Arizona recharge projects will seek locations in proximity to source water or transmission systems. The CAP aqueduct, the Aqua Fria, Salt and Verde rivers and the Salt River Project water distribution system. This arrangement will in some cases allow projects to use three different sources of water, which when recovered can be delivered to various locations in the Phoenix metropolitan area.

Geohydrologic Feasibility

The feasibility of a recharge project is first determined by the physical characteristics of the underground reservoir. The hydrology of the vadose or unsaturated zone and underlying aquifer can be evaluated by measuring such parameters as the infiltrating rate, the total volume of storage space available and those impacts to recharge project operations related to excessive water level rise. In the process of a feasibility evaluation, the regional geology should also be evaluated for physical boundaries to water flow and areas where water will be lost to the project by flow out of the recharge project basin. Often, monitor well drilling and aquifer testing will give geologic and hydrologic information that can be used to model the rise in water levels due to recharge. Measurements of vadose zone characteristics can also be performed in open boreholes to determine rates of water flow in the unsaturated zone. This testing will be an important part of the feasibility evaluation of all projects.

Land Use Constraints

The siting of a recharge project involves a critical evaluation of past and present land use to identify features such as land fills, potential liability due to adjacent residential areas and the value of land. One valuable technique to determine past and present land use is aerial photography. Historic photographs can show land use changes and identify impacts such as abandoned land fills, industrial areas or sewage treatment facilities. Additionally, title searches can help determine past land use as well as ownership. Land value should be determined by experienced appraisers and creative ideas on land exchanges or leasing can help hold down costs.

Potential liability is another important land use constraint that should also be addressed. The main issue to evaluate is attractive nuisance. Any facility in proximity to a residential area should be adequately protected from accidental injury or drownings. The end result is that many recharge facilities are fenced or guarded to prevent access to them. Also, in some cases, recharge facility design may be modified to limit liability concerns.

Water Quality of Source and Receiving Waters

Water quality is perhaps the most significant concern of recharge projects, although poor quality water is sometimes recharged to prevent salt water intrusion or to enhance wastewater treatment. In Arizona, a key element of the recharge facility permit process is to determine the changes in water quality resulting from the mixing of source and receiving waters. As such, all baseline monitoring should include complete evaluations of water quality of the aquifer for as many constituents as might possibly be a problem. Simply stated, the quality of all water involved in the project must be as good or better than the intended end use.

In Arizona where all ground water will apparently be classified as drinking water, source water to be recharged must be of drinking water quality or in the case of effluent, be shown to be hydraulically contained until extracted. Based on use of Central Arizona Project (CAP), Salt and Verde river waters, recharge should not cause any long-term quality problems. In fact, water quality should improve in many areas by recharging these waters.

Lastly, existing ground water contamination must be evaluated. In Arizona, the permitting process includes a permit from the Department of Environmental Quality, whereby studies will seek to determine the impact of recharge on existing ground water contamination. The main issue in this case is the concern that recharge waters might cause movement of contaminated ground water into areas of cleaner ground water.

SELECTION PROCESS

The best recharge site selection process will include a weighing of the technical and design considerations by their relative importance to all project participants as well as cost considerations. Also, a fatal flaw evaluation should be carried out to determine if factors such as the total cost of permitting or public concern will outweigh the benefits of a recharge project.

Selection of most favored sites is then performed according to weighing and fatal flaw evaluation and in the end, the final site or sites are selected.

FINAL SITE SELECTION

The final site or sites should be selected primarily on the basis of economics, technical feasibility and potential impacts. An economic evaluation of water transport, construction, land and water acquisition, and permit costs should be determined for the life of the project to ascertain the capital and operating and maintenance costs of the recovered water. The feasibility report on the project should include the costs of actual recharge, feasibility and any constraints on land use. In the end, any major impacts caused by a project must be mitigated before the final site selection is made. Thus, a combination of factors will shape the decision process and target only those recharge sites sharing the greatest number of positive attributes. Favored sites can then be further evaluated by implementing smaller scale pilot or demonstration projects which will help determine if a more significant investment should be made.

PRACTICAL AND ENVIRONMENTAL ASPECTS
OF GROUNDWATER RECHARGE
IN LOS ANGELES COUNTY, CALIFORNIA

BY
PETER M. WOOD

COUNTY OF LOS ANGELES
DEPARTMENT OF PUBLIC WORKS
P.O. BOX 4089 TERMINAL ANNEX
LOS ANGELES, CALIFORNIA 90051

ABSTRACT

In Los Angeles County, we have been recharging water since 1919. We have recharged 10,000,000 acre-feet of storm, imported (MWD), and reclaimed water in 28 facilities of some 2,300 acres.

The facilities vary in size from 5 to 600 acres and have intake capacities of from 15 cubic feet/second to 2,000 cubic feet/second. Infiltration rates range from 0.2 to 5 cfs per wetted acre in shallow and deep basins while recharge by injection wells varies from 0.2 to 0.8 cfs/well. The cost of recharge by injection wells is $75/acre-foot plus the cost of water ($185/acre-foot). The cost of surface recharge is about $20/acre-foot. Infiltration rates decrease when silty storm water is recharged during the winter months. It is then necessary to either remove the silt or utilize a 7-day wetting period followed by a 10-day drying period. This method has proven to rejuvenate the infiltration rate by allowing curling of the silt layer.

The quality of the water recharged is within limits set by various regulatory agencies and is constantly analyzed using current chemical testing methods.

Introduction

This report addresses some pratical and enviromental aspects of groundwater recharge in Los Angeles County. Included will be, a discussion on why we spread water, the types of water we spread, how it is spread, the coagulant chemicals we use, infiltration, battery spreading, reclaimed water, and the quality of water from storm runoff.

The two main functions of the Los Angeles County Flood Control District are the control of storm run-off and the conservation of water. Today the District, or as it is now called "Department of Public Works", operates 2300 miles of channels and storm drains including 14 major dams 120 major size debris basins. It also coorperates in the operating of 5 large flood control dams managed by the U.S. Army Corps of Engineers.

The drainage systems are designed to drain waters to the ocean as rapidly as possible, therefore the Departments two main objectives, flood control and water conservation are not always compatible. For example, a dam and reservoir operated solely for water supply would be as full as possible after a storm and the water retained would be part of the water supply. But, a dam and reservoir operated for flood control might have to be quickly drained to provide holding capacity for the next storm, therefore a satisfactory compromised operating plan had to be developed.

The department operates 28 spreading facilities for the conservation of flood waters. The capacity to create more facilities is restricted by the limited availability of suitable land and geologic situations. Many areas of the County have or are underlain with impervious materials, like clay which prevents infiltration. Further development is also often opposed by those who see the spreading grounds not used during the summer months and thus try to promote other uses for the land that are more economically advantageous.

In the 1950's and 1960's the philosoply in channel design was changed to incorporate "soft bottom" or earth inverts which allow natural Infiltration and act as a self scarifying facility that has proven cost-effective and very efficient. Channel improvements in the future should retain the "soft bottom" design whenever possible. The greatest promise for increased conservation in Los Angeles County is in the large flood control dams operated by the Corps of Engineers. In the case of Whittier Narrows Dam the conservation pool storage was non-existant prior to 1960 but in the late 1960's, with the Corps coorporations, a 1000 acre-feet conservation pool was established which grew to 2500 acre-feet in the 1970's. We are now looking forward to a 3500 acre-feet or greater pool as well as looking to other dams for improvement in holding pools. The Corps has been and is becoming more conservation minded especially because water is costing \$200/acre-feet and \$400/acre-feet at the tap.

Of the total rainfall in Los Angeles County only about 15% is lost to the ocean. Much of the waste is from the 1000 square mile San Fernando Valley drainage area. Since property values are extremely high and qualified recharge areas are few, well injection has been studied as an alternative to surface spreading. Injection wells could be constructed within a channel right-of-way to hold down costs. The various health agencies would require water be treated prior to being injected into the wells that recharge directly into aquifers. In addition the water must be treated to remove even minute amounts of suspended sediments, which will clog injection wells. The present cost of our seawater barrier well injection program using treated MWD water is $75/acre-feet plus the cost of treated water or about $260/acre-feet.

The injection system of recharge is only utilized in our seawater barrier program which was constructed in residential areas where no land was available and high costs prohibited using conventional shallow basins. Surface recharge was not available in the area.

WHY DO WE RECHARGE THE GROUNDWATER IN SOUTHERN CALIFORNIA?

Utilizing These Types of Water		
	Owens Valley	1913
	Storm Runoff	1919
	Colorado River Water	1952
	Cloud Seeding	1961-78
	Reclaimed Water	1962
	Northern California Water	1972

Northern California

20% of Water Consumed

6% of Population

70% of Water Falls

Southern California

80% of Water Consumed

94% of Population

40% water pumped from groundwater

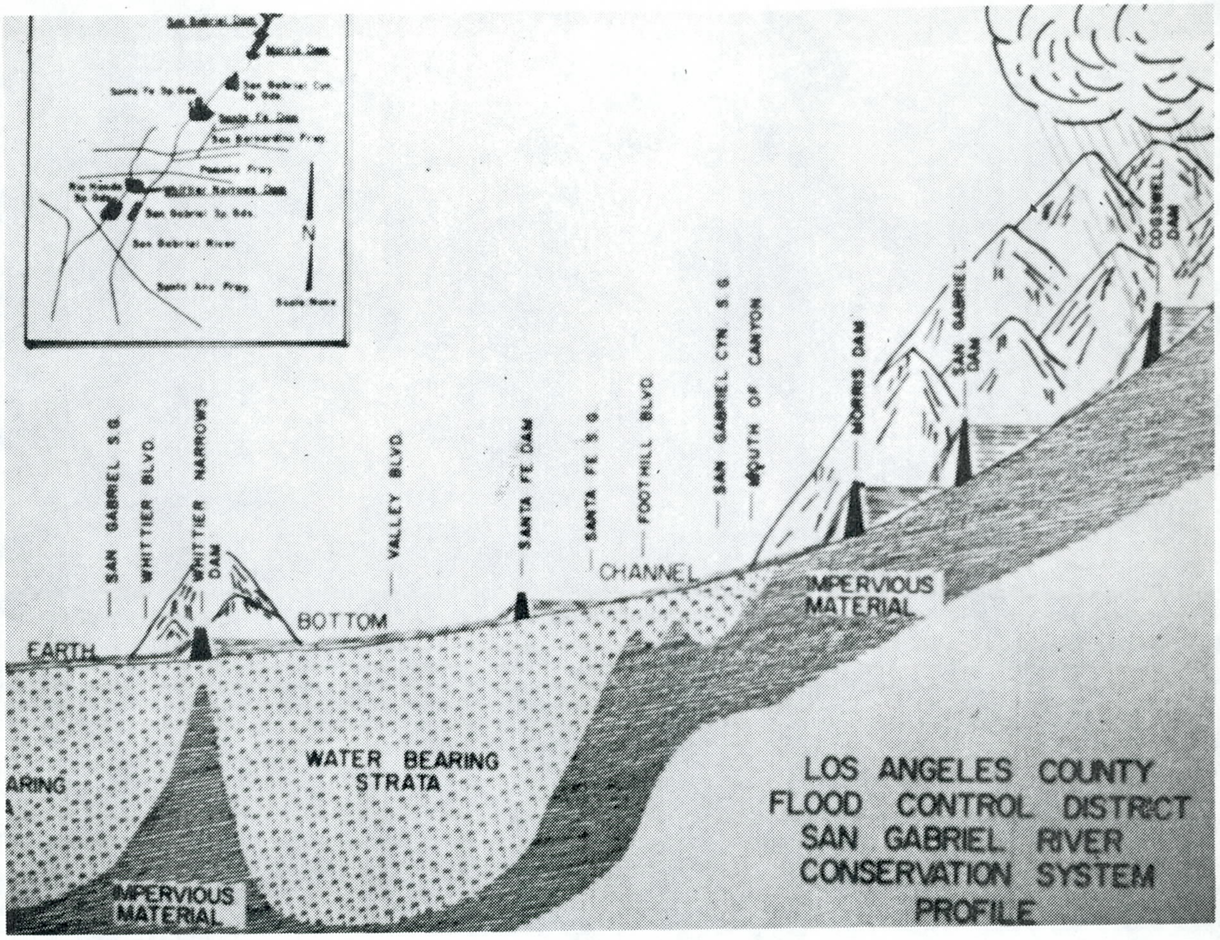
60% Imported water used

1,500,000 acre-feet used/year

18-40% of Groundwater is contaminated

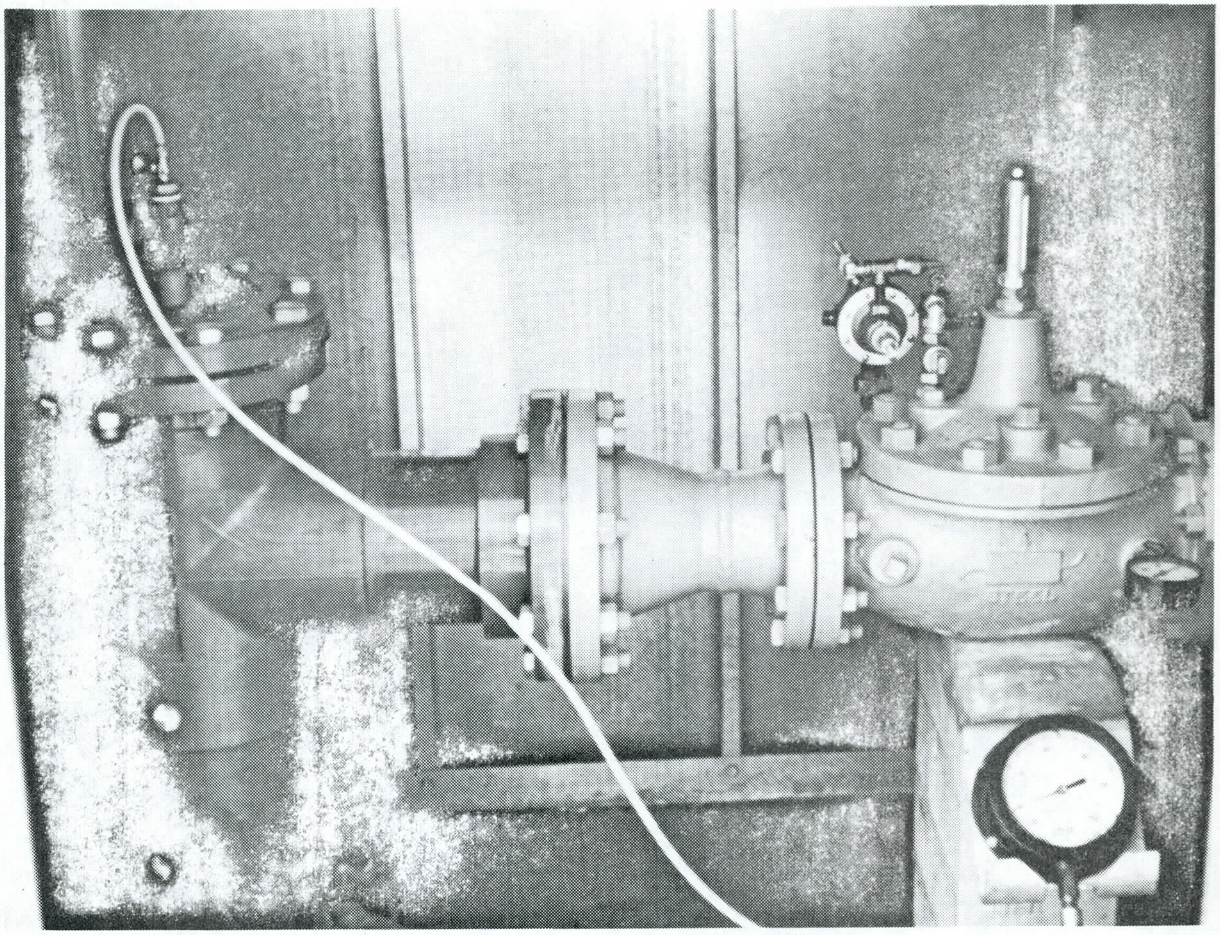
Only 15% of runoff wasted to ocean

Cloud seeding increased rainfall by 11%



PROFILE

SAN GABRIEL RIVER



INJECTION WELL

WHITTIER NARROWS FLOOD CONTROL BASIN

(CORPS OF ENGINEERS)

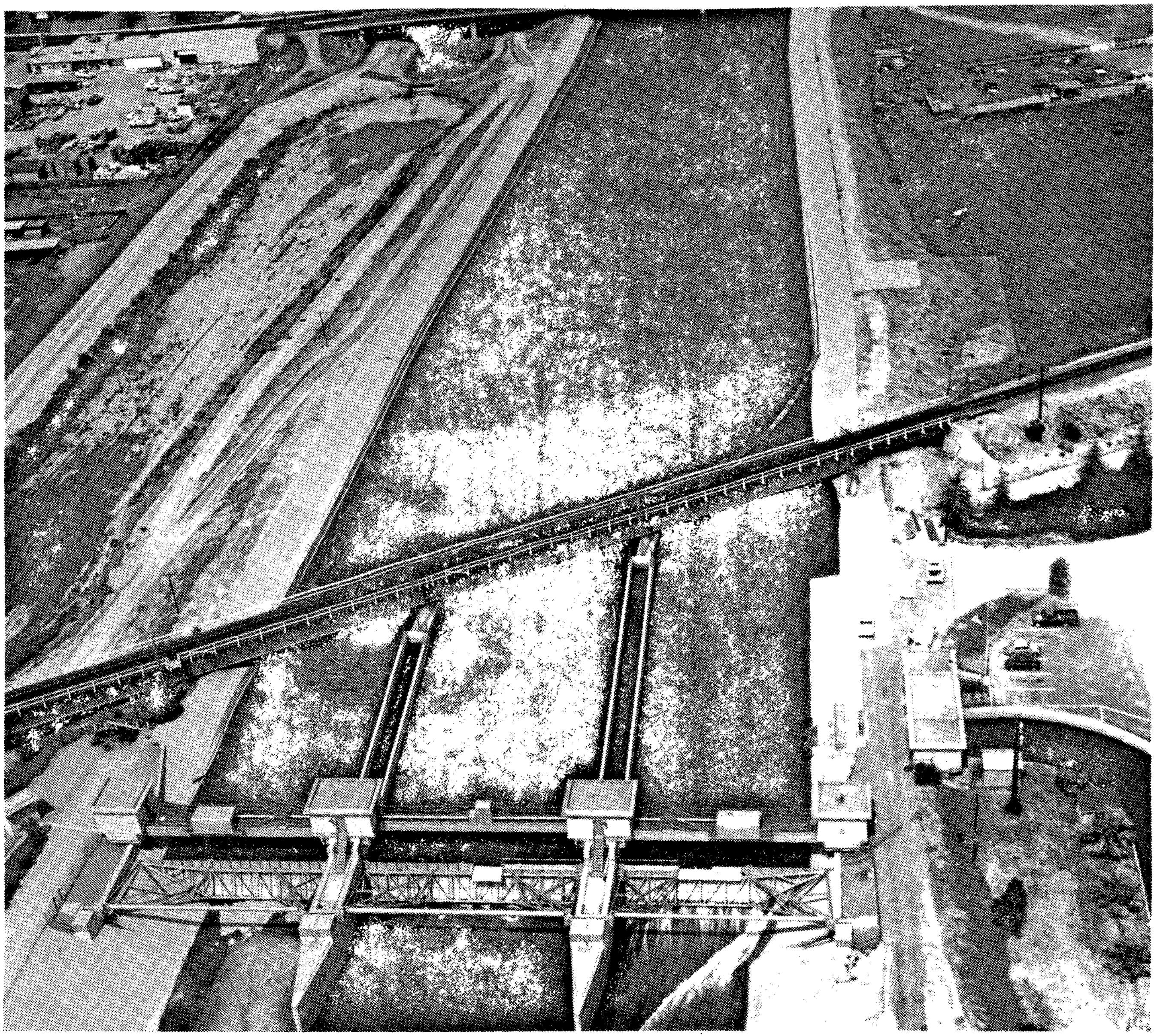
2500 ACRE-FOOT CONSERVATION POOL

RIO HONDO SIDE, SAN GABRIEL SIDE IN FOREGROUND

SAN GABRIEL COASTAL BASIN

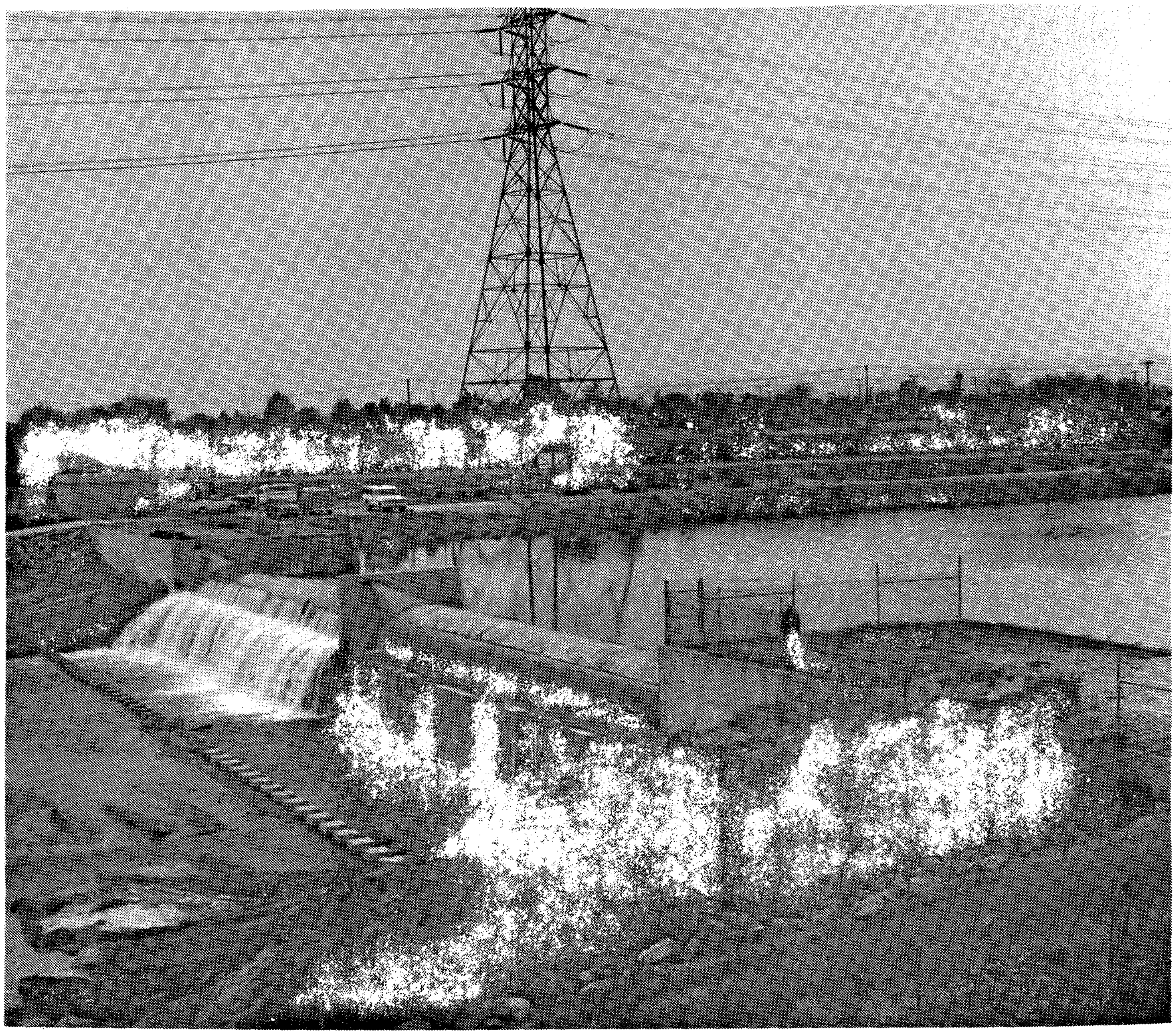
SPREADING GROUNDS

CHECK LEVEES IN SAN GABRIEL RIVER



RIO HONDO COASTAL BASIN
SPREADING GROUNDS
HEADWORKS INTAKE FACILITY

RIO HONDO COASTAL BASIN
SPREADING GROUNDS
NEW & OLD SIZE BASINS - 1986



SAN GABRIEL COASTAL BASIN SPREADING GROUNDS
INTAKE FACILITY
TWO 99-FOOT INFLATABLE RUBBER DAMS
1 - AIR & 1 - WATER

SAN GABRIEL COASTAL BASIN
SPREADING GROUNDS
INCLUDING CHECK LEVEES IN RIVER

General Information

Quantity of Recharge Waters

Types of Water	Recharge Method	Average Annual Amount Spread over last 10 Years	Historical Total Spread to Date
Reclaimed	Shallow & deep basins	21,000 Acre-Feet	500,000
Colorado River	Shallow & deep basins	85,000 Acre-Feet	2,225,000
Northern California	Shallow & deep basins		
Colorado River	Injection wells (Seawater Barrier)	35,000 Acre-Feet	1,000,000
Storm	Shallow basins and deep basins	200,000 Acre-Feet	5,000,000
Total all Water	All Types	300,000 Acre-Feet	8,725,000 Acre-Feet

Well Injection varies from 0.2-0.8 cfs/well (Seawater Barrier) with an average of 0.4 cfs/well we presently have 210 injection wells with 144 now in operations. Cost $260/acre-foot

Groundwater Recharge infiltration rates varies from 0.2-5 cfs/wetted acre 28 spreading facilities with shallow and deep basins 2300 wetted acres of spreading facilities in Los Angeles County Intake capacity varies from 15 cfs to 2000 cfs. Cost $20/Acre-Foot and does not include cost of water, if any.

Seven additional facilities owned by others totaling 700 acres which we cooperate in operations.

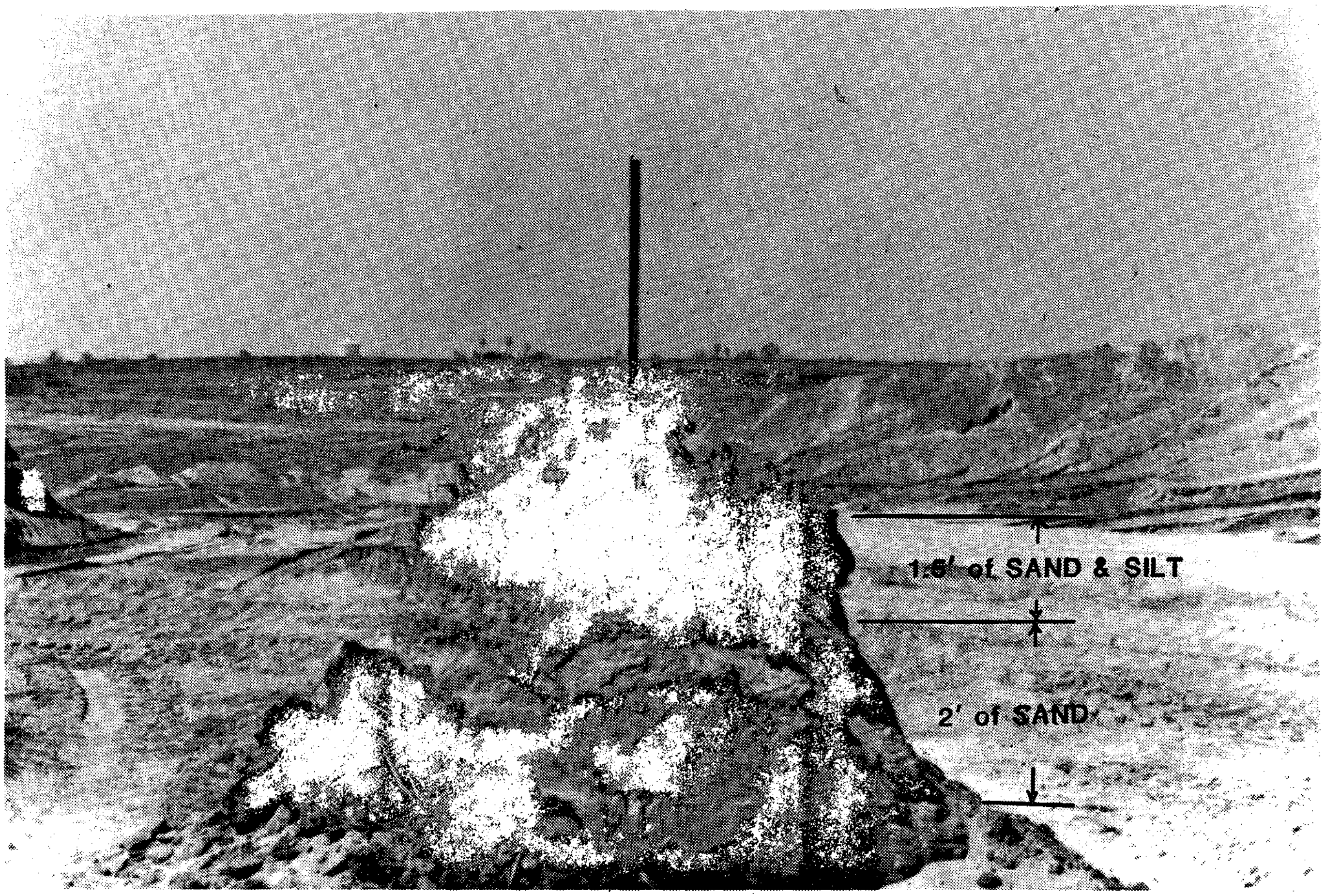
Budget - $9,000,000/year includes Operation and Maintenance and repair to spreading and barrier facilities, excludes major improvement expenditures.

INFILTRATION/PERCOLATION

SHALLOW BASINS

In Los Angeles County, the Department has recharged nearly 9,000,000 acre-feet of various types of water in its 28 spreading facilities. Our current program of removing the silts, some (2,000,000 cubic yards) accumulated over the past 60 years, has restored the infiltration rates and, perhaps nearly as important, allowed the basins to dry up much faster. This has enabled spreading to resume in these basins much more rapidly than before. Where it previously took up to 3 weeks for a basin to dry, they are now dry in 5-8 days. Depending on the weather, there has been a marked decrease in observed insect infestation due to the faster drying basins.

For the past 60 years very little material was removed from any of our spreading basins, rather it was the practice to rip or scarify the basin bottoms to restore the infiltration capacity. This proved to be very cost effective and a quick remedy, but over many years of constantly mixing the silts and sands,



RIO HONDO COASTAL BASIN
SPREADING GROUNDS
SILT REMOVAL

RIPPING SHALLOW BASIN

the top 18 inch of soil was becoming clogged at greater depth, thus making ripping to deeper depths necessary and more expensive. We currently estimate the cost of removing silt at $3-$4/cubic yard. Although infiltration rates often decrease up to 80 percent during the period of heavy spreading, it is our experience that there is a complete recovery during the summer months unless other sources of water are constantly being recharged. The long-term drying during the hot summer contributes to the recovery. At San Gabriel Spreading Grounds when there is an immediate need for improving infiltration, discing has proven to be the most effective method of rejuvenating the infiltration rate. Various soil conditioners and wetting agents have been tested, but have not shown to increase infiltration. The only things that appears to help the natural infiltration process are weeds and grasses. They seem to break up the surface layer of soil which maintains some improvement.

DEEP BASINS

In deep basins, over 20 feet in depth, problems in restoring infiltration rates differ greatly from shallow basins 2 feet to 10 feet deep. From day one, infiltration rates begin deteriorating because most of our deep basins receive storm water exclusively. Even deep basins which accept storm water in the winter months and imported water in the summer, suffer from the silt constantly being deposited on the side slopes and the basin bottom. The bottom will suffer first then the side slopes. Often after one season of spreading, a basin will no longer dry-up making it necessary to pump out the water, which is very costly, then re-excavate the basin bottom and scraping the side slopes. Sometimes it is adviseable just to scrape the side slopes down to the water-line and write off the bottom infiltration. This is often most economical and very practicle because the majority of the percolation is through the side slopes. Infiltration capacities have decreased from 34 cfs to 4 cfs in some of the deep basins after sustained spreading operations. Just scraping 1/2 to 2/3 up the side slope has restored 80 to 90% of the percolation rate. One reason to consider deep basins is that insects do not breed as prolifically, algae is less of a problem, and water stored in the pits can be released later to other downstream facilities if gravity drainage is available.

A list of Infiltration capacities of our facilities follows.

INFILTRATION CAPACITIES OF SPREADING FACILITIES

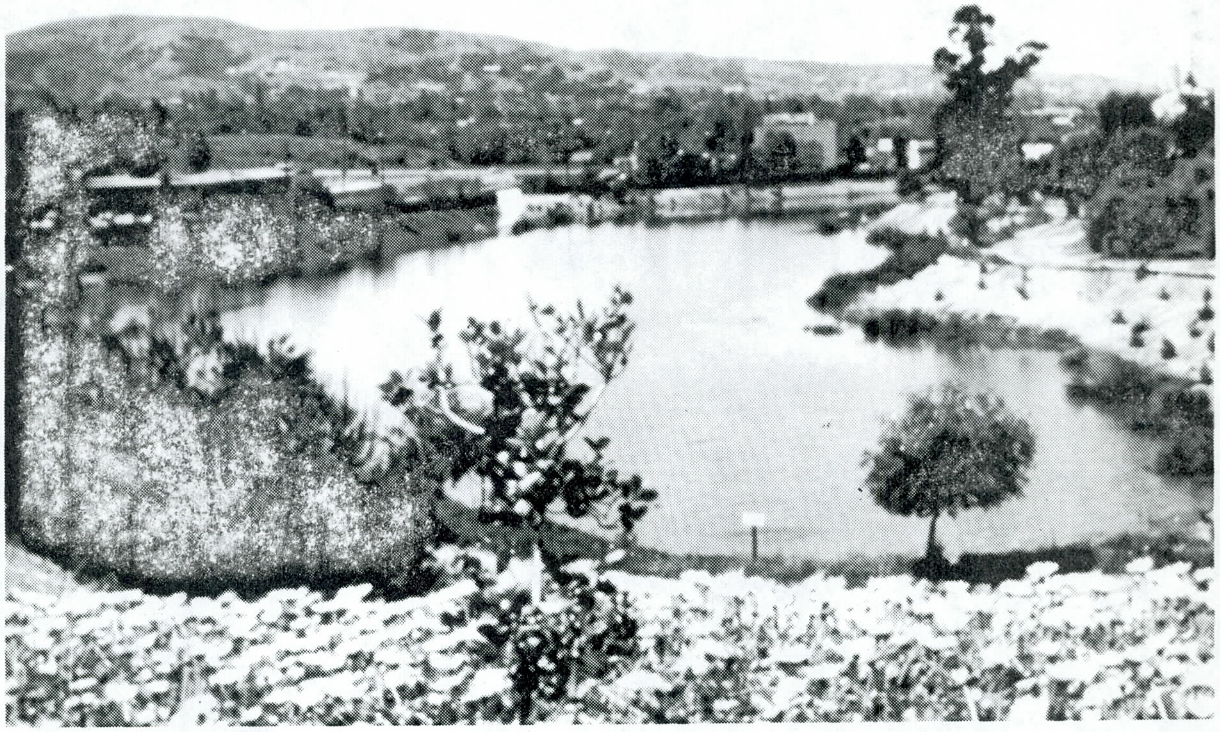
Facility	Capacities in CFS Short	Medium	Long	[Battery]
Arroyo Seco	22	18	18	--
Ben Lomond	25	18	16	12
Big Dalton	20	15	5	--
Branford	--	--	1	--
Buena Vista	--	--	7	--
Citrus	30	25	20	15
Dominguez	--	--	5	--
Eaton Basin	--	--	8	--
Eaton Wash	--	--	21	--
Forbes	10	10	10	5
Hansen	250	250	200	125
Irwindale	--	--	25	--
Little Dalton	25	20	15	--
Live Oak	15	13	12	--
Lopez	25	15	10	--
Pacoima	150	125	100	75
Peck	--	--	50	--
Rio Hondo	700	500	200	200
San Dimas	15	12	10	7
San Gabriel	125	75	60	60
San Gabriel Cyn.	--	--	22	--
San Gabriel River (Upper-Upper)	150	100	75	--
San Gabriel River (Upper)	200	150	100	--
San Gabriel River (Lower)	75	65	50	--
Santa Anita	15	10	4	--
Santa Fe	350	400	400	200
Sawpit	18	12	10	--
Walnut	--	--	6	--

Note: Deep Basins at Maximum Water Surface

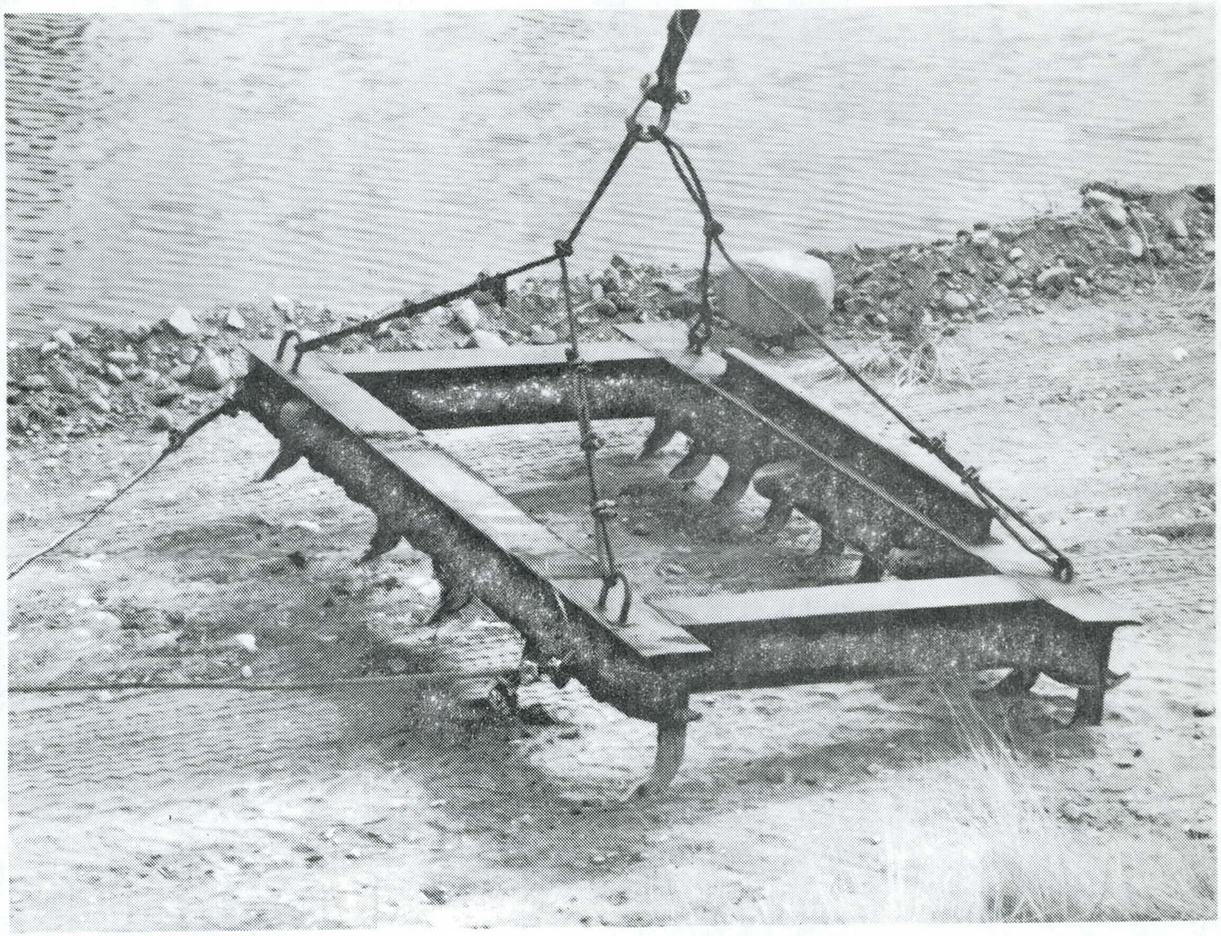
Short = 3 Days or Less
Medium = 3 To 14 Days
Long = 14 days or More

October 1986

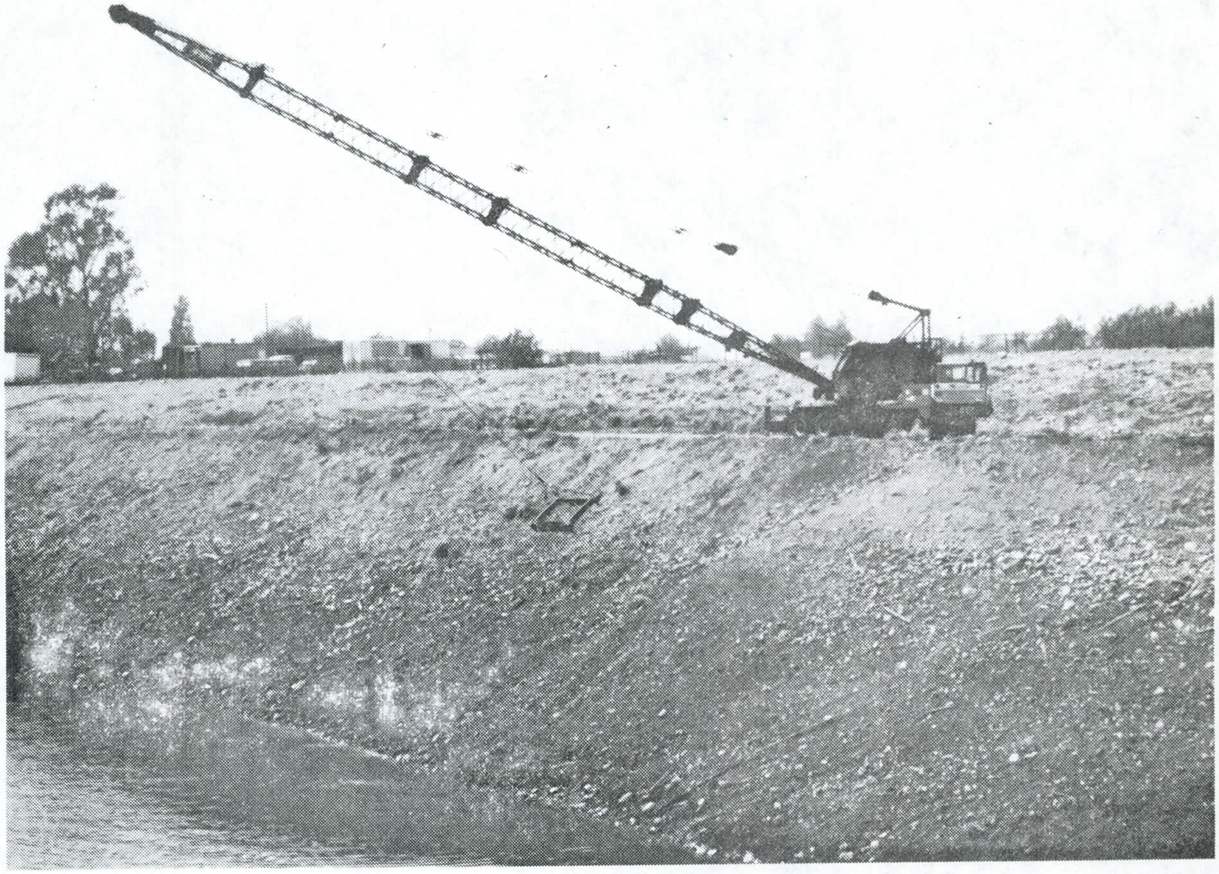
Battery = When groups of basins used to allow some basins to be drained while others are drying and still others are filling.



WALNUT SPREADING BASIN
(DEEP BASIN)



DEEP BASIN
SIDE SLOPE
SCRAPING TOOL



IRWINDALE SPREADING BASIN

SCRAPING SIDE SLOPES

USE OF COAGULANTS

When the District first began its spreading operations silt was allowed to enter the basins by accepting water containing 500 ppm of TDS at flow rates of 100 cfs for a storm of 7-8 hours. In so doing a thin layer of silt was deposited on the bottom of the basin reducing the infiltration rate by at least 50 percent over a few days time. For this reason we have now established a "desilting basin" in most of our larger facilities in conjunction with a chemical coagulant injection system. The chemical coagulants are added to the storm water in quantities of 1-3 ppm to help drop the silt out within the "desilting basin". This allows the cleaner water to enter the main spreading areas. By this method, the majority of areas can maintain the desired infiltration rates for a greater period of time. We are currently utilizing "Vanfloc 1/" and Magnifloc 592C 2/ for this purpose. Our tests have shown that silt leaden storm water of 2,000-3,000 ppm can be clarified to 200 ppm with chemical treatment and about an hour's retention time. The "desilting basins" require cleaning whenever the retention time is decreased dramatically, but can often go for a few years depending on the amount of rainfall and the quantity of silt deposited.

Various chemical coagulants have been tested since we first began treating water in 1962. The liquid type chemicals are more effective and easier to work with than the much more difficult powders that clog-up the injectors and mix at a much slower rate. The liquids now in use are poured or pumped into 1,200-gallon tanks, and mixed by air and water pressure for 30 minutes as then additional water is added. The mixture is then injected into the storm water usually at a cost of $1-$3 per acre-foot. By utilizing the flocculants, thousands of acre-feet of dirty water have been conserved, that would have been wasted to the ocean, while the majority of the spreading basins remain relatively clear of silt.

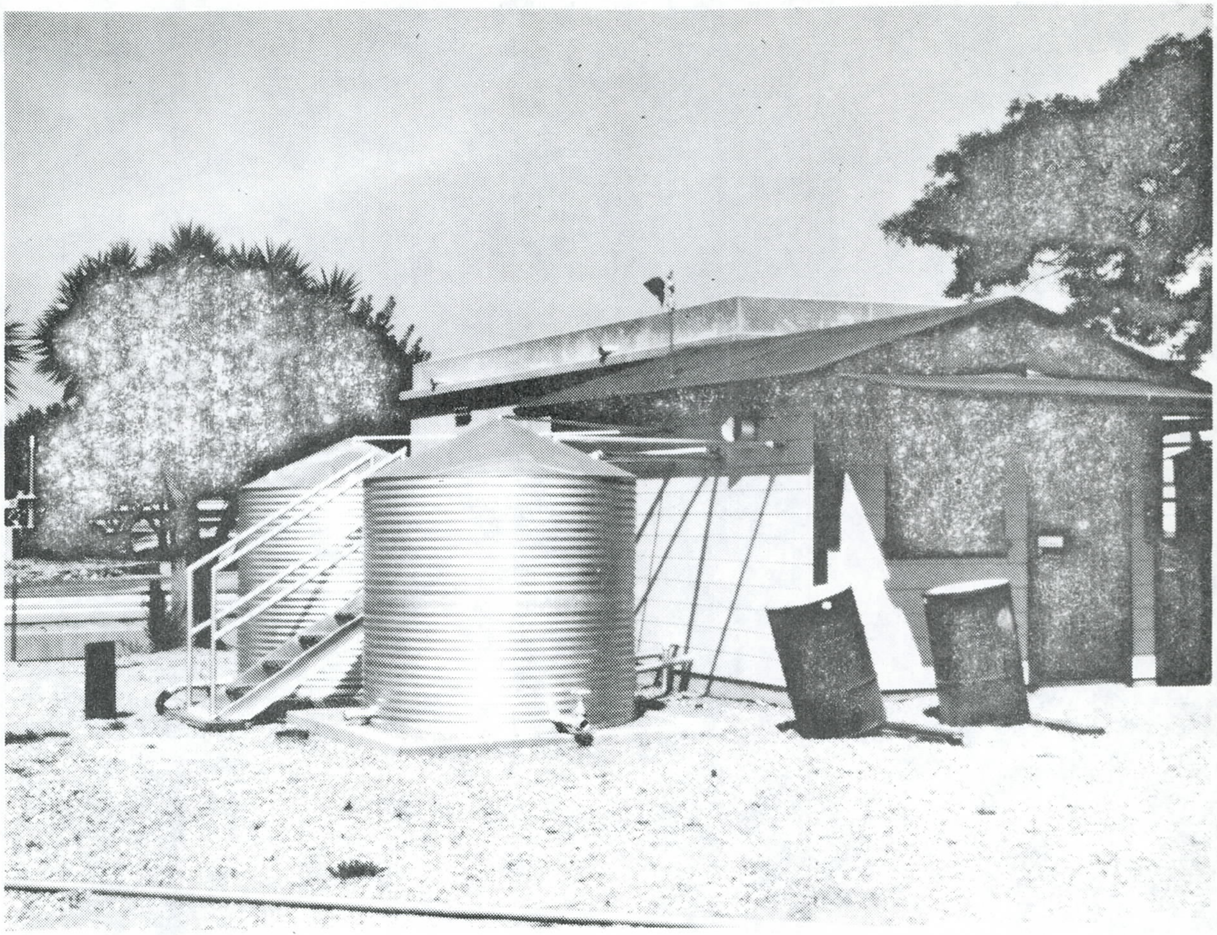
1/ Product of Van Waters and Rogers (division of Univar)
2/ Product of American Cyanamid Company

BATTERY SPREADING

By far the most effective method we have found to solve most of the problems encountered in urban spreading is utilizing the battery system which amounts to a 5-7 day wetting, and a 10-day drying cycle of groups of basins formed into a battery. This allows the bottom silts to curl up and allow the water to again infiltrate. We have found that infiltration rates have declined after 10 days of continuous spreading from 1.2 cfs/wetted acre to 0.3 cfs/wetted acre when basins are not allowed to fully dry and recover, even with silt layers of 1/8 inch in thickness. Our experience has shown that the wetting-drying cycle not only restores the infiltration rate, but also helps control insects, algae, and other problems associated with spreading.

INSECT CONTROLS

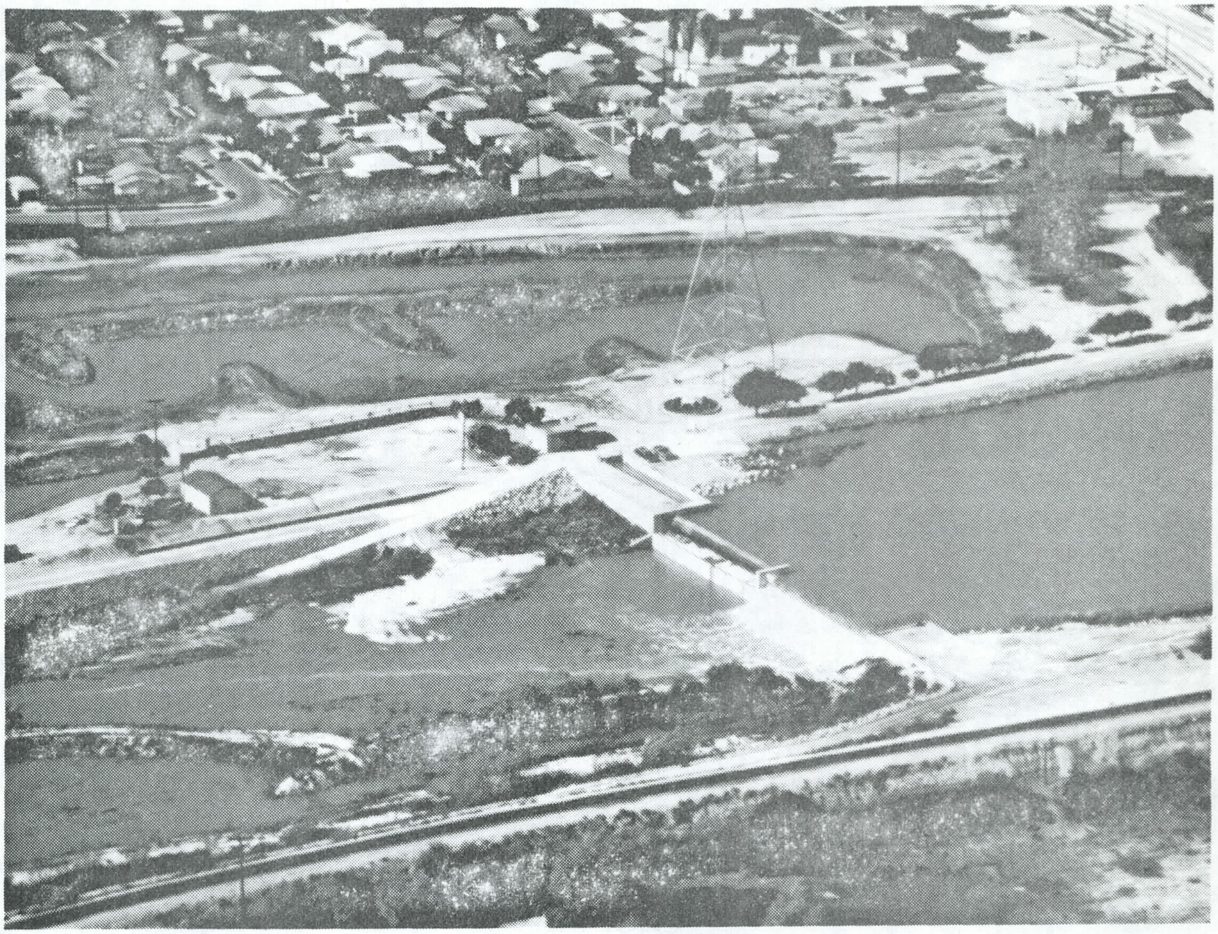
One of the biggest problems of long term spreading in the highly urbanized areas of Los Angeles County is the breeding of midges and mosquitoes. Recent outbreaks of various diseases carried by mosquitoes have made aerial and ground eradication necessary. The problem grew out of the necessity to ignore the



SAN GABRIEL COASTAL BASIN

SPREADING GROUNDS

FLOCCULENT PLANT



SAN GABRIEL COASTAL BASIN
SPREADING GROUNDS
INTAKE & DESILTING BASINS

SILT CURL

AFTER 9 DAYS

"battery system" of spreading for a period of time during reconstruction of some facilities, proving again the necessity for the wetting-drying cycle for maximum infiltration and proper insect control.

The problems with insect infestation usually occur during extended spreading, especially of imported water, and when the battery system cannot be fully utilized. The situation became such a problem that a contract was negotiated with the University of California at Riverside to study insect breeding. The Entomology Department directed the study and prepared a final report in conjunction with personnel from the Flood Control District who actually did most of the field investigation.

The results of this two-year study delineated various species of non-biting midges which can be controlled by the battery system of operation. It also pointed out that the particular aquatic environment of the spreading basins does not normally lend itself to extensive mosquito propagation. One significant finding was that the midges developed resistance to chemicals. The study showed that chemicals should not be used, rather a 5- to 7-day wet cycle followed by a 10- to 14-day drying cycle was most effective in controlling most insects. This study initiated the beginning of our battery system to control insects by drying of the silt, rejuvenating of the infiltration rates, and control of algae.

RECLAIMED WATER

In 1948, the first tests were undertaken to evaluate the feasibility of spreading reclaimed water. It was not until 1962 that the first water reclamation plant for this purpose was constructed in Whittier Narrows. The plant's mean-daily outflow was 20 cfs of primary treated water and has supplied 300,000 acre-feet for spreading since 1962. Later the San Jose Water Reclamation plant was constructed having a mean daily outflow of 80 cfs.

At the time the San Jose plant was constructed tertiary treatment was added to the Whittier Narrows Reclamation Plant (Anthracite coal, sand and gravel).

Our first experience of spreading reclaimed water at Whittier Narrows was quite spectacular. Seeing soap suds from the plant blowing throughout the canals, filling the basins and covering some nearby streets, was incredible. The problem became such a nuisance that it was necessary to install foam fractionation with air thus reducing the alkyl benzene sulfonate (ABS). During the plant's first three years of operation a study was conducted by the California Institute of Technology and others to determine how to reduce ABS concentration in the soil. Our personnel assisted in the study covering in the Whittier Narrows area by collecting water samples at various depths, namely 2, 4, 6, and 8 feet beneath the surface. Only non-diluted reclaimed water was used. The major findings showed, as did earlier studies, that purification of the reclaimed wastewater occurred in the first few feet of soil. It was determined that the detergent level was reduced from 2 mg/l to less than 0.2 mg/l within the first 8 feet of percolation. The study of viruses indicated that prior to the mass inoculations with Sabin Oral vaccine in 1963, no intestinal viruses were found in 800 ml samples take from the settled sewage, the plant effluent or the two-foot sampling pan. Following the inoculation, the samples showed significant virus levels in and leaving the plant, but no counts in the two-foot sampling pan. The increased polio virus levels were a result of the vaccine actually washing the viruses out of the body.

The present practice is to dilute reclaimed wastewater 2:1 with other water, on a long-term basis-this is not a direct dilution but rather a groundwater mixing. The maximum reclaimed water allowed to be spread is now 32,700 acre-feet/12-month period as set by the Water Quality Control Board. The CWBWRD is currently requesting the maximum be raised to 50,000 acre-feet/year.

Since the original health effects study of reclaimed water in the 1960's, ongoing studies have been taking place to continue studying the long-term effects of spreading reclaimed water. The latest summary by the County Sanitation Districts showed the following:

Findings

1. Reclaimed water complies with all Federally prescribed drinking water regulations for microorganisms and inorganic and organic chemicals.

2. No viruses were detected in (chlorinated) reclaimed water, or groundwater samples.

3. No abnormal problems exist with local residents health studies (infectious diseases, infant mortality, or cancer).

Conclusion

1. Whittier Narrows groundwater replenishment program does not demonstrate an adverse impact in the groundwater or population.

2. Need to continue monitoring and evaluation with respect to trace organic content of groundwater.

Recommendation

1. Continue spreading reclaimed water.

2. Monitoring program revised to include some organics indentified during study.

3. Total organic halogen testing should be investigated.

4. Evaluation of population in the Montebello Forebay.

5. Amount of reclaimed water spread should be based on average applications over several years rather than annual maximum.

Water Quality of Storm Runoff

The Departments Spreading Facilities Water Quality Monitoring Program was initiated in 1970. The original program consisted of monitoring the quality of both dry weather flow and storm runoff at Rio Hondo and San Gabriel Coastal Basin Spreading Grounds. The program was extended in 1984 to include twenty one additional facilities. Key parameters consisting of general minerals, bacterology, chlorinated organic solvents, pesticides, heavy metals and purgeable and non-purgeable organics were tested for in the 1985-86 program. Due to insufficient data from 21 of the 23 facilties no definite conclusion can be drawn from the findings, but in general the results of the first years tests were within the limits as established by various regulatory agencies for drinking water and water discharged into rivers.

Included in the Water Quality Program was a analysis of soil samples collected at Rio Hondo and San Gabriel Spreading Grounds. Analysis were made of volatile organics and heavy metals in an effort to gain a better understanding of the chemical contents of the large volume of silty material deposited over the past 60 years of spreading. High levels of lead were detected in two of the five composite soil samples. The lead was concentrated in the upper few inches of soil and has since been removed. It is interesting to note that recently several wells located in the proximity of Rio Hondo and San Gabriel Spreading Grounds were tested for priority pollutants and heavy metal and the results indicated that none of the wells showed concentrations of either.

Regulatory agencies have not established any water quality standards for spreading grounds recharging activities. However, for the purpose of comparing and evaluating the various data collected, the following standards were used as references:

I. Established by the Department of Health Services

   A. Primary and secondary drinking standards.
   B. Action levels for groundwater.

II. Established by the United States Environmental Protection Agency

   A. Primary and secondary drinking water standard.
   B. Action levels for hazardous waste.

III. Established by the California Regional Water Quality Control Board

   A. Discharge limitations for NPDES Permit.
   B. Minerials quality objectives for surface waters.

General Minerals
Summary 1985-86 Storm Season

	Limits: DOHS Groundwater	Limits: DOHS Drinking Water	Limits: CRWQCB Discharge	Samples
Total Dissolved Solids (TDS)		500 ppm	750 ppm	less than 500 ppm
Sulfate	-	250 ppm	300 ppm	2-220 ppm
Chloride	250 ppm	-	150 ppm	0.5-77 ppm
Floride	-	1.2 ppm	-	0.01-.075 ppm
Nitrate and Nitrite	-	10 ppm	-	highest=12 ppm
Bacteria	-	-	-	62,000 organism/ 100 ml. fecal coliform

Chlorinated Organic Solvents (PCE (DCE (TCE All Samples less than DOHS

Pesticide (13 including PCB 1242 and 1254) - 0.1 PPb Lindane in one sample no others found.

Purgeable and Non-purgeable Organics (97) - none exceeded DOHS levels

The following table lists purgeable and non-purgeable organics tested during the 1985-86 program.

Constituents in ppb	San Gabriel Spreading Grounds Storm I	San Gabriel Spreading Grounds Storm II	San Gabriel Spreading Grounds Storm III	Rio Hondo Spreading Grounds Storm I	Rio Hondo Spreading Grounds Storm II	Rio Hondo Spreading Grounds Storm III	Action Level ppb
Benzene			0.2				0.7
Bis(zethylhexye)phthlate					90		Not Available
Bromoform			0.3				Note (1)
Chloroform		0.6	0.2	0.1	0.1	0.2	Note (1)
Dibromochloroethene			0.8				Not available
Dichlorobromomethane			0.2				Note (1)
Diazrion	1.5	0.5			0.8		14
1,1 Dichloroethene		0.1		0.1	0.1		0.2
Methylene Chloride		6.0					40
O-xylene				0.1			620
Tolnene		0.6	0.5		0.1	0.1	100
1,1,1, Trichlorolthene	0.2	0.5	0.3	0.3			300
Trichlorothene		0.1					5.0
Tetrachloroethene	0.1	0.5	0.5	0.2	0.3	0.5	4.0
Vinylchloride			0.1				2.0
Atrazin	5.0	1.1	0.7	0.9	1.4	0.9	Not Available
Simazine	3.1	8.4	3.4	1.5	9.3	2.4	Not available

* Presented here are those findings which have a concentration level above detection limits.

Note (1) No action level is available; however, DOHS has established a concentration limit of 100 ppb for total trihalomethane in drinking water.

SOIL ANALYSES FOR SAMPLES COLLECTED
AT RIO HONDO AND SAN GABRIEL SPREADING GROUNDS

Constituent	Concentration in mg/kg					
	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4	Sample No. 5	TTLC*
Lead (Total)	170	20	14	180	65.0	**
Cadium	1.4	0.39	0.50	1.7	0.30	100
Chromium	42	11	10	40	14	500
Copper	57	17	11	59	23	2500
Nickel	43	9.4	6.9	3.5	10	2000
Zinc	210	59	42	200	42	5000
Arsenic	3.3	1.3	3.1	8.4	5.9	500
Mercury	0.18	0.04	0.03	0.17	0.03	20

*Total threshold Limit Concentration as established by the DOHS

**TTLC for organic lead and inorganic lead is 13mg/kg and 1,000 mg/kg, respectively. The results shown here are the combination of organic and inorganic lead.

Note: Sample No. 1 = composite sample composed of three samples taken from Basin No. 31 of Rio Hondo Spreading Grounds

Sample No. 2 = composite sample composed of two samples taken from Rio Hondo Channel at Whittier Narrows Dam

Sample No. 3 = composite sample composed of two samples taken from San Gabriel River at Whittier Narrows Dam

Sample No. 4 = Sample taken at Basin No. 8 of San Gabriel Spreading Grounds

Sample No. 5 = composite sample composed of two samples taken from Basins Nos. 9 and 10 of San Gabriel Spreading Grounds.

REFERENCE

Bay, E. C., and Anderson, L. D., University of California at Riverside, and Ingram, A. A., Los Angeles County Flood Control District, July 1962, "A Summary of Research on Chironomid Midges in the Los Angeles County Flood Control District Spreading Basins, including Recommendations for Preventing Outbreaks".

County of Los Angeles Department of Public Works, "Annual Report on Spreading Grounds Water Quality Monitoring 1985-1986.

County Sanitation Districts of Los Angeles County "Health Effects Study Summary, March 1984.

Los Angeles County Flood Control District, "Report on Impounding Rain Water", June 6, 1977

Los Angeles County Flood Control District, "Report on Infiltration Rates and Maintenance Problems of Deep Spreading Basins", by C. J. Reinhard, June 1973

McMichael, F. C. and McKee, "Report of Research on Wastewater Reclamation at Whittier Narrows", W. M. Keck Laboratory of Environmental Health Engineering, California Institute of Technology, September, 1965. McMichael, F.C., and McKee, M. E., W.M. Keck Laboratory of Environment Health Engineering, California Institute of Technology, September 1965.

State of California Department of Finance and Water Resources.

United States Environmental Protection Agency, "Released Supplemental Sampling Program Report" San Gabriel Basin Sites, June 1986.

Peter M. Wood is the Supervising Hydrographer II in charge of groundwater recharge, streamgaging and rainfall for the Los Angeles County Department of Public Works. He has spent twenty-seven years in this field.

ECONOMICS OF ARTIFICIAL GROUND WATER RECHARGE

William R. Mills, Jr.
William R. Mills & Associates
895 E. Yorba Linda Blvd., Suite J
Placentia, California 92670

and

Frank G. Postillion
Camp Dresser & McKee Inc.
110 S. Church, Suite 190
Tucson, Arizona 85701

ABSTRACT

This paper evaluates and compares three case studies in regard to economics of artificial ground water recharge. Types of artificial ground water recharge methods and facilities are reviewed including such spreading methods as ditch and furrow, shallow riverbed levees, shallow spreading basins, and deep basins or pits. In addition, subsurface recharge methods include injection wells and infiltration galleries. Some of the facilities using a combination of these recharge techniques are Orange County Water District and City of Phoenix.

Technical considerations sometimes dictate the recharge method and may even override economic considerations. Examples of technical considerations include injection wells chosen over surface spreading when land is not available or when subsurface restricting layers tend to restrict surface recharge.

The three case studies are Orange County Water District Surface Spreading Facilities, proposed in-channel spreading facilities on the Agua Fria River near Phoenix, Arizona and deep well injection of Colorado River Water at the Dominquez Gap study area. Evaluation of these studies reveal that (1) surface recharge costs are sensitive to land costs, (2) surface recharge costs without land and water costs, generally range from $10-15/AF, and may be slightly lower at the Agua Fria Site, and (3) injection costs are generally 5 to 10 times surface recharge costs.

INTRODUCTION

Numerous studies have described overall costs of artificial ground water recharge facilities (Argo and Cline, 1985; Lluria, 1985). These costs have generally been described in terms of capital and operation and maintenance costs, and sometimes included cost of land acquisition. In addition, one type of recharge operation was described (i.e. spreading basins or injection). This paper goes one step further by comparing actual cost data of two different types of recharge operations, surface spreading versus injection, and then compares differing costs depending upon geographical location. Three case studies will be described: surface spreading at the Orange County Water District, California; proposed in-channel spreading facilities on the Agua Fria River near Phoenix, Arizona; and the Dominguez Gap Well Injection Program in Los Angeles, California.

TYPES OF RECHARGE METHODS AND FACILITIES

The two most commonly used recharge methods are surface spreading and subsurface recharge. Spreading methods include flooding, ditches and furrow, irrigation, shallow riverbed levees, shallow spreading basins, and deep basin or pit techniques. In addition, artificial recharge may also be accomplished by using injection wells, shallow basins augmented by shafts or recharge wells, and infiltration galleries. Currently, the most commonly used methods for artificial recharge are shallow spreading basins and deep basins or pits. Figure 1 is a schematic of these recharge techniques.

Some facilities use a combination of these recharge techniques. For example, Orange County Water District (OCWD) employs in-channel T-Levees along the Santa Ana River, shallow off-channel basins and deep pits to recharge about 170,000 AF/yr. of combined Colorado River Water, and effluent dominated Santa Ana River water. In addition, OCWD injects tertiary treated effluent for control of sea water intrusion from their "Water Factory 21," (Argo and Cline 1985). Los Angeles Flood Control District (LAFCD) employes shallow off-channel spreading at their Rio Hondo spreading grounds and also deep basin pits. City of Phoenix is developing programs for shallow basin recharge of secondary effluent (Bouwer and Rice, 1984), in-channel recharge of Colorado River Water (Reynolds, 1987), and deep well injection of Central Arizona Project Water (Lluria, 1985).

TECHNICAL CONSIDERATIONS

Economics is certainly a major, if not overriding, consideration when establishing artificial ground water recharge facilities. But, in may cases, technical considerations are the principal factors dictating the type of recharge method. Thus, recharge economics is sometimes controlled by technical issues.

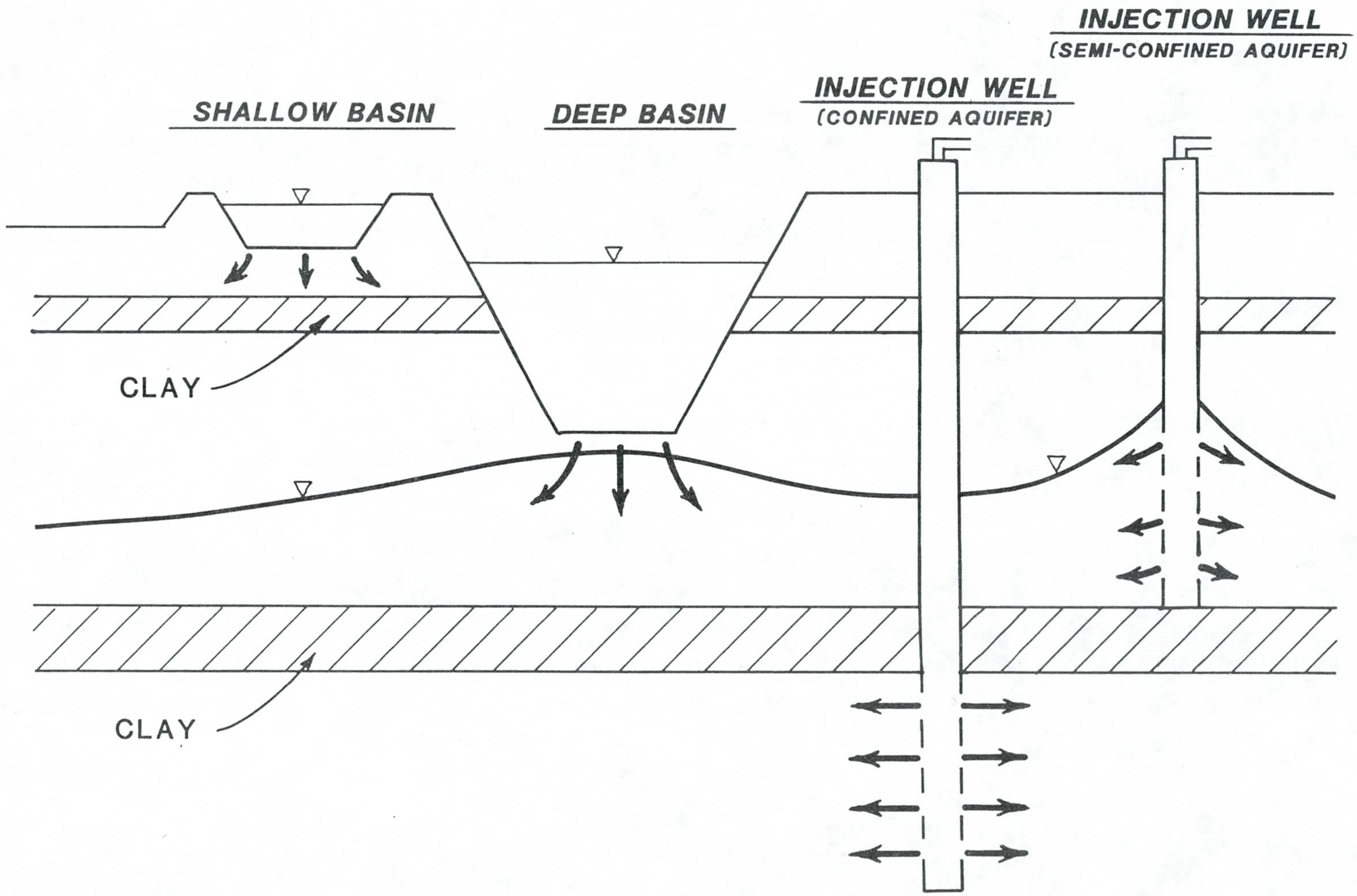


FIGURE 1. Schematic of Commonly Used Types of Recharge Techniques

Several situations may dictate one recharge method over another regardless of cost comparisons. For example, if there are shallow flow restricting layers, selection of a deep basin or injection well may be necessary, even though shallow basins could be less expensive (Figure 1). Or, if there is shallow poor quality ground water and the recharge water is of good quality, injection wells into a lower aquifer of better water quality could be the preferred method even though they may be more costly (Figure 1). In some cases in-channel recharge may be preferred over deep basins because of deep basin clogging problems. Character of source water as to availability and its physical and chemical properties may also dictate recharge methods. Treated effluent is more conducive to shallow basin recharge because of the necessity of frequent wet-dry cycles, while deep basins recharge better with water of low turbidity and low organic content which helps minimize clogging. Land availability is also another factor. In densely populated areas in Southern California land is just not available in some areas, yet control of sea water intrusion is mandated. Thus, well injection is the only feasible recharge method.

ECONOMICS OF SURFACE SPREADING

Two case studies will be discussed and comparisons made. The first study uses actual operating data from OCWD facilities over the last five years. The second study describes projected costs for a proposed recharge facility along the Agua Fria River near Phoenix, Arizona.

Orange County Water District Spreading Facilities

Orange County Water District in Southern California has a surface spreading area of 1,273 acres including in-channel T-levees, shallow off-channel basins, and deep basins. These facilities have a recharge capacity of about 200,000 AF/yr., but over the past five years have, on the average, recharged 167,000 AF/yr. As previously mentioned, OCWD recharges Colorado River water and local effluent dominated Santa Ana River water. Thus, water quality is high in TDS, has intermittent high turbidity, and secondary effluent character.

Table 1 describes field operations and planning and management costs of OCWD spreading facilities for the past five years. Field operation costs are mostly associated with reconstruction of the T-levee system after large flood flows in the Santa Ana River. Reconstruction takes place as many as twelve times a year, yet is cost effective due to the river's extremely high infiltration rates created by the T-levees. Other field operation costs include draining, drying and scraping shallow and deep basins at least once per year in order to restore infiltration rates which are reduced by physical and biological clogging. Planning and management costs include development of plans for future recharge facilities at Santiago Creek, annual reports, and long range stratgic planning.

FISCAL YEAR	FIELD OPERATIONS COST (K$)	PLANNING AND MANAGEMENT COST (K$)
1982	480	180
1983	830	410
1984	860	610
1985	900	530
1986	830	830
AVG.	780 / 167 KAF = $4.70/AF	510 / 167 KAF= $3.10/AF

Table 1. Field Operations and Planning and Management Costs at the Orange County Water District Spreading Facilities

Table 2 describes land, improvements and equipment costs for the OCWD spreading facilities. Most notable for land costs is the difference between historic values at $6.17/AF and present value of land at $134.63/AF. Fortunately, OCWD has purchased all their present and projected land for spreading operations, and currently does not intend to purchase additional land.

	COST (M$)	ANNUAL* COST (M$)	UNIT COST $/AF
IMPROVEMENTS	8	0.75	4.49
EQUIPMENT DEPRECIATION	-	0.18	1.08
LAND COSTS			
HISTORIC	11	1.00	6.17
PRESENT VALUE	240	22.50	134.63

*8% and 25 years

Table 2. Land, Improvements and Equipment Costs for Orange County Water District Spreading Facilities

A summary of all costs for surface spreading at OCWD indicates a relatively low cost of about $20/AF (Table 3). One cost which was not included in this analysis was cost of water purchase. This number is somewhat variable depending upon the availability of the source. Generally, in Southern California Colorado River water for replenishment purposes costs about $150 to $160/AF. Compared to Colorado purchase costs in Arizona, this is quite high. OCWD though, recharges 75% of Santa Ana River Water at no purchase cost, and 25% Colorado River Water. This amounts to about $37/AF average cost.

	UNIT COST ($/AF-FT)	
Field Operations	4.70	
Planning & Mgmt.	3.10	
Improvements	4.49	
Equipment	1.08	
Subtotal	13.37	
Land	6.17	
		19.54
	Say	$20/AC-FT

Table 3. Summary of Spreading Costs - Orange County Water District

AGUA FRIA RIVER SPREADING FACILITIES

As part of a feasibility study report for Arizona Municipal Water Users Association (AMWUA), an in-channel T-levee recharge facility on the ephemeral Agua Fria River was identified as the best site for recharge of surplus Colorado River Water from the Central Arizona Project CAP canal (Camp Dresser & McKee Inc. and W. R. Mills and Associates, 1986). The study evaluated costs of the proposed 200,000 AF facility and determined preliminary designs. City of Phoenix is further studying the Agua Fria River to determine final feasibility and meet permitting requirements (Reynolds, 1987).

Costs for the Agua Fria site are broken down into capital (Recharge Facility), data deficiencies and permitting requirements, operation and maintenance costs, water purchase and land purchase (Table 4).

ITEM	CONSTRUCTION COST (X1000)	ANNUAL COST (X1000)	ANNUAL UNIT COST ($/AF)
RECHARGE FACILITY			
Earthwork	540		
Beardsley Canal	90		
Turn Out Structure	40		
Parshall Flume	15		
Monitoring Wells	300		
Contingency, etc.	345		
Subtotal	1,330		
DATA DEFICIENCIES & PERMITTING	95		
Total	1,425	130(b)	1(c)
OPERATION & MAINTENANCE (a)	---	800	4
LAND ACQUISITION (d)	1,650	150(b)	1(c)
TOTAL	3,075	1,080	6

(a) Based on purchase of 200,000 AF/YR
(b) Annualization based on 8% interest over a period of 25 yrs.
(c) Rounded.
(d) Based on $3,000/acre average.

Table 4. SUMMARY OF COSTS -- 200,000 AC-FT/YR
AGUA FRIA RECHARGE FACILITY

Source: Camp Dresser & McKee Inc., and W. R. Mills and Associates. 1986.

Initial construction costs at $1.425 million, when capitalized over 25 years is about $1/AF. Annualized operation and maintenance costs are estimated at $4/AF. Land costs, based upon estimates of $3,000/acre are also quite low, and figure annually to average $1/AF for the life of the facility. Thus, total costs for the Agua Fria Facility are estimated to be about $6/AF, exclusive of water costs. Cost of surplus Colorado River water is about $35/AF. This amount will probably vary in the future, depending upon numerous factors beyond the scope of this paper.

In comparison with OCWD spreading facilities , the Agua Fria site costs are substantially low for two major reasons. First, land purchase costs for the Agua Fria site are substantially lower even compared to the historical costs of $6.17/AF for OCWD. Operations and maintenance costs will be lower because the Agua Fria T-levees will rarely get washed away, since the upstream dam and flood control system rarely releases flood waters except for occasional large events.

ECONOMICS OF RECHARGE BY INJECTION

Los Angeles Department of Public Works (LADPW) has over 170 injection wells which recharge a total of about 45,000 AF/yr of Colorado River water for control of sea water intrusion. The particular case study discussed in this paper is the Dominguez Gap deep well injection study. A total of 6,000 AF/yr is injected by 29 deep wells constructed for this project. The injection wells were drilled to a depth of 250 feet with a casing diameter of 12 inches. Typical injection rates were 0.5 cubic feet per second (cfs).

Table 5 summarizes the overall costs for the Dominguez Gap study. The primary costs involved with recharge by injection include well construction, operation costs, and filtration costs. Land costs were minimal since purchase is generally restricted to less than a quarter-acre per site. Total cost for recharge by well injection was about $100/AF annually. These numbers reasonably agree with other recharge by well injection studies (Lluria, 1985).

	CAPITAL COST (K$)	ANNUAL* COST (K$)	ANNUAL UNIT COST ($/AC-FT)
Well	100	9.4	25.88
Lateral	20	1.9	5.18
Land	2	0.2	0.52
Operations	---	10.0	27.62
Filtration	---	--	37.00
TOTAL			96.20
			Say $100/ac-ft

*8% and 25 yrs.

Table 5. Summary of Injection Costs, Los Angeles Department Public Works, Dominguez Gap Study

Compared to surface spreading, recharge by injection is more expensive, unless land costs are relatively high. Thus, surface recharge costs are highly sensitive to land cost, but well injection recharge is not. Without land costs injection costs are about five to ten times surface recharge costs.

SUMMARY AND CONCLUSIONS

Two case studies for surface spreading and one case study of recharge by injection have been evaluated for their overall costs. The OCWD study analysis had actual operational costs while the Agua Fria study discussed projected costs for surface spreading. The Dominguez Gap injection study also used actual operational costs for the analysis.

The following conclusions can be made concerning these case studies:

- Surface recharge costs are sensitive to land costs.
- Surface recharge costs, without land and water cost, generally range from $10-15/AF/yr, and may be slightly lower for the Agua Fria Site.
- Overall surface recharge costs at the Arizona (Agua Fria) site are substantially lower than the California site (OCWD) due to lower land costs.
- Injection costs are about 5 to 10 times surface recharge costs.

REFERENCES

Argo, D. G., and Cline N. M. 1985 Ground Water Recharge Operations at Water Factory 21, Orange County, California. In: Artificial Recharge of Ground Water, pp 359-396, Takashi Asano, (Ed.), Butterworth Publishers, Stoneham, Maine.

Bouwer, H., and Chase, W. R. 1984. Water Reuse in Phoenix, Arizona, Proceedings of The Water Reuse Symposium III, Volume 1, Future of Water Reuse, August 26-31, San Diego, California.

Camp Dresser & McKee Inc., and W. R. Mills and Associates, 1986, Feasibility Study Report: Riverbed Recharge Project, Prepared for Arizona Municipal Water Users Association, Phoenix, Arizona, August.

Lluria, M., 1985, City of Phoenix Cave Creek Recharge Project: Technical Aspects, Proceedings of Second Symposium on Artificial Recharge in Arizona, May 2-3, Tempe, Arizona, pp. 82-111.

Reynolds, C., 1987, City of Phoenix Project Plans, Proceedings of the Third Symposium on Artificial Recharge in Arizona, May 20-21, Tempe, Arizona.

Biographical Sketches

William R. Mills, Jr. is a consultant with more than twenty-five years experience in the field of ground water recharge. He is a registered engineer and geologist holding degrees in both fields. Mr. Mills received his B.S. in Geological Engineering at the Colorado School of Mines in 1959, and his M.S. in Civil and Environmental Engineering at Loyola University of Los Angeles in 1973. He is President of William R. Mills and Associate.

Frank Postillion received his M.S. in Agriculture at the University of Arizona in 1976 and a second M.S. in Watershed Hydrology at the University of Arizona in 1985. He has participated in numerous recharge studies over the last six years, including evaluations in Phoenix, Tucson, Orange County and Bakersfield, California. He currently is State Coordinator for ground water resources and recharge projects for Camp Dresser & McKee Inc., in Arizona.

ROLE OF RECHARGE IN FUTURE WATER MANAGEMENT FOR ARIZONA

BY

FRANK M. BARRIOS

DEPARTMENT OF WATER RESOURCES

2702 N. 3rd Street, Suite 2010

Phoenix, Arizona 85004

ABSTRACT

The two most important solutions to resolving Arizona's ground water problems include implementation of the state ground water code and the introduction of CAP water into Arizona.

Recent Recharge Legislation allows DWR to issue recharge permits for general recharge and for storage and recovery purposes.

The ground water code requires the Department of Water Resources to prepare and implement five management plans covering a time period from 1980-2025. The code created the Phoenix, Pinal, Tucson and Prescott Active Management Areas (AMA's). It is important to develop an augmentation plan that is compatible with management plan conservation requirements and to find ways to maximize our CAP water supplies.

Water planning communities must establish sound strategy and develop realistic objectives that will be consistent with attaining the goal of safe yield by the year 2025. Recharge is an excellent pathway to achieving these goals.

Recharge legislation would allow for optimum water management and includes provisions for retaining the same legal character of the water throughout the storage and recovery process. Combining recharge schemes with first management plan incentives on effluent can significantly augment existing water supplies.

Recharge can be used to augment CAP water supplies. Combining CAP Plan-6 features with recharge can provide additional augmentation. Water released from dams would be recharged and the evacuated reservoir space could be used to store augmented water. Recharge plans also need to be developed that will allow recharge of excess Colorado River water during periods of surplus runoff.

Effluent is underutilized because of problems with location and timing. Recharge can provide opportunities to lessen if not resolve these problems. Providing additional storage space by recharging reservoir releases can maximize augmented water supplies developed through weather modification and watershed management. Recharge for stormwater runoff, in-state and out-of-state augmentation proposals can also be beneficial.

INTRODUCTION

On the 12th of June, 1980 the Governor signed into Law the New Ground Water Management Act. This landmark legislation brought forth one of the most important solutions to Arizona's escalating ground water problems. An earlier, but no less important action, consisted of Arizona's efforts to bring Central Arizona Project water into central and southern Arizona. Fortunately, for us, we are now seeing the results of these monumental efforts. As required in the state ground water code the First Management Plans have been completed and the Second Management Plans are nearing completion. The CAP has been completed to Phoenix and the final leg of the aqueduct will be completed to Tucson sometime after 1990.

The passage of the State Ground Water code and the introduction of CAP water represent the two most important and effective solutions to our ground water problems. However, it is fully understood that in order for these solutions to obtain their optimum capabilities there will be a need to initiate supplemental augmentation programs. It is simply not enough, to just bring in CAP and require mandatory conservation. We have to combine these solutions with compatible augmentation programs. We need to use these two solutions as the basic foundation from which to build a permanent and attainable resolution of our ground water problems.

Legislation was recently passed that allowed DWR to issue permits for general recharge and for storage and recovery purposes. The general recharge permit would allow water to be recharged but makes no provision for the recovery of this water. The storage and recovery permit would allow water to be recharged and stored in an underground aquifer and correspondingly would allow recovery of the water. This latter permit basically establishes a water bank account that allows you to deposit water at a time when you might have an excess amount and to withdraw it at a latter date when you need it. Just like your checking account, you deposit your pay check when you receive it and withdraw funds when the bills come due.

The passage of Recharge Legislation has provided us with an excellent opportunity to augment our present water supplies. It is a tool, that if properly used can be very affective in helping us reach our stated management goals.

In order to better understand the philosophy of our proposed solution, it is important to explain a few of the specifics of the New State Ground Water Code.

As specified in the Code, the Department of Water Resources would prepare and implement five management plans, one covering each of five time periods, 1980-1990, 1990-2000, 2000-2010, 2010-2020 and 2020-2025. The law created four Active Management areas called AMA's and required development of plans for each AMA. These areas' basically represent groundwater basins where a serious ground water problem has been identified. The Phoenix AMA includes most of Maricopa County and a small segment of Pinal County. The Pinal AMA includes most of Pinal County. The Tucson AMA includes a large segment of Pima County and portions of Santa Cruz County. The Prescott AMA basically consists of the City of Prescott and Chino Valley areas of Yavapai County. In the Phoenix, Tucson and Prescott AMA's our legislated management goal is to reach safe yield by the year 2025. While in the Pinal AMA the goal is to preserve existing agricultural economy for as long as feasible, consistent with the necessity to preserve future water supplies for non-irrigation uses.

Each Management Plan will contain mandatory ground water conservation requirements for each AMA. It becomes very important to develop augmentation programs that are compatible with these conservation requirements and in order to accomplish the AMA goals, there is also a need to develop a strategy and establish objectives for each management plan. These objectives would control and direct the conservation requirements and the augmentation plans that would be implemented in each AMA.

The importance of developing a working strategy and establishing realistic, reasonable objectives cannot be over-emphasized. We cannot get from where we are now to where we plan to be in the future, at safe yield by the year 2025, without good strategy and attainable objectives. We need to build ourselves a pathway to safe-yield and one way to do that is through the use of recharge. This pathway must be constructed to be compatable with the Ground Water Code and directed to lead us where we need to be in the year 2025.

WATER MANAGEMENT THROUGH RECHARGE

The recharge legislation and the corresponding permitting process has been crafted to allow for optimum water management. For the storage and recovery permits the law provides that the water to be stored and the water to be recovered must be classified as the same type of water. As an example, if you only recharged CAP water, your withdrawal permit would correspondingly allow you only to recover CAP water. The same requirement would be used for the recharge of effluent (effluent in-effluent out). This storage and recovery classification parity can be used as a mechanism to augment existing water supplies.

In the First Management Plan, effluent uses are not counted against municipal water conservation requirements, correspondingly establishing incentives for the use of effluent. Certain municipal water demands, such as turf requirements can be met with effluent. If there are demands that are presently being satisfied by pumping ground water, and we decide to meet these same demands through the use of effluent, we are essentially conserving ground water for future uses.

In surface water storage systems we store the excess water for anticipated use in the future when the demands are greater than the existing supply. The same principal can be applied to underground storage and to the use of excess effluent. In essence we are augmenting our water supply by making complete use of the effluent available and correspondingly moving one step closer to our goal of safe yield.

The second important solution to our ground water problems is through the implementation of the Central Arizona Project. If properly structured, recharge can also be used to augment this vital water supply.

Plan -6 an authorized feature of the CAP consists primarily of construction of a new dam to replace existing Waddell Dam, on the Agua Fria and construction of a new enlarged Roosevelt Dam on the Salt River and construction of a new dam called Cliff Dam to be located between Horseshoe and Bartlett Dams on the Verde River. Plan -6 by itself will augment CAP Colorado River diversions by about 140,000 acre feet per year. However, it is possible to combine Plan 6 with a recharge project and to significantly increase this augmented water supply.

Through the use of storage and recovery permits we can slowly release water from the Plan-6 dams, recharge the water downstream and recover the water at a latter time period when there is a need to use this stored water. The releases from the dams will result in additional storage capacity and allow capture of water that normally would have been lost because of insufficient storage capacity.

Combining Recharge projects with Plan-6 allows us to optimize the use of these features and to maximize our augmented water supplies. However, there are also other opportunities available where CAP and recharge can provide additional augmented water for use in Arizona.

In the past, there have been many times, when there has been shortages on the Colorado River. Since 1983, Colorado River inflows have exceeded storage capacity resulting in the availability of significant amounts of surplus Colorado River water. These surplus conditions are assumed to be temporary and it is certain that there will again be shortage periods in the future. It is important to make use of these excess flows to augment our water supplies when the opportunities are available. Recharge programs need to be developed that will allow us to recharge and store these surplus flows during these temporary hydrologic periods of excessive runoff.

AUGMENTATION AND RECHARGE

As described, we have looked at ways that recharge programs can be beneficially used with the ground water code and with the CAP to augment our existing water supplies. Although the code and the CAP represent the two major solutions to resolving our ground water problems, it should be emphasized that development of augmentation options are also important and need to be implemented if we are ever to attain our stated management goals. Recharge can be used as a valuable tool for optimizing the use of these augmentation options.

Effluent represents a valuable resource that is presently being underutilized. The problems with effluent use are generally associated with the location of the source and with the differences in the time when the effluent is available and the time when it is needed. Recharge can provide opportunities to lessen, if not resolve these problems.

Excess effluent can be stored underground and recovered at a later date, when the demands are greater than the existing supply. In cases where the location of the source is a problem, exchange scenarios are being investigated as possible solutions.

As discussed in the Plan-6/Recharge Option, additional reservoir storage space can be made available through minor releases of water from upstream dams and eventual recharge and recovery downstream. The same plan can be selected for use with other augmentation schemes presently being analyzed including weather modification and watershed management.

As in the Plan-6/Recharge Options, the idea is to optimize the augmented water supply through the use of recharge. Combining the existing surface water storage systems with underground storage we can create additional storage, store additional augmented water supplies and use the stored water supply to meet future demands.

The Department has also looked at the use of stormwater runoff as a possible source of augmentation. Our first priority would be to use the water directly but if this were not possible, the recharge option would receive the next highest priority. Other significant augmentation options available to us consist of in-state and out-of-state water transfers. Many of the recharge plans previously discussed, or some deviation of these plans could be successfully used with the in-state and out-of-state transfer options.

The cities of Phoenix, Scottsdale and Mesa will be implementing projects requiring in-state water transfers. Only the City of Scottsdale will be transferring surface water and considering direct recharge. No doubt, innovative exchange programs could be combined with recharge options to allow all these cities to optimize the water supplies involved in these transfer projects.

THE FUTURE OF RECHARGE

Recharge will play an important role in future water management in Arizona. However, it is essential that we view recharge in perspective and to find out what blank space of the ground water problem solution puzzle that recharge fits into. The major component of this puzzle remains implementation of the ground water code and the introduction of the CAP. Recharge is an important part of the puzzle that allows us to optimize and maximize these solutions.

The Department of Water Resources as well as several other water resource entitites continue to look at ways to augment our present water supplies and to provide opportunities to lessen our overdependence on ground water. Recharge has provided a mechanism where we can optimize the potential for increased water supplies and maximize the augmentation efforts.

In the future recharge will grow in importance and continue to play an escalating role in water management in Arizona. However, in order to be effective recharge must be compatible with an overall plan, and must be directed toward attaining a future goal. In the Phoenix AMA which encompasses an entourage of cities called the Valley of the Sun, the plan is represented by the management plans developed under the authority of the ground water code, and the goal will be safe yield by the year 2025.

In the turning cogs and wheels of the mechanism that is being developed to resolve our ground water problems, recharge can be the special pin that allows safe yield to become a reality. The passage of the Recharge legislation placed the pin in the mechanism. Now its time to crank it up and see if it works.

RoleRechg

FMB:dk

ARTIFICIAL RECHARGE OF GROUNDWATER: A CITIZEN'S PERSPECTIVE

by Marybeth Carlile

A citizen's perspective?

In thinking about what I might bring to this audience in the way of a citizen's perspective, I thought about what recharge might mean to us if it became a reality in any significant way and I began to play the "if" game.

Recharge has become a watch word. It has positive connotions -- it may even mean "salvation" in the minds of some.

If we could just get this excess water to use - the water that seems to elude us now - that water we do not capture as it runs through our communities - that potential CAP water that runs on down the Colorado River past the Havasu intake.

If we could restore levels in our groundwater aquifers with this excess - to prevent potential subsidence - to balance our withdrawals from supplies - to help achieve safe yield...

If we could use the underground aquifers for water storage for our population expansion needs...

If recharge could help make us self sufficient in our water supplies... IF, IF, IF.

Recharge seems to hold great promise - Is that true? With enough resources (money and excess water) could recharge fulfill those needs, those dreams?
That is what we citizens would like to know. Does Artificial recharge hold the promise attributed to it?

You have all spent the last two days looking at where we are right now, today, in our knowledge, expertise and institutional arrangements with regard to using and implementing artificial recharge in Arizona.

With all this reality, what are your expectations?

I can tell you that mostly without this experience of reality, "John Q. Public", "the man on the street", the casual individual exposed to the notion of recharge - has great expectations! Call it wishful thinking, or an easy way of solving a potential shortage of that increasingly precious resource, water. Why not solve several problems at once by refilling and reusing our depleted aquifers, while at the same time capturing excess runoff, early year CAP surpluses and recycling our effluent efficiently? Why not?

If not, why not? That is a question that has been brought to the public attention in this maze of management solutions to our water problems.

Recharge has some magical qualities about it when you put it together with overdraft, excess flows of surface water, long term needs and often dry riverbeds. Why can't this combination of negatives be put together into a positive? Recharge?

Stealing quietly in upon the scene is pollution, most often the result of people's activities in our modern society - in urban settings, particularly where use of land along water courses and recharge areas, for waste storage and disposal is of major proportions.

The resulting water quality problems in the aquifers we depend upon raise the question of recharging relatively good water after bad. In some cases, of course, the opposite problem arises of whether relatively good water is good enough or will be cleaned up enough to join current aquifers of high quality water.

It is of concern, of course, but I don't believe the public cares about the intracacies of matching water qualities and what that means for artificial recharging. They just want and expect high quality water to use!

Likewise, the public is not really concerned with legal and institutional barriers. Surely they are easily dealt with and should not stand in the way of a water secure future!

However, I believe, the one factor that speaks loudest to the public - and partially because somehow there is a trust that someone is out there managing the feasibility, legal and quality questions -- that ultimate factor for the public - cost...

Is recharge the simple, inexpensive solution it has been touted to be? If it is, get on with it? If it is not, then tell us, level with us...
Explain to us that there are risks and costs but we have to do it anyway. Or that, at best, artificial recharge is only one small part of a multiple of management devices and techniques - albeit a necessary and important one.

If water clean up, dealing with drinking water standards for most of our water supplies, whether surface or underground, is really the big cost for a long term adequate supply, then that issue needs to be put in perspective.

Prevalence of water degradation, clean up costs, decisions on risk factors - utilizing the water supply available to us and delivering it at drinking water standards - may be the silent stalker here. But let's not confuse it with what artificial recharge is and can do. Recharge, though not cheap, may more easily fit into the picture if it becomes a recapture supply technique and is separated out from the quality factor.

Let's identify artificial recharge for what it really is; what it really can do and what it can't do.

Can Recharge -

1. Create long term storage for future use?
2. Play a part in aquifer replenishment - hence, safe yield?
3. Serve peak demand needs consistently?
4. Utilize various types of excess waters, e.g., effluent, flood flows, CAP? Is one type more easily recharged than the others?
5. Make use of most dry river beds?
6. Make use of <u>existing</u> well fields with use of injection wells?
7. Prevent subsidence?
8. Be fully recaptured for use?

   How does one sort these out in importance and usefulness?

You see the citizens of our communities are tuned in enough on water and its need for good management in our state that they need to know when a good idea merits their support - especially their monetary support.

How good an idea <u>is</u> Artificial Recharge?

Closing Remarks

by Alan Kleinman
Department of Water Resources, Phoenix, AZ

I appreciate the comments a speaker made yesterday morning and although I forgot who it was he quoted as saying when some pioneers first saw this Valley, they said this was a worthless area. A lot of people are like that. But there were those hardy souls who came and looked and said, this looks alright. And these pioneers drew the conclusion that they were going to live here, farm here, raise their families here, and build a metropolis here and then they went about finding ways to do it, to make it happen. There are lots of problems here still in the Salt River Valley, but we can work them out. I think sometimes people are a little too cautious, particularly today. Maybe we need to draw the conclusion and run out and start doing it.

The water problem in Arizona today is a problem of management rather than absolute shortage. We have drawn heavily on our bank account over the years during my life time. The recharge of water allows us an opportunity to replenish some of that bank account. I'm always asked by reporters, "Is there a water shortage in Arizona, is there a water crisis in Arizona?" This is a very difficult question to answer. The simplest answer I've come up with is, "Yes, there is a water shortage and there is a water crisis." There always has been a water crisis in Arizona. But that crisis has always been 20 or 30 years down the road and we must prepare today for that eventually. Some preparation has already been done by those men who went out and grubbed the mesquites out of the desert and built the Salt River Project, which is the big credit to this Valley. Those were the pioneer farmers who had no idea how they were ever going to pay for that project, but they knew that it was a good thing to do.

In 1891, fifty percent of the inhabitants of this Valley moved out because it was uninhabitable. I believe it was 1896, or just a few years later, we had the record flood on the Salt River, the greatest flood they've ever had.

The building of the Roosevelt Dam began, the foundations were laid, and one of the largest floods ever, came and wiped it out. In 1941, we had the most serious drought that we'd experienced since pioneers had been here. People began to move out at that time. In the late '40's, another serious drought. When I first saw Roosevelt Dam, there was no water in it. In fact, there was no water anywhere except under the ground. The great technological innovation that made Arizona inhabitable really lies in two things: the development of refrigerated air conditioning by the engineers, and the development of the turbine pump. The greatest drought insurance we have in Arizona lies underneath us and we've used it before, that's what got us through the '40's. I recall hearing on the radio as a young boy that there were three day worth of water left in the SRP system and then we would be finished. But on the third day, it began to rain.

The last eight to ten years have been exceptional water years. Most people, a very high percentage of people, that live in Arizona now have been here less than ten years. Because these last ten years have been exceptionally wet years, it is easy to fall into a very lackadaisical attitude. There have been special shows on TV showing the correlation of sun spot activity with tree rings as drought indicators. It is predicted that in the mid 1990's there will be a resurgent of important sun spot activity and a major drought in the Western United States. Now is the time to act and prepare for that drought.

Events such as droughts are not bad accidents. They're not bad luck. It's just the nature of the place in which we live. That's all there is to it. The time for recharge has arrived in Arizona. We have legislation in place and we have conveyance facilities in place. During the period of 1978 through 1980, 5.4 million acre feet of water was wasted down the Salt River. It went right by us. From 1983 to the present time, 55 million acre feet of water have gone down the Colorado River past Morales Dam and into the Gulf of California and lost to future use. We need, and we can recharge, that water and to replenish that bank account. We need to recharge all that we can afford to recharge when the water is there, not when we are in a drought period. Unfortunately, there are some signs that maybe our good water period is over already. We may have missed the window of opportunity. I don't worry too much about the engineering solution. Engineers have always been extremely clever and come up with solutions. I don't worry too much about the legal solutions. I do worry about the institutional and bureaucratic aspects of groundwater recharge. I do worry about economics and I can say that because I'm an economist. But these engineers come up with these wonderful schemes and then we economists tell them why it won't work. It won't work because it won't repay itself. I think Arizona is at the point where we need some, shall we say, creative economics and some creative bureaucratic actions. We need to bank ahead and we need to prepare for the future. The engineers, hydrologists, and water planners must utilize their expertise to take advantage of this window of opportunity.

I've been greatly illuminated by the work that's been done previously, especially in California. They've spent 30 to 40 years doing recharge. Arizona doesn't need to reinvent the wheel. The petroleum industry for 40 years has worked with water flood injection systems and secondary oil recovery programs. Hundreds of millions of dollars have been spent in research and application. There is an opportunity to learn from previous experience and jump on the learning curve where it is, and not start at the bottom.

In the legal and institutional aspects we have a very clear mandate from the legislature. We need to take advantage of this window of opportunity to perform large scale recharge in Arizona.

As Director of the Arizona Department of Water Resources, I realize that in one 18 month period there was 30 million acre feet of water that was lost down the Colorado and we cannot afford an 18 month permit process to do recharge projects. We at the Department of Water Resources are committed to expedite the process. We need our sister agencies to do the same thing. "Let's not get bogged down in rhetoric, let' not get bogged down in bureaucratic impediments; let's get moving now and get the job done."

In Arizona, we need to increase our efforts to work with all involved to help them to negotiate and cite specific approaches to recharge. We need to set up flexible rules which are flexible enough to allow custom tailoring of each recharge site while protecting resource and water uses. These rules should allow for pilot projects and operating revisions, as a project develops.

The Department of Water Resources and the Department of Health Services, needs to expedite the recharge permit procedure. The Departments need to be involved in the initial planning efforts with the Salt River Project (SRP), and the Cities of Mesa and Phoenix so everyone can understand the problems early on. These Cities and SRP came to the Department of Water Resources five months ago and held preliminary discussions. I feel it is important that the Department of Water Resources and the Department of Health Services (DWR and DHS) participate in those planning processes at the local level with SRP, Mesa, Phoenix Scottsdale, and others so that we can understand the problems early on. In that way, when a permit is submitted, the DWR and DHS can understand what you're doing and not take six months or eighteen months while recharge planners wait around for us to decide what to do on the permit.

We need creative regulators, we need creative economics and creative project planners in Arizona today. Now is the time to act on groundwater recharge.

RECHARGE SYMPOSIUM SPEAKERS

Barrios, Frank M. - Phoenix Active Management Area
Bouwer, Herman - U.S. Water Conservation Laboratory

Carlile, Marybeth - Southern Arizona Water Resources Assoc.
Chase, Bill - City of Phoenix
Cline, Neil - Camp Dresser & McKee, Irving, CA

Danos, Val - Arizona Municipal Water Users Association
Dozier, Larry - Central Arizona Water Conservation District
Dueker, Leonard - City of Scottsdale

Erwin, Carol - U.S. Bureau of Reclamation

Finlayson, Donald J. - DWR, Sacramento, CA

Harrison, T. J. - City of Tucson
Hem, J. D. - U.S. Geological Survey, Menlo Park, CA

Johnson, R. Bruce - City of Tucson Water Department

Kleinman, Alan P. - Arizona Department of Water Resources
Kleinschmidt, Alan - Salt River Project
Kohlhoff, Karl - City of Mesa

Lewis, Lionel - Maricopa County Flood Control District
Lord, Bill - Water Resources Research Institute

Mack, R. Bruce - Salt River Project
McCain, Bob - Arizona Municipal Water Users Association
Mills, Bill - Camp Dresser & McKee, Irving, CA

O'Hare, Craig - Arizona Department of Water Resources
Onyskow, Larry - Cella-Barr Associates

Postillion, Frank - Camp Dresser & McKee

Randall, Rich - Ch2M Hill
Reynolds, Carroll - City of Phoenix

Small, Gary - Salt River Project
Smutzer, Dave - Pima Dept. of Transportation & Flood Control

Weiss, Norm - Arizona Department of Health Services
Wheeler, Bill - Central Arizona Project Association
Wilson, L. G. - Water Resources Research Center
Wilson, D. S. - Salt River Project
Wohlers, Chris - Environmental Protection Agency
Wood, Pete - Whittier Narrows Project, County of Los Angeles

CORPORATE SPONSORS

AN WEST, INC.
4120 North 20th Street
Phoenix, AZ 85016
(602) 957-3681

John Carollo Engineers
3877 Norrh 7th Street, Suite 301
Phoenix, AZ 85014
(602) 263-9500

CH2M Hill
310 South Wilmot Road, Suite B-210
Tucson, AZ 85711
(602) 748-9144

Camp, Dresser & McKee
120 West Broadway, Suite 190
Tucson, AZ 85701
(602) 792-3573

Cella Barr Associates
5062 North 19th Avenue
Phoenix, AZ 85015
(602) 242-2999

Collar, Williams & White Engineering
2702 North 44th Street, Suite 205B
Phoenix, AZ 85008
(602) 947-5433

D Squared Ranch
Montello
Nevada

Dames and Moore
7500 North Dreamy Draw Drive, Suite 145
Phoenix, AZ 85020
(602) 371-1110

Franzoy Corey Engineers
5030 East Sunrise Road
Ahwautukee, AZ 85044
(602) 583-0903

Greeley Hansen Engineers
Phoenix Gateway Center, Suite 400
426 North 44th Street
Phoenix, AZ 85008
(602) 275-5595

Layne-Western Company, Inc.
12030 East Riggs Road
Chandler, AZ 85249
(602) 895-9404

Malcolm Pirnie, Inc.
2650 South 46th Street, Suite 102
Phoenix, AZ 85034-7416
(602) 241-1770

Kenneth D. Schmidt & Associates
Groundwater Quality Consultants
4120 North 20th Street, Suite F
Phoenix, AZ 85016
(602) 956-8711

Stewart Brothers Drilling Company
P. O. Box 2067
Grants, NM 87021
(505) 370-1313

Woodward-Clyde Consultants
The Camelback Arboleda
1661 East Camelback Road, Suite 250
Phoenix, AZ 85016
(602) 264-1157

ARTIFICIAL RECHARGE SYMPOSIUM REGISTRATION LIST

Penelope S. Ahearn
Hydrology Department
AZ. Department of Water Resources
99 East Virginia
Phoenix, AZ. 85004
(602) 255-1586

Lynn Almer
Bureau of Reclamation
P. O. Box 9980
Phoenix, AZ. 85068
(602)870-6760

Wallace A. Ambrose
Greeley and Hansen
426 N. 44th St., Suite 400
Phoenix, AZ. 85008
(602)275-5595

Catherine Balzano
Planning & Compliance Division
AZ. Department of Water Resources
99 E. Virginia
Phoenix, AZ. 85004
(602) 255-1546

Reg Barnes
Basic Data Section
AZ. Dept. Water Resources
2810 S. 24th St., Suite 122
Phoenix, AZ. 85034
(602) 255-1543

Frank M. Barrios, Director
Phoenix AMA, AZ. Department of Water Resources
2702 N. 3rd St., Suite 2010
Phoenix, AZ. 85004
(602) 255-1512

Robert V. Barton
Bureau of Reclamation
P. O. Box 427
Boulder City, NV. 89005
(702) 293-8585

Larry Beddome
Senior Water Rights Specialist
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85072-2025
(602) 236-5469

Kate Berry
ERO Resource Corp.
2801 Youngfield #121
Golden, CO. 80401
(303) 231-9022

Bidhu Bhusham Bhattacharya
Kasai-Subarnarekha Project
Central Ground Water Board
Stocking Road
Dhatkidhin, Jamshedpur, India 831001

Jim Binick
The Adams Group, Inc.
4520 N. Central Ave., Suite 500
Phoenix, AZ. 85012
(602) 264-9599

William C. Blackman, Jr.
Manager, Office of Emergency Response
& Environmental Analysis
AZ. Department of Health Services
2005 N. Central Ave.
Phoenix, AZ. 85004
(602) 257-2303

Douglas C. Bleakly
Woodward-Clyde Consultants
1390 Market St., Suite 250
San Francisco, CA. 94102
(415) 553-2046

Kip Kelso Boden
P. O. Box 25846
Tucson, AZ. 85740
(602) 297-5624

Dick Bradford
City of Mesa
Utility Operations
340 E. 6th St.
Mesa, AZ. 85201
(602) 834-2131

Don Bradtke
Town of Gilbert
119 N. Gilbert Rd.
Gilbert, AZ. 85234
(602) 892-0802

Phil Briggs, Deputy Director
Engineering Div., AZ. Department of Water Resources
99 E. Virginia
Phoenix, AZ. 85004
(602) 255-1708

Becky Buehl
CAWCD - Board Member
848 N. Standage
Mesa, AZ. 85201
(602) 835-1935

Nathan Buras
Dept. of Hydrology & Water Resources
University of Arizona
Tucson, AZ. 85721
(602) 621-5082

Earl E. Burnett
U. S. Bureau of Reclamation
P. O. Bin 12487
Yuma, AZ. 85365
(602) 726-2656

Martha Bush
AZ. State Senate
Attorney-Majority
1700 W. Washington
Phoenix, AZ. 85007
(602) 255-1707

Dean Bartley P. Cardon
Forbes, 306
College of Agriculture
University of Arizona
Tucson, AZ. 85721
(602) 621-7621

Marybeth Carlile
So. AZ. Water Resources Assoc.
48 N. Tucson Blvd., Suite 106
Tucson, AZ. 85716

Randy Chandler
Bureau of Reclamation
Arizona Project Office
P. O. Box 9980
Phoenix, AZ. 85068
(602) 870-2196

Shiou Chen
AZ. Department of Health Services
1740 W. Adams
Phoenix, AZ. 85007
(602) 255-1188

Neil Cline
Camp Dresser & McKee
Cambridge Court
2701 N. 16th St.
Phoenix, AZ. 85006
(602) 277-9966

Debra Daniel
AZ. Dept. of Health Services
3345 E. Highline Canal
Phoenix, AZ. 85040
(602) 257-6892

Val Danos
AZ. Municipal Water Users Assoc.
505 N. 2nd St., Suite 385
Phoenix, AZ. 85004
(602) 256-0999

Stephen Davis
Malcolm Pirnie, Inc.
2650 S. 46th St., Suite 102
Phoenix, AZ. 85034
(602) 241-1770

David Dennison
Councilman, Town of Carefree
P. O. Box 740
Carefree, AZ. 85377
(602) 488-3686

Steve DeTommaso
McGuckin Drilling, Inc.
1509 E. Elwood
Phoenix, AZ. 85040
(602) 268-0785

Richard Dillenburg
AZ. Dept. of Water Resources
Basic Data Section
6419 S. 43rd Pl.
Phoenix, AZ. 85040
(602) 437-3797

Herb Dishlip, Deputy Director
Water Management
AZ. Dept. of Water Resources
99 E. Virginia
Phoenix, AZ. 85004
(602) 255-1553

Joe Dixon
U. S. Army Corps of Engineers
3002 N. 27th St.
Phoenix, AZ. 85016
(602) 241-2003

Greg Dozier
Attorney General's Office
1275 W. Washington
Phoenix, AZ. 85007
(602) 255-1610

Jim DuBois
AZ. Dept. of Health Services
2005 N. Central
Phoenix, AZ. 85004
(602) 257-6892

Gordon Dutt
Dept. Soil & Water Science
University of Arizona
Tucson, AZ. 85721
(602) 621-1381

Ronald J. Effertz
U. S. Bureau of Reclamation
P. O. Box 427
Boulder City, NV. 89005
(702) 293-8557

William Engstrom
AZ. Department of Health Services
1740 W. Adams
Phoenix, AZ. 85007
(602) 255-1188

John Erickson
Water Resource Associates
3033 N. 44th St.
Phoenix, AZ. 85018
(602) 952-0681

Charlie Ester
Hydrology Department
Salt River Project
1521 N. Project Dr.
Tempe, AZ. 85281
(602) 236-2587

Sandra Eto
Bureau of Reclamation
P. O. Box 9980
Phoenix, AZ. 85068
(602) 870-6760

Roger Evans
Salt River Indian Community
Department of Community Development
Route 1, Box 216
Scottsdale, AZ. 85256
(602) 941-7281

Wayne Evans
City of Mesa
Utility Operations
Mesa, AZ. 85201
(602) 890-3229

Henry T. Eyrich
Pima Association of Governments
405 Transamerica Building
Tucson, AZ. 85701
(602) 792-1093

Bob Farrer
Special Assistant to Director
AZ. Department of Water Resources
99 E. Virginia
Phoenix, AZ. 85004
(602) 255-1540

Larry D. Fellows
AZ. Geological Survey
845 N. Park Ave.
Tucson, AZ. 85719
(602) 621-7906

Steven J. Figgins, Staff Scientist
Geraghty & Miller, Inc.
3322 E. Ft. Lowell Rd.
Tucson, AZ. 85716
(602) 881-4949

Dan Finlayson
Principal Engineer
CA. Dept. of Water Resources
617 El Toro Way
Davis, CA. 95616
(916) 756-3776

George Fletcher
Dames & Moore
7500 N. Dreamy Draw
Suite 145
Phoenix, AZ. 85020
(602) 371-1110

Maury Ford
Boyle Engineering
7600 N. 16th St., Suite 110
Phoenix, AZ. 85020
(602) 943-6800

Twana Fox
Bureau of Reclamation
Arizona Project Office
P. O. Box 9980
Phoenix, AZ. 85068
(602) 870-2196

Jay W. Franson, P. E.
Ungerman Engineering
P. O. Box 39610
Phoenix, AZ. 85069
(602) 375-2085

Jerry Freund
Public Service Director
City of Prescott
P. O. Box 2059
Prescott, AZ. 86302
(602) 445-3500 X260

Denise Fuerst
AZ. State Land Department
Hydrology Section
1624 W. Adams
Phoenix, AZ. 85007
(602) 255-3509

Jim Gaetjens
City of Mesa
Utility Operations
340 E. 6th St.
Mesa, AZ. 85201
(602) 834-2130

Jim Geiser
Dames & Moore
7500 N. Dreamy Draw Dr. #145
Phoenix, AZ. 85020
(602) 371-1110

Harold A. Goodman
City of Glendale
5850 W. Glendale Ave.
Glendale, AZ. 85302
(602) 435-4212

Arthur Gordon
Woodward-Clyde Consultants
1661 E. Camelback, Suite 250
Phoenix, AZ. 85016
(602) 264-1157

David D. Graham
U.S. Geological Survey
FB-44 Federal Building
300 W. Congress
Tucson, AZ. 85701
(602) 629-6291

Bill Greenslade
Dames & Moore
7500 N. Dreamy Draw, Suite 145
Phoenix, AZ. 85020
(602) 371-1110

Mike Grogan
Bureau of Reclamation
320 E. Kimberly Dr.
Henderson, NV. 89015
(602) 565-7782

Dennis G. Hall
Errol L. Montgomery & Associates
1075 E. Ft. Lowell, Suite B
Tucson, AZ. 85719
(602) 881-4912

Norman Hallman
Town of Gilbert
119 N. Gilbert Rd.
Gilbert, AZ. 85234
(602) 892-0802

Leonard C. Halpenny
Water Development Corporation
3938 Santa Barbara
Tucson, AZ. 85711
(602) 327-7412

Phillip C. Halpenny
Water Development Corporation
3938 Santa Barbara
Tucson, AZ. 85711
(602) 327-7412

Robert S. Harding
Groundwater Consultant
1625 E. Edgewater Dr.
Tempe, AZ. 85283
(602) 839-9834

Robert B. Hardy
City of Prescott
Engineering Division
P. O. Box 2059
Prescott, AZ. 86302
(602) 445-3500 X.247

John W. Harshbarger
Errol L. Montgomery & Associates
1075 E. Ft. Lowell, Suite B
Tucson, AZ. 85719
(602) 881-4912

Lisa Hastings
AZ. Dept. of Health Services
2005 N. Central #200
Phoenix, AZ. 85004
(602) 257-2322

Rep. Larry Hawke
House of Representatives
1700 W. Washington
Phoenix, AZ. 85007
(602) 255-4900

Alan Haws
Engineering Enterprises
1225 W. Main
Norman, OK. 73069
(405) 329-8300

Mark Hay
Water Quality & Geohydrology
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85072
(602) 236-2683

Lynn K. Heidenreich
City of Tucson - Tucson Water
P. O. Box 27210
Tucson, AZ. 85726-7210
(602) 791-4331

Dave Heinert
Water Group Management Staff
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85072
(602) 236-5472

John D. Hem
345 Middlefield Rd. MS 427
Menlo Park, CA. 94025
(415) 329-4531

John Hewitt
A-N West, Inc.
4120 N. 20th St.
Phoenix, AZ. 85016
(602) 957-3681

Richard J. Heydenburg
11614 Elkhead Range Rd.
Littleton, CO. 80127
(303) 972-1804

Dr. Robert W. Hinks, Associate Professor
Dept. of Civil Engineering
Arizona State University
Tempe, AZ. 85287
602-965-3589

Charles B. Hinkley
Water Resources Consultant
8115 N. 18th St., #112
Phoenix, AZ. 85020
(602) 997-7056

Gary L. Hix
Western Well & Pump, Inc.
120 N. 44th St., #100
Phoenix, AZ. 85034
(602) 267-0711

Steve Hoffman
AZ. State Land Department
1624 W. Adams
Phoenix, AZ. 85007
(602) 255-3500

Terry D. Hudgins
Arizona Public Service
P. O. Box 53999, #1711
Phoenix, AZ. 85072-3999
(602) 250-2878

Loretta B. Humphrey
City Attorney's Office
City of Tucson
P. O. Box 27210
Tucson, AZ. 85726-7210
(602) 791-4221

J. Phillip Hutton
Harding Lawson Associates
2600 N. Central Ave., Suite 800]
Phoenix, AZ. 85004
(602) 263-1942

Carmine Iadarola
Agua San Network
7951 E. Maplewood #327
Englewood, CO. 80111
(303) 694-2295

Dave Jacovitch
WELENCO
1920 E. 3rd St., Suite 21
Tempe, AZ. 85281
(602) 968-7176

Richard Jeffries
Boyle Engineering
7600 N. 16th St., Suite 110
Phoenix, AZ. 85020
(602) 943-6800

Bruce Johnson
City of Tucson - Tucson Water
P. O. Box 27210
Tucson, AZ. 85726-7210
(602) 791-43

Linda Johnson
Water Quality Lab.
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85072
(602) 235-2517

Denzil Jones
City of Tempe
Water/Wastewater
P. O. Box 5002
Tempe, AZ. 85281
(602) 731-8261

Keith A. Jones
Woodward-Clyde Consultants
The Camelback Arboleda
1661 E. Camelback Rd., Suite 250
Phoenix, AZ. 85016
(602) 264-1157

James Kaylor
City of Glendale
5850 West Glendale Ave.
Glendale, AZ. 85301
(602) 931-5561

Curt Kennedy
Hydrology Department
Salt River Project
1521 N. Project Dr.
Tempe, AZ. 85281
(602) 236-2714

David L. Kirchner
Vice President
Water Resources Associates, Inc.
3033 N. 44th St., Suite 228
Phoenix, AZ. 85018
(602) 952-0681

Alan P. Kleinman, Director
AZ. Department of Water Resources
99 E. Virginia
Phoenix, AZ. 85004
(602) 255-1553

Alan Kleinschmidt
Water Quality Lab.
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85072-2025
(602) 236-2615

Lionel Klikoff
AZ. Department of Health Services
1740 West Adams
Phoenix, AZ. 85007
(602) 255-1188

Karl Kohlhoff
Water Resources Advisor
City of Mesa
55 N. Center
Mesa, AZ. 85201
(602) 834-2273

Rong-Heny Kuo
International Boundary & Water Commission
4171 N. Mesa C-310
El Paso, TX. 79902
(915)-534-6704

Susan Kutz
Department of Microbiology, Bldg. 90
University of Arizona
Tucson, AZ. 85721
(602) 621-6911

Douglas J. Lanning
Civil Engineering Student-ASU
1340 E. Hall St.
Tempe, AZ. 85281
(602) 968-1208

Robert Larson
AZ. Department of Health Services
1740 West Adams
Phoenix, AZ. 85007
(602) 255-1188

Scott M. Larson
American Engineering
3864 N. 27th Ave.
Phoenix, AZ. 85017
(602) 277-3386

Nyle D. Layton
Hydrology Department
AZ. Department of Water Resources
2810 S. 24th St., Suite 122
Phoenix, AZ. 85034
(602) 255-1543

Sandy Lee
Attorney General's Office
1275 W. Washington
Phoenix, AZ. 85007
(602) 255-1610

Julie M. Lemmon
Larry J. Richmond, P.C.
1419 N. 3rd St., Suite 100
Phoenix, AZ. 85004
(602) 271-0505

Carol Lewin
Attorney General's Office
1275 W. Washington
Phoenix, AZ. 85007
(602) 255-1610

David Lewis
AZ. Department of Health Services
1740 West Adams
Phoenix, AZ. 85007
(602) 255-1188

Mario Lluria
Water Quality and Geohydrology
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85072-2025
(602) 236-5520

Sue Lofgren
The FORUM
2411 S. Newberry Rd.
Tempe, AZ. 85282
(602) 967-4156

William Lord
Water Resources Research Center

Daryl Lovvik
Director of Water Resource Dept.
Tohono O'odham Nation
P. O. Box 837
Sells, AZ. 85634
(602) 383-2221

Tim Luke
Attorney General's Office
1275 W. Washington
Phoenix, AZ. 85007
(602) 255-1610

Kamal Mahmood
Kasai-Subarnarekha Project
Central Ground Water Board
Stocking Road
Dhatkidhim, Jamshepur,India 831001

Karen M. Marotta
John Carolo Engineers
3877 N. 7th St., Suite 400
Phoenix, AZ. 85014

W. Gerald Matlock
Agricultural Engineering Department
University of Arizona
507 Shantz Building
Tucson, AZ. 85721
(602) 621-7224

Paul Matuska
U. S. Bureau of Reclamation
P. O. Bin 12487
Yuma, AZ. 85365
(602) 726-2656

John R. McCain
AMWUA
505 N. 2nd St., Suite 385
Phoenix, AZ. 85004
(602) 256-0999

Tom McLean
City of Tucson-Tucson Water
P. O. Box 27210
Tucson, AZ. 85726-7210
(602) 791-4331

Rod McMullin
4202 N. 64th St.
Scottsdale, AZ. 85251
(602) 945-5650

Bhusham Kumar Mendiratta
Executive Engineer
Central Ground Water Board, NHIV
Faridabad (Haryana) India

Jeanne Merz
City of Tucson - Tucson Water
P. O. Box 27210
Tucson, AZ. 85726-7210
(602) 791-4331

Andrew Messer
Errol L. Montgomery & Associates
1075 E. Ft. Lowell Suite B
Tucson, AZ. 85719

Harry Meyer
City of Tempe - Water Production
P. O. Box 5002
Tempe, AZ. 85281
(602) 731-823

George P. Michael, Jr., P.E.
Director of Public Works
City of Sierra Vista
2400 East Tacoma St.
Sierra Vista, AZ. 85635
(602) 458-3315

Ronald L. Miller, Ph.D.
Environmental Health Services Division
AZ. Department of Health Services
2005 N. Central Ave., Room 202-A
Phoenix, AZ. 85004
(602) 257-2300

Marti Minnich
Dept. Soil & Water Science
University of Arizona
Tucson, AZ. 85721
(602) 621-3244

Jim Mitchell
Senior Water Rights Specialist
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85072-2025
(602) 236-5262

Kim Mitchell
Hydrology Department
AZ. Department of Water Resources
99 East Virginia
Phoenix, AZ. 85004
(602) 255-1586

Marvin Murray
Bureau of Reclamation
Arizona Project Office
P. O. Box 9980
Phoenix, AZ. 85068
(602) 870-2196

Steven M. Myers
Basic Data Section
AZ. Department of Water Resources
2810 S. 24th St., Suite 122
Phoenix, AZ. 85034
(602) 255-1543

Edmund G. Nassar
U. S. Geological Survey
Water Resources Division
2817 S. Pennington Ave.
Mesa, AZ. 85202
(602) 831-7498

Craig O'Hare
Tucson AMA
AZ. Dept. of Water Resources
310 S. Meyer
Tucson, AZ. 85701
(602) 628-5858

Mark Olson
Water Resource Associates
3033 N. 44th St.
Phoenix, AZ. 85018
(602) 951-0681

Karen O'Regan
City of Chandler
200 E. Commonwealth Ave.
Chandler, AZ. 85225
(602) 899-9797

Stephanie Ostrom
State Health Dept.
2005 N. Central #202
Phoenix, AZ. 85004
(602) 257-2319

Earl Pearson
Salt River Indian Community
Department of Community Development
Route 1, Box 216
Scottsdale, AZ. 85256
(602) 941-7281

Mark Perez
Basic Data Section
AZ. Department of Water Resources
2810 S. 24th St., Suite 122
Phoenix, AZ. 85034
(602) 255-1543

George Pogue
Motorola, Inc.
8210 E. McDowell Rd. (S260)
Scottsdale, AZ. 85252
(602) 949-4123

Stanley Powell
Bookman Edmonston Engineering, Inc.
2702 N. 44th St., Suite 107B
Phoenix, AZ. 85008
(602) 956-4747

Andy Rendes
AZ. Department of Health Services
1740 W. Adams
Phoenix, AZ. 85007
(602) 255-

Richard Rhone
Bookman-Edmonston Engineering, Inc.
100 N. Brand Blvd.
Glendale, CA. 91203
(818) 244-0117

Hugh Ricci
Nevada Div. of Water Resources
12540 Creek Crest Dr.
Reno, NV. 89511
(702) 851-2169

Jeff Riddle
Water Quality & Geohydrology
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85025
(602) 236-3575

David C. Roberts
Water Rights Specialist
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85072-2025
(602) 236-2343

John Robertson
AZ. Dept. of Health Services
1147 W. Laird St
Tempe, AZ. 85281
(602) 829-0372

Gary Rogers
Dames & Moore
7500 N. Dreamy Draw Dr., #145
Phoenix, AZ. 85020
(602) 371-1110

Kelly Rowe
James M. Montgomery C.E., Inc.
17802 Sky Park Circle, #201
Irvine, CA. 92714
(714) 261-7210

Lee Rozaklis
WBL Associates
1909 W. Broadway, Suite 300
Boulder, CO. 80302
(303) 443-7839

Homer Saidi
AZ. Department of Water Resources
Statewide Planning Division
99 E. Virginia
Phoenix, AZ. 85007
(602) 255-1546

Miguel Santiago
AZ. Department of Health Services
1740 West Adams
Phoenix, AZ. 85007
(602) 255-1188

Lee Schoon
Sage Engineering
3220 S. Feir Ln.
Tempe, AZ. 85281
(602) 438-8257

Raymond L. Schreurs
Engineering Enterprises
1225 W. Main
Norman, OK. 73069
(405) 329-8300

Paul G. Sebenik
Paul G. Sebenik & Associates
1201 W. Vista Ave.
Phoenix, AZ. 85021
(602) 247-1823

Greg Seifert
Dames & Moore
7500 N. Dreamy Draw, Suite 145
Phoenix, AZ. 85020
(602) 371-1110

Oralynn Self
Arizona State University Student
1639 E. Campus Drive
Tempe, AZ. 85282
(602) 820-5389

Michael S. Sewell
Basic Data Section
AZ. Department of Water Resources
2810 S. 24th St., Suite 122
Phoenix, AZ. 85034
(602) 255-1543

Tamara A. Shreeve
City of Glendale
5850 West Glendale Ave.
Glendale, AZ. 85301
(602) 931-5561

Robert C. Siemak
James M. Montgomery Consulting Engineers
17802 Sky Park Circle, Suite 201
Irvine, CA. 92714
(714) 261-7210

Doug Smith
Kinney Management Services
P. O. Box 50069
Phoenix, AZ. 85076
(602) 820-3451

Lester Snow
Tucson AMA
AZ. Department of Water Resources
310 S. Meyer
Tucson, AZ. 85701
(602) 628-5858

Lee Sobchak
AZ. Department of Health Services
1740 West Adams
Phoenix, AZ. 85007
(602) 255-1188

Joseph J. Soltis
AZ. State Laboratory Services
AZ. Department of Health Services
1520 West Adams St.
Phoenix, AZ. 85007
(602) 255-1188

Ed Steckenrider
Public Lands Department
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85072
(602) 236-8184

Cornelius Steeline
Department of Chemistry
University of Arizona
Tucson, AZ. 85721
(602) 621-2780

Gordon Stephenson
Dames & Moore
7500 N. Dreamy Draw, Suite 145
Phoenix, AZ. 85020
(602) 371-1110

Robin Stinnett
AZ. Municipal Water Users Assoc.
505 N. 2nd St., Suite 385
Phoenix, AZ. 85004
(602) 256-0999

Chuck Strand
Public Works Director
Town of Gilbert
119 N. Gilbert Rd.
Gilbert, AZ. 85234

Gregg S. TenEyck
Leonard Rice Consulting
2401 15th St., #300
Denver, CO. 80202
(303) 455-9539

Dr. Richard M. Tinlin, V. P.
Geraghty & Miller, Inc.
3322 E. Ft. Lowell Rd.
Tucson, AZ. 85716
(602) 881-4949

Donald L. Tombling
Water Acquisition Manager
City of Lakewood
445 S. Allison Pkwy.
Lakewood, CO> 80226
(303) 987-7641

Frank Turek
A-N WEST, INC.
4120 N. 20th St.
Phoenix, AZ. 85012
(602) 957-3681

Nancy Turner
Analytical Technologies, Inc.
2113 S. 48th St., #107
Tempe, AZ. 85282
(602) 438-1530

Gary Ullinsky
AZ. Department of Health Services
1740 West Adams
Phoenix, AZ. 85007
(602) 255-1188

Lloyd V. Urban, Ph.D., P.E.
Texas Tech University
Water Resources Center
P. O. Box 4630
Lubbock, TX. 79409
(806) 742-3597

Bill Vineyard
AZ. Department of Health Services
1740 West Adams
Phoenix, AZ. 85007
(602) 255-1188

Bobby Wallace
U. S. Geological Survey
7344 E. Polk St.
Scottsdale, AZ. 85257
(602) 241-5435

Mary G. Wallace
Water Resources Research Center
Geology 318
University of Arizona
Tucson, AZ. 85716
(602)

Bill Warskow
Manager, Water Rights Division
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85072-2025
(602) 236-5680

Dr. Marvin Waterstone
Associate Director
Water Resources Research Center
University of Arizona
Tucson, AZ. 85721
(602) 621-7607

Bill Wiley
AZ. Dept. of Health Services
2005 N. Central
Phoenix, AZ. 85004
(602) 257-2350

Steve Willis
601 S. Alma School Rd.
Mesa, AZ. 85202
(602) 965-5175

Linda Wingert
Steich, Lang
4500 AZ. Bank Plaza
33 N. Stone Ave.
Tucson, AZ. 85701
(602) 628-1419

Ralph Wisz
Utilities Director
City of Mesa
c/o Utilities Administration
Mesa, AZ. 85201
(602) 834-2741

Garry J. Wohlgemuth
James M. Montgomery Consulting Engineers, Inc.
9850 N. 32nd St., Suite B-110
Phoenix, AZ. 85028
(602) 971-6091

Don Womack
Assistant General Manager-Water
Salt River Project
P. O. Box 52025
Phoenix, AZ. 85072-5025
(602) 236-5474

Peter M. Wood
County of Los Angeles
Department of Public Works
P. O. Box 4089 Terminal Annex
Los Angeles, CA. 90051
(213) 226-4384