TECHNICAL APPENDIX

Plan of Study for a Demonstration Recharge Project in the Salt River Valley

Phoenix Urban Study
Final Report

U.S. Army Engineer District
Los Angeles Corps of Engineers

December 1981

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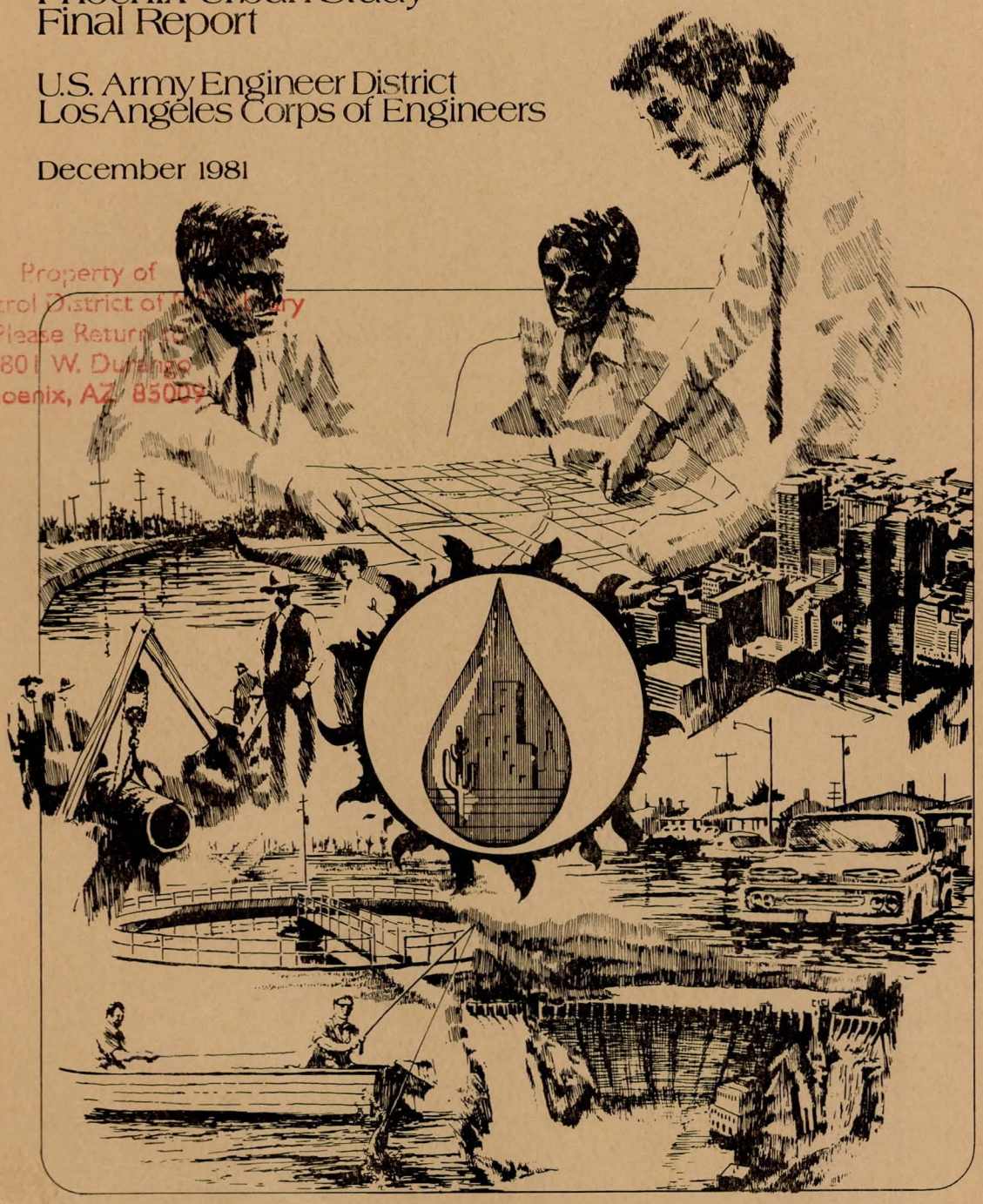

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PLAN OF STUDY FOR A DEMONSTRATION RECHARGE PROJECT IN THE SALT RIVER VALLEY

PREPARED FOR

THE U.S. ARMY CORPS OF ENGINEERS

LOS ANGELES DISTRICT

BY

THE WATER RESOURCES RESEARCH CENTER

THE COLLEGE OF EARTH SCIENCES

AND

THE SCHOOL OF RENEWABLE NATURAL RESOURCES

THE COLLEGE OF AGRICULTURE

UNIVERSITY OF ARIZONA

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PLAN OF STUDY FOR A DEMONSTRATION RECHARGE PROJECT IN THE SALT RIVER VALLEY

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EXECUTIVE SUMMARY

Introduction

This report presents a comprehensive plan of study for a proposed project demonstrating artificial ground-water recharge in the East Basin of the Salt River Valley, near Phoenix, Arizona. The plan of study was conducted for the U.S. Army Corps of Engineers as part of the Phoenix Urban Study, and represents the second phase of a five-phase planning process. Initiation of an artificial recharge project in the Phoenix, Arizona area must accommodate elements within the following constraint areas: (1) technical, (2) environmental, (3) institutional, (4) legal, and (5) economic considerations. Principal features of these constraint areas are reviewed in detail in respective sections of the report.

Each area of constraint is defined and evaluated in relation to various activities associated with a demonstration project, including: planning, design, construction, operation and maintenance, and monitoring. In addition to specifying engineering design alternatives, this report identifies several potential water sources and evaluates five alternative sites for a demonstration project within the study area. The plan of study presents available information and defines data gaps in each constraint area. A time-line of specific, sequential work tasks and budgetary requirements to correct informational deficiencies are identified and described within the respective areas of constraint.

Technical Considerations

The three basic technical elements of a recharge project are infiltration, storage and recapture. The long-term infiltration rate at a potential site governs the expected quantity of ground-water recharge, the areal requirements for a project, and land costs. The storage element consists of the combined storage capacity of the vadose zone and ground-water zone. The recapture element requires estimating the fraction of recharged water potentially available for recovery, as well as defining possible beneficiaries of recharge.

Characterization of these elements in the East Basin and site-specific project area entails defining available hydrogeologic information; identifying hydrogeologic data needs; and delineating techniques for obtaining hydrogeologic data. Available hydrogeologic data for the East Basin are reviewed, including the following: (1) distribution and hydraulic properties of soils; (2) stratigraphy; (3) water-bearing properties of basin fill; (4) existing ground water elevations; (5) existing depths to ground water; (6) location of perched ground water; and (7) the areal distribution of water quality parameters (e.g. salinity). Also reviewed are the existing recharge mechanisms in the East Basin, including natural recharge in the Salt River, canal seepage and deep percolation of irrigation water. Techniques for overcoming hydrogeologic information gaps are reviewed.

Environmental Considerations

The Environmental Section provides a basic description of the environment in the study area, together with an outline of potential concerns and issues to be addressed in a site-specific environmental report for a recharge project.

Generally, the vast majority of the land within the study area is a disturbed environment, with only small tracts of native riparian community remaining in the flood plain. Specific features of the environment in the study area are described under the following eight categories: vegetation, wildlife, cultural resources, health and safety considerations, socio-economic considerations, aesthetics, soils, and surface hydrology. Problems regarding each of these areas are examined. The most important concerns during the construction phase of the project include the short-term effects on archaeological sites, and the public health-related problems of dust and noise. Important long-term environmental concerns include the effects of recharge operations on ground-water levels, vector propogation, riparian vegetation enhancement, and water quality. Information is currently available in all these areas of concern, but site-specific monitoring is needed to assess the reversibility and retrievability of individual environmental components.

If care is taken in site selection and location of access roads, there should be no large-scale adverse environmental effects associated with the implementation of a demonstration project. A full-scale project will require an environmental impact statement to address the topic areas reviewed in this section.

Institutional Considerations

The institutional analysis in this report discusses three objectives: (1) to initiate an inventory of the institutions which will be involved in, or impacted by, an artificial ground-water recharge project in the study area; (2) to determine the institutional incentives and constraints which may influence the implementation of both a demonstration and full-scale recharge project, and to suggest an analytical process for assuring that such institutional considerations are examined during all project phases; and (3) to estimate the staff and time required to incorporate the institutional analysis component.

A survey of relevant institutions in the Salt River Valley indicates that interest in and support for artificial recharge is high. However, some of the individuals contacted during this phase expressed several reservations with regard to the feasibility of a recharge project, which may constrain its implementation. Primary concerns are questions of ownership and beneficiaries, economic feasibility, management, water quality, technical feasibility, and engineering design.

In regard to the demonstration project, three major recommendations for further institutional study are offered: (1) to complete and expand the institutional inventory; (2) to form a technical advisory committee to monitor the progress of a demonstration project and to advise the managers on matters which may affect artificial recharge, and (3) to create a citizen participation program related to the recharge projects. Recommendations for implementing a full-scale project include, continuing the activities of the technical advisory committee and the citizen participation program, analyzing

the institutional variables which have affected recharge projects in other geographical areas, and determining the institutional requirements for operating and managing a full-scale project.

Legal Considerations

Artificial recharge has four legal aspects: (1) the right to utilize storage space; (2) the right to recharge the space with procured water; (3) the right to retain ownership during storage; and (4) the right to recapture the co-mingled stored water. None of these rights are presently recognized in Arizona. Under Arizona law, the overlying owner can essentially pump all the water lying beneath the surface. If a sponsoring entity were to recharge a ground-water basin, it would neither receive the full benefit nor apportion the benefits of such a program. The benefit would accrue to all overlying owners who have the ability to pump.

California and Washington provide model legal reforms on ground-water recharge that might be readily adopted by Arizona. One of the following approaches may provide either a full or interim solution: modification of enabling legislation of an existing entity to allow recharge within its service area; statutory recognition of the recharge rights; multi-entity contracts within the dispersion area; intergovernmental agreement within the dispersion area; unilateral institutional action; and appointment of a water master. The options will be reduced when a recharge program moves from the demonstration phase to a full-scale project.

Another essential legal consideration is that water allocation and distribution in the Salt River Project (SRP) area is subject to the water rights provisions of the Kent Decree, which established a well-defined structure of water rights in the Salt River Valley. Any full-scale recharge project would have to be operated in conformity with SRP activities under the Decree.

Economic Considerations

This section views the proposed demonstration project as an applied research project; a project from which practical knowledge

will result. As an applied research project the demonstration project is not subject to the requirement of traditional benefit-cost analysis. Therefore, the main emphasis of this section is on the full-scale recharge project.

This section develops the methodologies by which benefits and costs may be quantified for a potential full-scale project. Quantification of economic elements is viewed as an iterative process; therefore, no attempt is made to quantify actual benefits or costs in this, the first iteration. Data and knowledge derived from the proposed demonstration project, can later be applied to quantifying most of the benefits and costs of the full-scale project.

The financial feasibility of the project may become a major obstacle impeding project construction. Although it may be possible to demonstrate that benefits exceed costs, it may be difficult to raise sufficient funds from project beneficiaries to cover the costs of project installation and operation. This is due, first, to the fact that Arizona water law allows all pumpers to extract ground water as long as their use is reasonable, i.e., Arizona water law does not require beneficiaries to compensate the agency controlling recharge facilities; and second, the benefits are so indeterminant that no institutional framework exists for setting charges and collecting funds for project repayment. Thus, major obstacles to maximizing the economic returns of the project appear to be legal and institutional in nature.

Engineering Considerations

Final selection of a specific design of a demonstration recharge project must await the choice of a specific site satisfying technical, environmental, legal, institutional and economic criteria. The four alternative recharge methods considered in the report are: (1) in-channel basins; (2) off-channel basins; (3) pits; and (4) wells. Alternative, conceptualized designs are reviewed, together with planning needs, recommended construction techniques, and operational and management schemes. Appurtenant facilities are discussed, including:

shop, laboratory, office, meteorological station, and storage space, within a fenced compound.

To quantify the fraction of recharged water potentially recoverable by pumping, monitoring facilities are needed to observe the disposition of recharged water in the vadose zone and ground-water zone, and to record the mixing of recharged water and native ground water. Data on recharge tests and related activities should be collected in a form suitable for computer input. Brief monthly reports and comprehensive annual reports are recommended.

Personnel to operate and manage the project should include a manager, laboratory technicians, shop and field personnel, data analyst, secretary and student assistants. Studies are recommended for the preconstruction period, during the operation and management of the project, and during monitoring.

1. INTRODUCTION

Paralleling the ever-increasing demand on ground water in Arizona is an augmented awareness by the public, and governing officials, of the need for an effective set of policies to manage ground water. Recently, the Arizona Water Commission (1978) examined the potential of 12 alternative methods for managing subsurface water in the principal ground-water basins of the state. One of the methods considered was artificial recharge.[1]

Artificial recharge comprises an array of techniques for placing water from various sources into storage within ground-water reservoirs. This report presents a plan of study for a demonstration recharge project in the Salt River Valley. In addition to specifying alternative engineering approaches for a demonstration project, using several potential water sources, the plan of study reviews associated implications of legal, institutional, economic, environmental, and technical factors.

1.1 Ground-Water Reservoirs and Conjunctive Management

Fundamentally, a ground-water reservoir includes those subsurface geologic formations capable of storing and yielding waters. Figure 1-1 schematically compares a surface reservoir with a conceptualized ground-water reservoir. The latter is typical of those found in unconsolidated alluvium in western valleys. The cross-section is subdivided into the "vadose zone" and the "ground-water zone." The ground-water zone is analogous to the pool of water in storage within a surface reservoir. The unsaturated void space of the vadose zone represents the volume available

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[1] The other methods included: interbasin transfer, watershed management, conservation, declaration of basins as critical ground-water areas, pro-rata reduction of developed rights, pro-rata reduction of unexercised rights, purchase and retirement of developed rights, purchase and retirement of unexercised rights, retirement of developed rights without payment, pump tax to control use, growth controls, and freeze withdrawals.

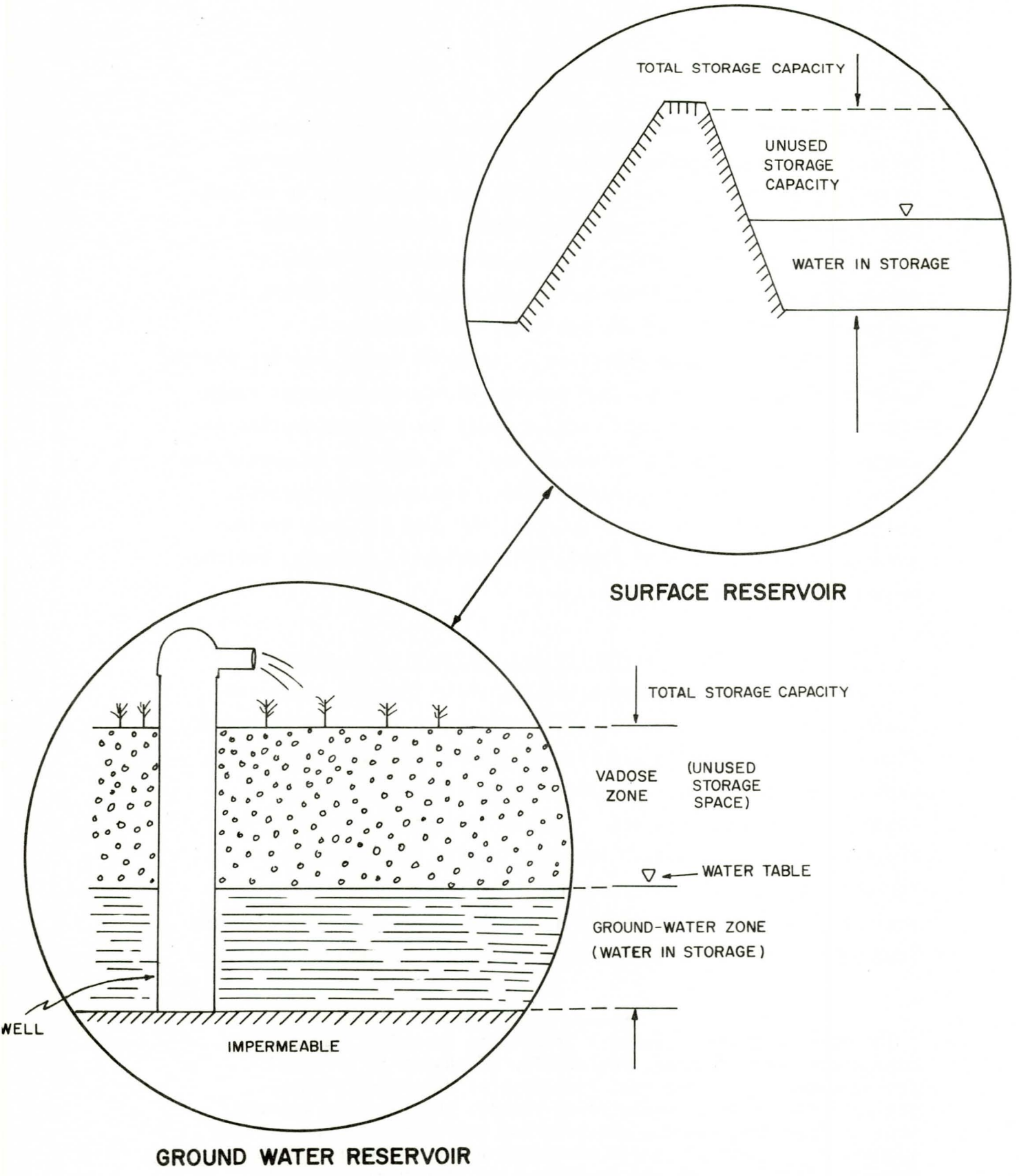


Figure 1-1. Comparison of Surface Reservoirs and Ground-Water Reservoirs.

for additional storage. This space roughly parallels the empty storage volume of a reservoir. The depth of available storage in the vadose zone changes as the water table responds to pumping and recharge. In contrast to this simple illustration, ground-water reservoirs may consist of several water-bearing zones (aquifers) at various depths and of varying thicknesses and areal extent, with intervening vadose regions (see Bouwer, 1978, p. 6).

Advantages of storing water in ground-water reservoirs compared to surface reservoirs include the following, listed in a United Nations (1975) report, and by Thomas and Phoenix (1976):

1. In many western valleys ground-water reservoirs provide greater capacity for storage than surface reservoirs. For example, in the Sacramento Valley of California, with a surface area of 10,000 Km^2 (3,840 square miles), the average effective porosity of sediments in the regions from 7 m to 70 m (23 ft. to 230 ft.) below ground surface is estimated to be about 7%. The corresponding volume available for water storage is approximately 44×10^9 m^3 (37×10^6 acre-feet) (United Nations, 1975).
2. Ground-water reservoirs are less susceptible to catastrophic events such as earthquakes, precluding damage to downstream areas and ensuring a continuation of water availability.
3. Ground-water reservoirs largely eliminate evaporation losses, except for those with shallow water tables. In arid regions reduction in evaporation losses represents a substantial water savings.
4. During recharge of ground-water reservoirs, an improvement in the physical and biological quality of water may occur.
5. In addition to storage properties, ground-water reservoirs transmit water from regions of higher to lower hydraulic heads. The flow rates, however, are markedly lower than flow rates in surface canals.

Disadvantages of storage in ground-water reservoirs include:

1. All the water placed into storage may not be recovered because of residual storage requirements.

2. Energy costs to pump water back to the surface may be high.

3. In some cases, a deterioration in chemical water quality may occur.

The joint or "conjunctive" management of surface and ground-water reservoirs is an effective technique for managing water resources in a given basin. An elementary operational mode of conjuctive management entails pumping enough ground water to offset deficits in surface water availability. Thus, in periods of deficient surface water the draft on ground water increases. Conversely, pumping is decreased during periods of abundant surface water.

In the basic mode of conjuctive management special facilities or structures are not provided for replenishing ground water. Partial replenishment may occur as a result of recharge in local stream channels, irrigation return flow to ground water, and canal seepage. An example of an area managed conjunctively without deliberate replenishment is an irrigated reach of the South Platte River in Colorado. When surface water is unavailable in sufficient quantity to meet the rights of all users, ground water is pumped by the owners of junior rights (Young and Bredehoeft, 1972). An unplanned consequence of pumping is that recharge in the river is augmented by the steepened hydraulic gradients in the ground-water system. A second example of conjunctive management without deliberate recharge is in the Salt River Valley. The Salt River Project discharges ground water from a large network of wells into surface canals to supplement surface water. Recharge occurs in the Salt River when water is released from upstream surface reservoirs. Incidental recharge in the valley also occurs from canal seepage and irrigation return flow.

An alternative mode of conjunctive operation involves the joint management of surface and ground waters, as described above, but incorporates artificial recharge for the replenishment of ground water. Conjunctive use, including artificial recharge, has been practiced for many years in California. For example,

the City of Los Angeles routinely recharges water from the Owens Valley and Colorado River using in-channel and out-of-channel spreading basins, and recharges wells. In Israel conjunctive management, including artificial recharge, is the basis of the national water policy. Fresh water from Lake Kinneret is transported in the National Water Carrier to areas of consumption. Surface water in the National Water Carrier is supplemented with pumped ground water from the two major aquifers. Alternatively, lake water, reclaimed wastewater and runoff are recharged into the aquifers via recharge wells, dual-purpose wells, and spreading basins.

The three basic elements of planned recharge in a conjunctive operation are: 1) infiltration, 2) subsurface storage, and 3) recapture. Infiltration refers to the movement of water through a soil surface during a water spreading operation, or through the perforations of a well casing during well recharge. Storage occurs in the void spaces of the vadose zone and zone of saturation. The third element, recapture, requires pumping from wells within the boundaries of the management agency. Because of variations in the direction of ground-water motion (for example, due to anisotropy), ground-water users not contributing to the expense of the operation may also benefit.

1.2 The Potential for Artificial Recharge in Ground-Water Basins of Arizona

From a technical viewpoint, the potential for artificial recharge and conjunctive use in Arizona appears to be great. For example, the structural basins between mountain blocks in the Basin and Range Physiographic Province are filled to depths of several thousands of feet with older and younger alluvium. The storage and hydraulic properties of these sediments have been relatively well defined in certain basins of the state, such as the Tucson Basin. Inasmuch as the population densities of Arizona, together with available water sources, are concentrated in the Salt River

Valley and the Tucson Basin, within the upper Santa Cruz River Valley, it appears that conjunctive management operations should be initiated first in these regions. Ranking these basins in order of greatest technical need for conjunctive management, the Salt River Valley ranks ahead of the Tucson Basin for two principal reasons. First, the supply of surface water potentially available for conjunctive operations is greater in the Salt River Valley than in the Tucson Basin. Second, the draft on ground-water supplies has been greatest in the Phoenix area. Since 1923, more than 70 million acre-feet of water has been pumped from the entire Salt River Valley (Arizona Water Commission Draft Report, 1978). In the eastern Salt River Valley, water level declines since 1923 have been as much as 420 feet in the Queen Creek area near the San Tan Mountains, and 360 feet east of Mesa. In the central Salt River Valley, declines have been less than 100 feet southwest of Chandler to about 150 feet in the Chandler area, increasing to 250 feet in Mesa and 300 feet near Scottsdale. The greatest decline has occurred since the 1940's when intense ground-water development began.

In a recent report to the Arizona Groundwater Management Study Commission, the Arizona Water Commission (1978) examined recharge as an alternative option for ground-water management in the Salt River Valley. Flood water was considered to be the major water source available for recharge. Thus, the report stated: "The usable water supply of the basin might reasonably be augmented by an average of from 50,000 to 70,000 acre-feet per year through efforts to increase recharge from flood flows of the Salt River. Facilities to develop the additional recharge might include recharge areas servicable from Salt River Project canals, recharge basins in the Salt River channel and injection wells."

1.3 Constraints on Conjunctive Management and Artificial Recharge Projects in Arizona

Initiation of a conjunctive management program in Arizona must accommodate elements within the following five constraint areas:

1) technical, 2) environmental, 3) legal, 4) institutional and 5) economic considerations. Each of these constraint areas must be defined and evaluated in relation to various artificial recharge project activities including planning, design, construction, operation and maintenance, and monitoring.

1.3.1 Technical Constraints

Technical constraints have generally received the most detailed investigation and are the most widely recognized of the constraint areas involved with artificial recharge. A primary constraint in many potential recharge areas is the need for surface storage of available sources of recharge water. Regarding recharge of flood waters in the Salt River Valley, for example, the Arizona Water Commission (1978) stated the following, "...before any significant program to recharge surplus flows of the Salt and Verde Rivers can be implemented, flood control storage must be provided on the Salt River so that flows can be reduced to a manageable size....the flood control structures will enhance the opportunity for recharge in the area by increasing the flow duration of recharge events."

In a recent report by the California Department of Water Resources (1978) it was concluded that the specific technical-engineering criteria which should be satisfied in a potential ground-water storage basin are: 1) nearby facilities for importing water, 2) readily available spreading facilities, 3) adequate storage capacity in ground-water reservoirs, 4) hydraulic connection between point of spreading and point of recapture, 5) no major water quality problems in the ground-water reservoir, 6) relatively small distance to water table at potential recapture (recovery) sites, and 7) minimal distances between potential recapture sites and points of use. Items 3) through 6) require detailed information on the hydrogeology of the proposed recharge area.

In designing, operating and managing a recharge project the effective rate of recharge, measured by long-term infiltration rates, is of prime importance. Thus, Schumann in a statement to the Interagency Task Force on Orme Dam Alternatives (1977) stated that the potential for recharge along the Salt and Gila Rivers in

the Phoenix area is great, but that "... technical studies are needed to determine long-term infiltration characteristics of the unconsolidated alluvium that underlies the stream channels and their flood plains" Infiltration rates are a function of surface soils, subsurface geology, hydrogeologic conditions and quality of the recharge water (see Appendix A).

Technical-engineering information needs for a demonstration project require intensive field investigations prior to and during operation. A monitoring program is an integral part of such investigations.

1.3.2 Environmental Considerations

The construction and operation of recharge facilities should have minimal adverse impact upon the local environment. Some improvements in environmental settings may be expected from ground-water recharge. Environmental considerations include: 1) proximity of site to landfills and hazardous waste-disposal sites; 2) effect on local vegetation and wildlife; 3) proximity to archaeological/historical sites; 4) proximity to populated areas; 5) possible air quality effects; 6) effect on natural drainage; 7) effect of insect and rodent vectors, and 8) effect on soils.

The general purposes of an environmental analysis for a demonstration recharge project are to describe the project area prior to implementing recharge operations; to assess potential short and long-term effects on the natural environment; and to suggest mitigating factors.

1.3.3 Institutional Constraints

Typical institutional requirements include the development of an overall management structure from existing governmental or private institutions which can effectively implement and operate the proposed recharge program. The agency responsible for recharge programs, for example, must possess a combination of technical capability, financial means and sufficient authority. A related consideration involves achieving sufficient public acceptance through citizen involvement to implement artificial

recharge plans. Effective implementation and operation of a recharge project require a sound centralized management plan, which assumes the existence of an adequate legal framework.

Institutional assessment involves an examination of the various local, state and federal policies relating to or impacting upon artificial recharge operations; examination of the institutional requirements of the proposed recharge project; and determination of the capabilities of current institutions to implement those requirements.

1.3.4 Legal Constraints

The legal constraints associated with artificial recharge are closely related to the institutional aspects. In fact, the absence of a workable legal framework makes it difficult to establish adequate institutional and administrative procedures. Significant legal constraints include the lack of precedent concerning control and ownership of recharge water, right to recharge, use of subsurface space, recovery of recharged water and the consideration of underground storage of water as a beneficial use. Such constraints can be overcome through favorable judicial interpretations or by legislative enactment of effective constitutional or statutory law.

1.3.5 Economic Constraints

A United Nations (1975) report on artificial recharge and ground-water storage indicates: "Any proposed planned artificial recharge scheme should first be evaluated to determine its financial feasibility and economic justification. Financial feasibility refers to the ability of the project beneficiaries to repay the cost of the project. Economic justification, expressed in terms of a cost-benefit ratio, permits comparison of alternative projects to select the most economical projects."

In order to properly estimate and allocate economic costs and benefits, the various beneficiaries of the project, both public and private, must be identified. The identification of beneficiaries and quantification of potential benefits comprise

two specific problems in the planning and implementation of a viable recharge program. In addition, the economic justification for an artificial recharge project must be evaluated in relation to the occurrence of natural recharge and in terms of the costs and benefits of recovering recharged ground water when compared to the costs and benefits of surface storage.

1.4 Planning a Recharge Program

A few small-scale artificial recharge projects of an investigative nature have been conducted in the state, such as those reported by Bouwer, Rice and Escarcega (1974), Maddox and Resnick (1961), and Wilson (1972). These projects were primarily concerned with technical, engineering, and environmental considerations, and to a less extent with legal, institutional and economic factors. Unplanned recharge occurs by irrigation return flow and by canal seepage. At this time there is a pressing need for a demonstration recharge project followed by a full-scale project, in an appropriate basin such as the Salt River Valley. The overall purpose of a demonstration project would be to identify and examine elements within all five contraint areas; thereby, facilitating the design and implementation of a full-scale recharge project.

The evolution of a ground-water recharge project in a given basin generally comprises the following four phases:

1.4.1 Phase I:

Identification of subregions of the basin most suitable for infiltration, storage and recovery of recharge water; and identification of the quantity and quality of available water sources.

1.4.2 Phase II:

Preparation of a detailed plan of study for a demonstration recharge project, including: 1) defining information availability and needs in five constraint areas (technical, environmental, legal, institutional and economic); 2) developing engineering plans for alternative recharge techniques; 3) identifying alternative recharge sites and water sources; and 4) preparing an estimate of budgetary requirements and time frame for activities in Phase III.

1.4.3 Phase III:

Implementation of a demonstration project involving the following items: 1) a second iteration through elements of the five contraint areas, particularly to quantify unknowns identified in the first iteration; 2) physically constructing, operating, managing, and monitoring a demonstration recharge operation; and 3) using collected information to plan and design a full-scale recharge project. A closely related purpose is to demonstrate the feasibility of incorporating an artificial recharge function into the design of future water resource projects.

1.4.4 Phase IV:

Construction, operation and management, and monitoring of a full-scale, long-term recharge project, based on the limitations imposed by the five constraint areas. The full-scale project would be evaluated in terms of the economic benefit and long-term utility of recharge technology to achieve conjunctive management of surface and ground-water supplies.

It should be stressed that the progression of a project from Phase I through Phase IV requires that problems arising during each stage are not insurmountable. Thus, a "go" or "stop" decision must be logically reached at the end of each phase.

1.5 Review of Phase I Activities, Phoenix Urban Study

Essentially, the Phase I activities for a recharge project in the Salt River Valley were completed and reported upon as a component of the Phoenix Urban Study prepared by the U.S. Army Corps of Engineers (1977). In that study, the feasibility of conserving floodwaters and other sources in the Phoenix area via artificial recharge techniques was examined. The focus of the study was on two watersheds: the Salt River watershed and the collective group of watersheds comprising the "New River and Phoenix City Streams."

The study was cursory and based upon somewhat tenuous assumptions. Nevertheless, it was concluded tentatively that artificial recharge via basins would conserve only small amounts

of floodwater on the "New River and Phoenix City Streams" flood control project of the U.S. Army Corps of Engineers. In contrast, artificial recharge appeared to be a viable approach for conserving floodwaters along the Salt River.

The reach between Granite Reef Diversion Dam and the Tempe Buttes appears to be particularly suitable for artificial recharge for the following reasons: 1) the channel is normally dry because the upstream structures preclude surface flows in the rivers except for controlled releases; 2) the ground-water table has been markedly lowered in the region because of large pumping drafts; and 3) the river bed is comprised mainly of coarse, boulder-sized deposits ideally suited for infiltration basins. The reach downstream of the Tempe Buttes was not considered to be suitable for artificial recharge because of shallow water tables. Alternate designs for recharge basin systems were included.

The major potential water source for recharge examined in the report was water released from the then proposed Orme Dam, at the confluence of the Salt and Verde Rivers. Based on 86 years of flow data a computer program, HEC-5C, was used to estimate the amount of water available both for recharge and "additional water." "Additional water" is released by SRP into their canals to users with established rights whenever large flows exceed the storage capacity of SRP reservoirs. The total amount of "additional water" plus normal deliveries is limited by the total canal capacity. In the analysis it was stipulated that releases from Orme Dam for recharge and "additional water" would be available only when the reservoir pool at the proposed Orme Dam exceeded 410,010 acre-feet. Two scenarios were examined: 1) giving recharge a priority, 355 cfs (260,000 acre-feet per year) would be used for infiltration, and 79 cfs (68,000 acre-feet per year) for "additional water"; and 2) giving "additional water" priority, 350 cfs (250,000 acre-feet per year) would be available for "additional water." and 93 cfs (68,000 acre-feet per year) for recharge. Although the results of Phase I activities were positive, in view of the number

of assumptions it was recommended that a demonstration recharge project should be conducted along the Salt River.

In a separate report, the Arizona Water Commission (1978) also speculated upon the amount of water potentially available for artificial recharge in the Salt River. As indicated above, the AWC estimates that between 50,000 and 70,000 acre-feet per year of flood water might be available, on the average, for recharge.

2. PHASE II ACTIVITIES: PLAN OF STUDY FOR A DEMONSTRATION RECHARGE PROJECT

This report presents the results of activities conducted during the second phase of a recharge project in the Salt River Valley near Phoenix, Arizona. The general goals of activities during this phase were to evaluate the feasibility of a demonstration recharge project and to present a plan of study to facilitate planning, constructing, and monitoring such a project. Specific objectives were as follows:

1. Determine available information and define data gaps in each of the five constraint areas;
2. Identify specific work tasks to overcome informational gaps in each constraint area and propose alternatives for obtaining information needed to plan a demonstration project;
3. Recommend a sequence of work tasks within the constraint areas for implementing a demonstration project;
4. Estimate a range of costs for accomplishing recommended work tasks to plan and implement a demonstration project;
5. Select and evaluate several alternative demonstration sites within the study area; and
6. Assess the general implications of a full-scale, long-term ground-water recharge program.

Specific study objectives were delineated for each of the five constraint areas (study elements) and are reviewed in detail in subsequent sections of this report.

2.1 General Study Procedures

Evaluating the potential of ground-water recharge requires an interdisciplinary approach. Therefore, an interdisciplinary study team was assembled to provide a comprehensive first iteration through the five respective constraint areas, also referred to as study elements. Each of the study elements was under the

direction of respective work-unit leaders. In order to integrate the recommendations and conclusions of all study elements, periodic review meetings were held to insure the necessary coordination and interaction among respective study team members and work-unit leaders.

An extensive search of available literature in the five study elements relative to artificial recharge was conducted utilizing the Remote Console (RECON) capabilities offered through the University of Arizona's Office of Arid Lands Studies. Throughout the study process additional literature and informational sources were incorporated into the original list of references. The review of existing literature was used to develop a background of information on previous artificial recharge efforts and to identify informational and data gaps which must be satisfied prior to planning and implementing artificial recharge operations within the study area.

Utilization of existing literature precluded unnecessary duplication of effort. It also permitted concentration on the assessment of available information relative to specific study objectives and the identification of apparent informational deficiencies. Such deficiencies were translated into specific recommended work tasks and a suggested time-line sequence and fiscal budget for completing the recommended tasks. The literature search and review effort are documented in the bibliography of this report.

Numerous field trips were conducted in the Phoenix area to review the study area and conduct personal interviews with representatives of various agencies, organizations and other institutions. Such trips were helpful in defining the salient features of the study area and in reviewing and selecting alternative demonstration sites. The personal interview procedure served the dual purposes of defining informational gaps and ascertaining the interests and attitudes of those institutions whose functions relate to the study elements. A detailed list of contacts and personal interviews conducted throughout the study effort is included as Appendix C.

The specific study approach and associated methodology used in the study elements is described in detail in Sections 5 through 9.

2.2 Organization of Report

The ensuing report is organized into the following sections:

1. Section 3, reviews the salient features of the project area, including geomorphologic characteristics, hydrological-water supply features, institutional relationships, and anthropological considerations.
2. Section 4 describes available water sources in the project area, briefly reviewing the quantity and quality of each source.
3. Detailed sections on technical (Section 5), environmental (Section 6), institutional (Section 7), legal (Section 8), and economic (Section 9) considerations, include a) objectives, b) specific study approaches, c) general observations or background information, d) site-specific implications, e) general implications, f) conclusions and recommendations for further activities, and g) estimated costs and time frame for further activities.
4. Section 10 includes designs of alternative recharge methods, including a) preliminary activities, b) planning requirements, c) design and construction, d) operation and management of recharge facilities, e) monitoring, data processing and reporting, f) recommended experiments, and g) estimated budget and time frame.
5. Section 11 is a review of alternative recharge sites, with a description of site characteristics, and site assessment within the five constraint areas.

3. DESCRIPTION OF PROPOSED PROJECT AREA

The general area identified in Phase I for a potential demonstration recharge project and full-scale project, encompasses a 16 mile reach of the Salt River channel and floodplain, extending downstream from the Granite Reef Diversion Dam to the Tempe Butte and Tempe Bridges. Plate 1 depicts the boundaries of the project area as well as a portion of the contiguous land surface. The project area coincides with the so-called "modern" floodplain, as delineated by Burt and Pewe (1978). The plate shows details of the region north and south of the project area including topography, canals, principal thoroughfares, and institutional boundaries.

3.1 Physiography

The project area is within the Salt River Valley, typical of basins in the Basin and Range Physiographic Province. Characteristically, such basins comprise alluvial valleys bounded by mountain blocks. The Salt River Valley is divided into two major basins, designated the East and West Basins, by a series of buttes near Tempe. The buttes run north to south from the Phoenix Mountains to the South Mountain. The proposed project would be entirely within the East Basin. A sub-basin north of the Salt River is designated as Paradise Valley. The sub-basin to the south of the river is called the Chandler Basin (Schmidt, Personal communication 1978).

The elevation in the East Basin ranges from 1200 feet to 3600 feet in the surrounding mountains. The slope in the valley is very gentle (1% to 3% grade) and dips southerly and westerly. From Granite Reef Diversion Dam to the Tempe and Papago Buttes, the Salt River has a slope of 1 to 3%. Vegetation is of the low desert type, with creosote bush predominating. Where ground water is shallow phreatophytes prevail, including: salt cedars, mesquite and cottonwoods. Palo Verde trees are also found in the valley.

3.2 Climate

The Phoenix area has a hot arid climate with an average annual rainfall of 6.5 inches and a potential evaporation rate of 6 feet per year (Sellers and Hill, 1975). The annual average temperature extremes are 114°F to 23°F (taken from data at Granite Reef Diversion Dam). Most of the year's rain occurs in the summer in the form of thunderstorms which produce high intensity, short duration storms. The winter rain is less consistent and results from frontal storms from the Pacific, producing overcast skies and showers. The largest storms are produced in the summer when weak tropical disturbances move northward from the Pacific Ocean and Gulf of Mexico. The following precipitation rates can be expected with a 1% probability:

2.66 inches in 1 hour
2.97 inches in 3 hours
3.35 inches in 6 hours
3.69 inches in 12 hours
4.04 inches in 24 hours (ibid)

3.3 Geomorphology

The entire basin is a bowl-like depression ringed by mountains of igneous, sedimentary and metamorphic rocks. A pediment of intermediate slope and only a few miles in width separates the flat valley from the rugged mountains. It is made up of pediment and alluvial fans that are covered with coarse, weathered debris from the mountains. The coarse sediments near the mountain edge become finer towards the valley. Dry washes originating on the pediment are oriented towards the Salt River. During runoff, most washes lose their flow onto the desert floor before reaching a main channel. Sheet flow occurs during rain events due to the intensity of the storms and the soil types. On the northside of the river the sheet flow is southerly; however, the Arizona Canal embankment catches the flow and heavy vegetation is found growing on the north side of the canal.

Below the Granite Reef Diversion Dam the Salt River is ephemeral due to reservoir storage behind the upstream dams. Any flow now results from floods and/or releases from the dams. There is a low flow channel and floodplain. Both consist of coarse sand, gravel and boulders, deposited during high velocity. The floodplain varies from a few hundred feet in width to three miles at the widest point.

An escarpment below the Mesa Terrace is 20 to 30 feet high. The terrace contains a soil profile overlying the sand, gravel and boulders. Caliche is also found in layers beneath the surface of the terrace. Prior to cutting between the Tempe and Papago Buttes the Salt River flowed southerly to join the Gila River south of the city of Chandler. Because of this meandering and shifting, river gravel deposits are found throughout the valley, especially south of the river.

3.4 Water Supply Agencies

Among the many water management agencies in the Salt River Valley, the principal agency is the Salt River Project (SRP). The SRP comprises two distinct legal entities: the Salt River Project Agricultural Improvement and Power District (SRPAIPD) and the Salt River Valley Water Users Association (SRVWUA). The initial organization of the project was the SRVWUA, established in 1903, in response to the Federal Reclamation Act of 1902. The original Assocation comprised 4800 landownders banding together for federal assistance under the Act to construct storage reservoirs on the Salt River. An agreement between the SRVWUA and the federal government was entered into in 1904. Construction of Roosevelt Dam (now called Theodore Roosevelt Dam) was started in 1905 and completed in 1911. Granite Reef Diversion Dam was started in 1906 and completed in 1908.

All landowners of the Association were deemed to have equal rights to stored water and pumped ground water. Older rights to water flowing in the Salt and Verde Rivers were adjudicated under the Kent Decree of 1910 (see Section 8). According to the decree,

landowners using water for beneficial purposes during the period 1869 through 1909 were entitled to "normal flow water" pursuant to the chronological order in which rights were obtained. Entitlement to normal flow water is over and above rights to stored water and today certain lands still obtain "additional water" (see Section 8).

The project was operated by the United States Reclamation Service (predecessor of the U.S. Bureau of Reclamation) until 1917, when the Association assumed operational responsibilities. In 1937 the Salt River Project Agricultural Improvement and Power District (SRPAIPD) was established to secure the rights, privileges, exemptions, and immunities granted political subdivisions in Arizona. Thus, the SRPAIPD is a municipal corporation, whereas the SRVWUA is an Arizona corporation. Establishment of the District facilitated refinancing outstanding Assocation bonds. Subsequently, all Association properties were transferred to the District, although the Association continued to operate the Project. In 1949 the initial contract establishing the District, was amended to permit the District to operate the electrical system, with the Association managing and providing "...water resources to the lands appurtenant to the shares held by members of the Association within the boundaries of the Salt River Valley Reservoir District" (Staff, Arizona Groundwater Management Study Commission, 1978).

The principal dams managed by the SRP on the Salt River together with storage capacity are: 1) Theodore Roosevelt Dam, 1,381,580 ac-ft; 2) Horse Mesa Dam, 245,138 ac-ft; 3) Mormon Flat Dam, 57,582 ac-ft; and 4) Stewart Mountain Dam, 69,765 ac-ft. On the Verde River, the two dams are: 1) Horseshoe Dam, 139,238 ac-ft, and 2) Bartlett Dam, 178,477 ac-ft. It should be noted that these structures are designed principally for water storage and <u>not</u> for flood control. Granite Reef Diversion Dam, located on the Salt River downstream of the confluence of the Salt and Verde Rivers, is used to divert water into the Arizona and South Canals.

The SRP water delivery system includes 131 miles of canals (of which 61 miles were lined as of 1977); 878 miles of laterals (726 miles lined or piped) and 250 miles of drainage ditches

(55 miles lined or piped). The project owns about 250 deep wells, supplementing surface water. In 1977 the total volume of water delivered through the SRP system was 910,506 ac-ft; of this amount 591,830 ac-ft. was derived from reservoir storage and 318,676 ac-ft. from wells (Salt River Project, 1978).

As shown on Plate 1, the Arizona Canal transports water from the Granite Reef Diversion Dam to project lands and municipal customers north of the Salt River. The South Canal delivers water to project lands and municipal customers south of the river. The Arizona Canal supplies Tempe with surface water via a lateral canal, the New Cross-Cut Canal. Lateral canals extending from the South Canal include the Roosevelt Water Conservation District Canal; the Eastern Canal; the Consolidated Canal; and the Tempe Canal.

The Salt River Indian Irrigation Project obtains SRP water from the Arizona Canal, via diversion works at the Evergreen Wasteway, for irrigation of lands south of the Canal. Indian land north of the Canal is exterior to the SRP delivery area and water is derived entirely from wells.

The second major water purveyor in the area is the Roosevelt Water Conservation District (RWCD), bounded by the Roosevelt Water Conservation District Canal and the Eastern Canal. The main pumping plant of the RWCD lifts water from the South Canal into the RWCD Canal for irrigation of land in the district.

Other water supply agencies in the area shown on Plate 1 include those associated with the principal municipalities of Tempe, Scottsdale and Mesa. In 1977, Tempe pumped 3,620 ac-ft. of ground water, and received about 22,600 ac-ft. of water from the SRP system (Staff, Arizona Groundwater Management Study Commission, 1978). During 1977, Scottsdale pumped 8,846 ac-ft. of ground water, with no SRP water augmentation (ibid). The City of Mesa pumped 17,185 ac-ft. in 1977, and obtained 12,975 ac-ft. of surface water from the SRP system. The City of Mesa treats about 30% of its sewage, with 70% being treated at the 91st Avenue treatment plant in Phoenix. Treated wastewater from the Mesa plant is sold to a

nearby farmer for use in irrigation. Sewage from Tempe and Scottsdale is treated entirely in the 91st Avenue plant.

3.5 Institutions

There are seventeen cities and towns within the Phoenix metropolitan area. Of these, Mesa, Scottsdale, Phoenix, Tempe, and possibly Chandler and Gilbert would be the most directly impacted by both demonstration and full-scale projects located in the proposed recharge area. The Salt River-Pima-Maricopa Indian Community is a major landowner in the area, and will be significantly involved in most recharge operations. Several federal, state and local water and land management agencies are also likely to be interested in or directly impacted by projects in the proposed recharge area. These entities include: the U.S. Bureau of Reclamation, the U.S. Bureau of Land Management, the Arizona Water Commission, the Arizona State Land Department, the Arizona Groundwater Management Study Commission, the Maricopa County Flood Control District, the Salt River Project, and the Roosevelt Water Conservation District. In addition to the impact of a recharge project on public institutions, individuals owning wells would also be affected.

3.6 Environmental-Archaeological Factors

A number of active and abandoned sanitary landfills are located along and within the Salt River channel. These landfills include those which are, or have been, managed by the Salt River-Pima-Maricopa Indian Community.

Numerous archaeological sites are also located along the Salt River channel.

4. WATER SOURCES

The principal water sources in the project area are listed in Table 4-1. Also included in the table is a selection of the potential sources which would be most suitable for a full-scale recharge project and for a demonstration recharge project, respectively. The selection of sources for a full-scale project is based on the premise that a large quantity of water should be recharged over a prolonged period of time. Similarly, for a demonstration project, sources available on a prolonged basis would be most desirable. However, as discussed in Section 10, a demonstration project could comprise two sites: a primary site near a continuous water source and a secondary source used to recharge periodic sources.

Salient features of the more important sources are discussed below:

4.1 Flood Water

Controlled flood waters are available in the project area from two possible sources: 1) spillage over Granite Reef Diversion Dam, and 2) releases into four wasteways: the Evergreen Drain, the Indian Bend Drain, the Hennessey Drain, and the Tempe Drain. The locations of these sources are shown on Plate 1. Spillage over Granite Reef Diversion Dam occurs when water is released from the upstream control structures on the Salt and Verde Rivers (see Section 3.4) to provide storage for snowmelt and rainfall runoff. Sheet flow and wash flows discharging into the Arizona and South Canal are diverted to the Salt River in the four wasteways. For example, such flows originating on the Salt River-Pima-Maricopa Indian Reservation discharge into the Arizona Canal at several locations between the diversion headworks to the reservation irrigation system, and Granite Reef Diversion Dam. To avoid overflowing the canal, water is diverted to the Salt River through the Evergreen Drain.

TABLE 4-1

Water Sources in the Project Area

AGGREGATION OF WATER SOURCES IN PROJECT AREA	POTENTIAL WATER SOURCES FOR A FULL-SCALE RECHARGE PROJECT	POTENTIAL WATER SOURCES FOR A DEMONSTRATION RECHARGE PROJECT
Controlled releases of Salt and Verde River Water from upstream reservoirs during flooding periods.	Controlled releases of Salt and Verde River Water from upstream reservoirs during flooding periods.	Controlled releases of Salt and Verde River water from upstream reservoirs to provide flood control storage.
Controlled releases of Salt and Verde River water from upstream reservoirs to provide flood control storage.	Controlled releases of Salt and Verde River water from upstream reservoirs to provide flood control storage.	Sewage effluent.
Sewage effluent.	Colorado River water released through Central Arizona Project facilities.	Irrigation tail water.
Urban runoff.		Ground water.
Irrigation tail water.		
Colorado River water released through Central Arizona Project facilities.		
Ground water.		

Data on the volumes of water released to the Salt River as overflow from Granite Reef Diversion Dam and the four wasteways during the period 1913-1977 are presented in Table 5-2 (Courtesy: Salt River Project). As pointed out in Section 5 total releases ranged from 0 acre-feet (AF) in water year 1962, to 1,245,510 AF in 1973. The average flow for 65 years of record was 82,000 AF, but because of the variability of releases from year to year, this average value is not meaningful. Note also that in 67 years only 96 releases were reported for a total of 899 days; moreover, releases occur during short periods and peak discharge rates may be high (see Table 5-3).

In addition to the above technical constraints on using flood water in a demonstration project, there may be legal control as a consequence of the Kent Decree. A discussion of this decree can be found in Section 8.

In view of the uncertain availability of flood water, the short duration of flood events, and legal uncertainties, this source is not suitable for a primary demonstration project. However, abandoned gravel pits could be used as secondary sites to recharge periodic flood waters, provided there are no legal impediments.

In a cooperative effort, the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation are currently evaluating alternatives for flood control in the Phoenix metropolitan area. Among the options being considered by these agencies for flood control on the Salt and Verde Rivers are the following (U.S. Bureau of Reclamation, 1979):

1. Roosevelt Dam and Lake. Raise Roosevelt Dam to provide additional reservoir space on the Salt River primarily for flood control.
2. Horseshoe Dam and Reservoir. Replace the existing Verde River structure with a larger dam to provide additional space, primarily for flood control.
3. Tangle Creek Site Dam and Reservoir. Construct a new dam on the Verde River upstream from Horseshoe Reservoir, primarily for flood control.

4. Cliff Site Dam and Reservoir. Construct a new dam on the Verde River about 2 miles downstream from Horseshoe Dam. This new reservoir would incorporate the existing storage in Horseshoe Reservoir but would provide additional capacity, primarily for flood control.
5. Confluence Site Dam and Reservoir. Construct a dam at the confluence of the Salt and Verde Rivers. This structure could be the proposed Orme Dam or a modified version, to provide CAP regulatory storage and/or flood control.
6. Granite Reef Site Dam and Reservoir. Construct a dam about 4 miles downstream from the confluence on the Salt River at Granite Reef Diversion Dam to provide both regulatory storage and/or flood control. This is primarily an alternative location of the confluence site.
7. Flexible Reservoir Operating Guidelines. Develop a set of procedures for more sophisticated flood forecasting and Salt River Project reservoir operation which attempt to further minimize downstream flood damage.

If and when one or more of these options is implemented, artificial recharge could be used to effective advantage as a method for disposition and conservation of captured flood water.

4.2 Controlled Releases from Upstream Reservoirs

Besides releasing water from upstream reservoirs to provide flood storage, water could be released specifically for a demonstration or full-scale recharge project. In view of the legal foundation of current Arizona water law on which the Salt River Project operates ("the water belongs to the land"), this approach is currently infeasible.

4.3 Ground Water

The suggestion that ground water could be used in a demonstration recharge project appears at first glance to be contradictory. Obviously, pumped water would not be a cost-effective source. Thus, only a fraction of the water would be returned to the source aquifer.

The remaining fraction would be held back, in storage, within the vadose zone, or be lost by evapotranspiration. However, it should be noted that these costs and water losses must be balanced against the information gained from operating a demonstration, experimental facility. In particular, valuable data could be gained for designing, implementing, and managing a full-scale project in a sound technical fashion.

Ground water could be obtained for a demonstration recharge project either by drilling a well specifically for the project, or by contracting for ground water from a water service agency. Installing and operating a well could be extremely costly and may be precluded by state regulations. The second alternative would probably entail buying ground water from the Salt River Project.

Inasmuch as SRP water cannot legally be used on off-project lands, it would be necessary to employ the following procedure: 1) pump ground water from a SRP well on off-project lands and transport pumped water in project canals to a diversion point, and 2) convey an equivalent quantity of water to off-project lands on which the demonstration project is located. In the above scenario it is presumed that a structure would be available to convey water to the project site. Such a structure could comprise an existing wasteway (e.g. the Evergreen Wasteway) or a specifically constructed canal or pipeline (see Section 10). Implementation of this scheme would require authorization from the Board of Directors of the Salt River Project.

4.4 Central Arizona Project Water

Three alternatives are possible for procuring Central Arizona Project (CAP) water for a demonstration project: 1) contractually purchasing CAP water, 2) diverting water from storage facilities on the Colorado River, and 3) using CAP water contracted for by the Salt River-Maricopa Indian Community in a joint recreation-recharge project.

4.4.1 Contractual Procurement of CAP Water

Water could be purchased from the U.S. Bureau of Reclamation for a demonstration project if sufficient interest in and support for a demonstration project is generated among appropriate state and local agencies (Burbey, personal communication, 1978). In order to obtain CAP water, the allocations would need to be re-adjusted to accommodate water demands of a recharge project. Such a reallocation would require an initiative by state and local agencies expressing a strong interest in the use of CAP water for recharge purposes. Two state and local agencies would be involved in the reallocation of CAP waters. The Arizona Water Commission, as a state agency, serves in an advisory role on behalf of the Governor of Arizona to recommend allocation of CAP waters to the U.S. Secretary of the Interior, who has the ultimate authority for water allocation and contract administration for the Central Arizona Project. The Secretary is represented in such administrative functions by the U.S. Bureau of Reclamation. The Central Arizona Water Conservation District (CAWCD) - a special purpose district established by Arizona statute for the purpose of contracting for and providing repayment of CAP water as required by the federal reclamation act - serves as a local, multi-county water service agency providing for revenue collection to repay CAP project costs. The CAWCD will contract for water delivered by the Bureau of Reclamation through CAP facilities and function as a water service agency to users of CAP waters. It is possible through statutory provisions that the CAWCD could serve as the sponsoring and management agency for a full-scale recharge project.

A three party contract would be entered into when allocating water for a recharge project: 1) the Department of Interior, represented by the U.S. Bureau of Reclamation, 2) the Central Arizona Water Conservation District, and 3) a "user agency" comprising the action agency responsible for implementing the recharge project.

4.4.2 Diversion of Surface Water from Storage Facilities on the Colorado River

An alternative mechanism for obtaining water via the CAP aqueduct system comprises obtaining overflow water from control structures (i.e. Lake Mead and Lake Powell) on the Colorado River. Such spills would occur during periods of excessive runoff. Generally, this option exists mainly for water users along the Colorado River (Burbey, personal communication, 1978). However, CAP water users could obtain surplus water stored in Lake Mead by paying pumping costs to lift water into the CAP aqueduct. Such costs could amount to $25 to $30 per acre foot (ibid), considerably more than costs to obtain ground water from SRP.

This supply would be available only at infrequent intervals; flow rates would be high; periods of availability would be of short duration, and legally the water would be subject to CAP allocation. Consequently, this source would be inappropriate for a demonstration project.

4.4.3 Use of CAP Water in a Joint Recreation - Recharge Project

CAP water could be delivered to the Salt River-Pima-Maricopa Reservation via a delivery system from Granite Reef aquaduct for a joint recreation-artificial recharge project on the reservation. The site or sites would be located north of the Arizona Canal. Representatives of the tribe have expressed an interest in such a possibility. In this case CAP water would be obtained under the Salt River-Pima-Maricopa Indian allocation. Water costs would be assessed proportionately against the recreation and recharge elements.

4.4.4 Comments

CAP water will not be available in the vicinity of the general project area until 1985. Consequently, CAP water is not a viable source for a demonstration recharge project at this time. In addition, CAP water could be relatively high in total salt content, with undesirable levels of sulfate. However, CAP water remains a potential source for a full-scale, long-term recharge program subject to contracting and other legal provisions involved with

CAP water allocations.

4.5 Sewage Effluent

The only source of sewage effluent for a demonstration recharge project in the project area is the Mesa Sewage Treatment Plant. Investigations using this source would essentially duplicate land treatment studies by Bouwer and associates (U.S.D.A. Water Conservation Laboratory) at the Flushing Meadows and 23rd Avenue spreading sites located in Phoenix, Arizona. Wastewater receives secondary treatment at the Mesa plant by a trickling filter. Currently, treated effluent is sold to a neighboring farmer for irrigation use, or discharged to drying-percolation beds. The quantity of effluent is approximately two to three million gallons per day (mgd). The quality of effluent is unknown, but presumably EPA and State water quality standards are satisfied. Effluent could be a source of undesirable levels of nitrogen, bacteria, virus, and refractory organics. A monitoring program would be mandatory if this source were used in a demonstration project.

4.6 Irrigation Tailwater

Tailwater from irrigation on the Salt River-Maricopa Indian Reservation could be used in a demonstration project. Presently, several ponds are used on the reservation to collect tailwater which is then pumped back into the delivery system. However, in some areas, such as near Evergreen Wash, uncollected tailwater discharges toward the river. The quantity and quality of irrigation tailwater from this source is undetermined.

5. TECHNICAL CONSIDERATIONS

From a technical viewpoint the development of plans for artificial recharge in a ground-water basin comprises the following two basic stages: 1) examining the regional hydrogeology of the entire basin, and 2) obtaining specific hydrogeological data at alternative sites within the basin. Insight gained from the first stage aids in estimating the overall feasibility of artificial recharge in the basin and facilitates locating alternative sites for a project. Activities during the second stage lead to the final selection of a site. In practice the activities during these stages would be correlated with parallel programs in other constraint areas: legal, institutional, economic and environmental.

The purpose of this section is to review elements of the first stage. The East Basin is the generalized ground-water basin of interest with respect to artificial recharge and the project area is defined on Plate 1. The second stage would be conducted during a demonstration recharge project.

Specific objectives of this section are to 1) inventory known information sources on the hydrogeology of the East Basin and project area, 2) define data needs to facilitate selecting a recharge site, and 3) suggest approaches for collecting additional data during the third stage, together with budgetary requirements and an estimated time line.

5.1 Study Approaches

The inventory of known hydrogeological information in the East Basin and project area entailed 1) reviewing published references, 2) contacting agencies and individuals with experience in the area, and 3) conducting field trips.

Initially a RECON search was conducted for an annotated bibliography of ongoing research efforts in the area. Papers published by workers with the United States Geological Survey were reviewed, including 1) Anderson (1968); 2) Arteaga, et al. (1968); 3) Babcock

(1975); 4) Briggs and Werho (1966); 5) Laney, et al. (1978); 6) Lee (1905); 7) McDonald, Wolcott and Bluhm (1947); and 8) Schumann (1974). Other important references included 1) Adams (1974); 2) Arizona Water Commission (1978); 3) Thiele (1961); 4) Thiele (1965); 5) the United States Environmental Protection Agency (1970); and 6) the United States Bureau of Reclamation (1976).

Individuals with competency in water-related subject areas were contacted for assistance in answering the following questions: 1) what do we know about the hydrogeology in the East Basin in general and the project area in particular; 2) what do we need to know (i.e., what are the data gaps); and 3) how should we procede to overcome information deficiencies, in order to plan a demonstration and full-scale recharge project? Specific individuals contacted are listed in Appendix C. Associated agencies included: 1) the United States Geological Survey, Phoenix and Tucson offices; 2) the Soil Conservation Service, Phoenix; 3) the Water Conservation Laboratory, Tempe; 4) the Salt River Project, Tempe; 5) the Arizona Water Commission, Pheonix; 6) the Arizona State University; 7) Arizona State Land Department, and 8) Arizona Department of Health Services.

Several field trips were made to assess the geology and geomorphology of the project area and potential recharge sites.

5.2 Hydrogeological Features of the East Basin and the Project Area

5.2.1 Geology

5.2.1.1 General

The evolution of the East Basin parallels that of other structural basins in the Basin and Range Physiographic Province of Arizona. As described in a recent report of the U.S. Bureau of Reclamation (1977), the outline of this province was apparently formed by regional warping and large scale normal faulting during middle Tertiary time. Thick deposits of conglomerate, sandstone

and volcanic rocks accumulated during this period. Further evolution of the basins is described in the U.S. Bureau of Reclamation (ibid) report:

> Continued differential uplift and subsidence accompanied by normal faulting that probably extended into Pliocene time accentuated the early Basin and Range features. Alluvial and lacustrine-playa type "valley fill" deposits, comprising the effective central Airzona ground water reservoirs, began to accumulate on the dissected middle Tertiary rocks. Uplift and erosion continued into the Quaternary with alternating periods of subsidence and deposition with accompanying volcanic activity....The magnitude and periods of uplift or subsidence, the effect of this movement on existing drainage patterns, and contemporaneous volcanic activity have determined the vertical sequence and lateral variations of "valley fill" deposits in any one basin or group of basins. The type of drainage that existed during the "filling" process, major or tributary, interior or through flowing, also is a major determinant of the geologic framework of any one basin.

Pediments are apparent at the base of mountain fronts as small bedrock masses projecting through thin deposits of alluvium. The pediments change abruptly into steep scarps at fault boundaries.

Gravity surveys in the "Paradise Valley-Chandler-Queen Creek Subarea" of the Central Arizona Project (ibid), indicate a principal structural basin, east of Chandler, with an elongated trough extending eastward. In Paradise Valley, a narrow north-northwesterly extending trough, with two gravity lows, was observed. The thickness of layered sediments in the area varies from 0 feet near the mountains to as much as 10,000 feet in the structural trough east of Chandler. In the Valley, numerous wells have been constructed to 1500 feet without contacting bedrock. In Paradise Valley an oil well reached bedrock at 5150 feet (ibid).

5.2.1.2 Soils

5.2.1.2.1 General

The soils of the East basin have been classified into six soil associations. A soil association is a group of soils that are arranged in a distinctive pattern with set proportions of each soil. The name of the association is derived from the major soil type. The six associations found in the area are Rock Land; Antho-Valencia,

Laveen, Mohall-Contine, Gilman-Estrella-Avondale and Alluvial Land. The Rock Land Association, which comprises 10% of the land area, occurs along the edges of the mountains and buttes where the slopes are steep. It is made up of Rock outcrops and shallow gravelly soil over bedrock. In this association a soil horizon is thin or absent and runoff is rapid because of the low infiltration capacity. The Antho-Valencia, Laveen, Mohall-Contine, and Gilman-Estrella-Avondale are well drained loam soils on gently sloping (0-3%) land. The Antho-Valencia Association, which makes up 11% of the area is on alluvial fans. The antho soils are sandy or gravelly loams of depth of 40 inches or more. The Valencia usually has a layer of sandy loam followed by a clay loam layer and then another sandy loam layer. These soils are used for cultivation and as a source for road fill and sub grade. Soils of the Laveen Association are on the old alluvial fans and terraces and occupy 15% of the area. They are a mixture of gravelly sandy loams and calcareous loams with a surface layer of clay loam or brown loam followed in depth by a layer of loam containing greater than 15% lime. The Mohall-Contine Association is on 29% of the area and rests on the old alluvial fans. This is a clay loam or sandy clay loam which usually has a lower layer of calcium carbonate. The Gilman-Estrella-Avondale Association, which occupies 33% of the area, is in the flood plains and alluvial fans on nearly level surfaces. It consists of loams and clay loams. The Alluvial Land Association only makes up 2% of the area and is an extremely well drained gravelly sand and boulder alluvium in the stream channels and channel lowlands. The area is used as a source of sand and gravel and is poorly vegetated (Adams, 1974).

A general transect of soils from the mountains to the river would include: 1) Rock Land in the mountains, buttes and along their pediments; 2) Antho-Valencia on the alluvial fan, toward the river; 3) Mohall-Contine on the older fans; 4) Laveen on the terrace above the flood plain; 5) Gilman-Estrella-Avondale in the flood plain; and 6) alluvial land association in and near the

channel (Adams, 1974). Excluding the area near the mountain edges and in the river channel and low area, most of the basin soils have a calcareous deposit in the subsurface layer that has a high degree of cementation. Layers of carbonates continue to be seen at lower levels in the vertical profiles of wells (Lee, 1905).

5.2.1.2.2 Soils of the Project Area

The main soil type in the project area is the Alluvial Land which lies in the channel and floodplain. Its texture varies from silts and clay to cobbles and boulders, with cobbles and coarse sand on the surface. The soils that border the floodplain are: 1) Antho sand loam; 2) Avondale clay loam; 3) Carrizo fine sandy loam; 4) Carrizo gravelly loamy sand; 5) Gilman loam; 6) Gilman fine sandy loam; 7) Pinant very gravelly loam; 8) Pimer clay loam; and 9) Vint loamy fine sand.

5.2.1.3 Stratigraphy

5.2.1.3.1 General

Generally there are two major stratigraphic divisions in the basins of the Basin and Range Province: the undifferentiated basement complex, and late Tertiary to Recent valley-fill deposits (U.S. Bureau of Reclamation, 1977). The basement complex, constituting the base of the valley fill and surrounding mountains, contains Precambrian granite, gneiss, and schist; intrusive granites and extrusive volcanic flows; and middle Tertiary and older sedimentary rocks. Only the middle Tertiary sedimentary and volcanic rocks are potential ground-water sources, where saturated.

The classification of units in the valley-fill deposits of the East Basin is presently undergoing revision (Laney, Personal communication, 1978). A classification adapted by the U.S. Bureau of Reclamation (1977) includes three units. In successive depths, these units are: 1) the Upper Alluvial Unit; 2) the Middle Fine-Grained Unit; and 3) the Lower Conglomerate Unit. For purposes of discussion the U.S. Bureau of Reclamation system will be used in this report.

In general, the Lower Conglomerate Unit, of middle to late Tertiary age, is a dark reddish brown and is composed of conglomerate breccia, sandstone and gypsiferous clay. Pebble and cobble-size fragments found in the formation reflect the local sources, such as granite or volcanics. This formation, which presumably underlies most of the basin, is moderately deformed and crops out along the edge of the East Basin, such as the Papago Buttes. The conglomerate varies in thickness from 0 feet near outcrops to 2,000 feet or more at the deeper portions of the valley (U.S. Bureau of Reclamation, 1977).

The red comglomerate is overlain by a gray conglomerate of the Middle Fine-Grained Unit, near the mountain fronts, and by the lower evaporite section of the Middle Fine-Grained Unit in the center of the basin. The Middle Fine-Grained Unit resulted from internal drainage conditions caused by middle to late Tertiary normal faulting and volcanic activity. The volcanic activity created lacustine-playa deposits (ibid.). The unit is composed of interbedded deposits of sand, silt and clay and some evaporites. The unit can be subdivided vertically into two principal zones; an upper zone containing somewhat coarser material, and a lower zone containing fine-grained material and massive evaporites. The upper zone contains silt, sand, gravel and cemented conglomerates. The zone is gray where the material is coarse, and blue, green, brown or gray where it is fine-grained. The bottom of the zone is gypsiferous where it grades into the lower zone. The lower zone of this unit contains massive deposits of gypsum and halite and contains ground water of poor quality. This zone is dark brown to reddish brown and has some andesite and basaltic flows in the lower section (Laney, Personal communication, 1978). Laterally the Middle Fine-Grained Unit varies from a moderately cemented gray conglomerate near the mountain front; into coarser-grained material near the edge of the basin; thence into fine silty material near the center of the basin. The thickness of the Middle Fine-Grained

Unit varies from about 200 feet to a few thousand feet (Laney, Personal Communication, 1978).

The Upper Alluvial Unit may be separated into an upper zone and a lower zone. The upper zone is tan to brown in color, and comprises unconsolidated sand, gravel and boulders. The thickness of the upper zone varies from 0 feet to 300 feet. In the project area alluvium of this unit was deposited by the Salt River. The lower zone is brown to light reddish brown in color, consisting of unconsolidated and semi-consolidated silt, sand, gravel and boulders. The thickness of the lower zone varies from 200 feet to 800 feet (Laney, Personal communication, 1978).

5.2.1.3.2 Stratigraphy in the Project Area

The present state of knowledge of subsurface geology along the river channel is rather sketchy, being based on observations of outcrops and on drillers' logs. Drillers' logs are generally not particularly quantitative, but are useful in identifying the extent of course and fine-grained material, caliche, cementation, and bedrock. Downstream for about a mile from Granite Reef Diversion Dam, there are outcrops of granite along the Salt River channel. The alluvium in the adjoining hills and the outcrops in the stream end abruptly, suggesting the presence of a fault escarpment. The river channel lies on top of the Upper Alluvial Unit, which is mainly coarse grained.

A geological section, located on a left to right diagonal across TIN, R5E is reported by the U.S. Bureau of Reclamation (1977). The section intersects the Salt River a short distance downstream of Mesa. According to information on the section, it appears that the Middle Fine-Grained Unit is completely missing beneath the river. In particular, the Upper Alluvial Unit contacts the lower conglomerate Unit at a depth of about 800 feet. Near Tempe there is a sharp break in strata where coarse river material was deposited on top of fine material. The break corresponds to the base of the upper zone within the Upper Alluvial Unit. Bedrock crops out in the vicinity of the Tempe and Papago Buttes.

5.2.2 Hydrology

5.2.2.1 Surface Hydrology

The total watershed area of the Salt River and its principal tributary, the Verde River, is 12,000 square miles. The headwaters of these rivers are along the Mogollen Rim. As pointed out in a previous section, the series of dams on the rivers preclude normal flow in the Salt River downstream of Granite Reef Diversion Dam. Water behind Granite Reef Diversion Dam is shunted into the Arizona and South Canals. Occasionally such diversions are unable to cope with the flows arriving from upstream dams and spillage occurs over the dam. In addition to such spillage, surface water also reaches the river channel via drains. In the project area, defined on Plate 1, the principal drains are the Evergreen drain, the Hennessy drain, the Tempe drain, and the Indian Bend drain.

Combined diversions to the Salt River from Granite Reef Diversion Dam and the system of drains, during water years 1913 through 1977, are shown on Table 5-1 (Courtesy: Salt River Project). Total discharges arranged in ascending order of magnitude for the same period are shown on Table 5-2 (Courtesy: Salt River Project). Note that the total flows ranged from 0 acre feet (AF) in water year 1962, to 1,245,510 AF in 1973. Wide differences in flow have occurred from year to year. For example, in 1941 the total discharge was 915,487 AF but only 1076 AF in 1942. Also note the prolonged high flow (flows less than 10,000 AF) period from 1913 through 1923, and the extensive dry period (flows less than 10,000 AF) from 1941 through 1964. The average flow for 65 years of record was 82,000 AF. Inasmuch as flows are so variable this average figure is not particularly meaningful. Thus flows in excess of 82,000 AF occurred only 16 times in 65 years.

Peak discharges, in cubic feet per second (cfs), below Granite Reef Diversion Dam during the period 1911 through 1978 are summarized on Table 5-3. Values of the total number of releases and total days of discharge are also included. The greatest peak discharge during the period was 113,000 cfs in 1978 and the lowest

was 1000 cfs in 1973. The total number of releases over the dam was 96, for a total of 899 days. There were no releases during the prolonged dry period 1941 to 1965.

TABLE 5-1

TOTAL DIVERSIONS AND/OR FLOW TO THE SALT RIVER IN ACRE FEET, 1913-1977

(Courtesy Salt River Project)

Year	Grand Wasteway	Ever-green Drain	Hennessey Drain	Tempe Drain	Indian Bend Drain	PH. #2 Wasteway	San Francisco Waste-way	Total to Salt River
1913		610	11,100	0	0	-	-	11,710
1914		0	11,200	0	0	-	-	11,200
1915		7,100	78,500	0	0	-	5,680	91,280
1916	6,970	26,300	80,200	0	0	-	0	113,470
1917	50,300	2,770	46,500	0	0	-	0	99,570
1918	33,400	0	12,500	0	7,600	-	0	53,570
1919	68,800	9,530	50,400	0	0	-	0	128,730
1920	221,000	5,670	76,000	0	0	58,000	0	360,670
1921	94,000	0	14,400	0	0	518	1,958	110,876
1922	133,000	229	43,300	0	0	2,300	11,600	190,429
1923	64,200	0	13,000	0	0	1,150	9,460	87,810
1924	38,800	869	0	0	4,460	1,810	6,510	52,449
1925	3,010	1,260	61	0	845	0	**	5,176
1926	25,900	5,000	8	15	1,110	1,290		33,323
1927	66,700	7,810	0	2,160	920	-		77,590
1928	15,300	685	0	0	2,240	**		18,225
1929	374	1,040	99	0	0			1,513
1930	2,650	1,740	684	0	77			5,151
1931	8,670	5,190	701	1,060	48			15,669
1932	46,500	2,670	1,010	11,700	125			62,005
1933	22	404	197	0	0			623
1934	334	853	0	0	17			1,204

TABLE 5-1
(continued)

Year	Below Granite Reef	Ever-green Drain	Hennessey Drain	Tempe Drain	Indian Bend Drain	Total to Salt River (ac-ft)
1935	88,977	1,287	1,154	275	-	91,693
1936	7,452	1,438	443	0	-	9,333
1937	407,930	3,318	2,052	1,715	114	415,129
1938	210,909	915	341	65	478	212,744
1939	2,578	1,547	314	0	6,332	10,771
1940	11,621	1,388	770	314	3,219	17,312
1941	880,213	11,268	9,693	13,930	383	915,487
1942	154	0	557	365	0	1,076
1943	3,629	1,101	712	131	1,759	7,332
1944	966	226	40	309	0	1,541
1945	1,420	557	46	0	22	2,045
1946	1,793	268	22	0	244	2,327
1947	704	0	28	0	0	732
1948	196	0	0	0	0	196
1949	1,581	1,036	332	0	89	3,038
1950	1,469	0	0	0	58	1,527
1951	16,347	560	216	234	3,154	20,511
1952	3,243	488	177	0	42	3,950
1953	86	0	0	0	0	86
1954	3,686	1,156	0	0	557	5,399
1955	5,899	902	452	111	593	7,957
1956	58	0	0	0	0	58
1957	2,000	0	0	0	0	2,000
1958	792	688	78	78	28	1,664

TABLE 5-1
(continued)

Year	Below Granite Reef	Ever-green Drain	Hennessey Drain	Tempe Drain	Indian Bend Drain	Total to Salt River (ac-ft)
1959	17,122	601	0	0	446	18,169
1960	5,002	0	0	0	0	5,002
1961	397	0	0	0	0	397
1962	0	0	0	0	0	0
1963	942	518	128	0	0	1,588
1964	7,005	665	0	0	115	7,785
1965	195,700	0	0	0	0	195,700
1966	380,371	506	0	38	619	381,534
1967	11,719	1,054	290	105	1,093	14,261
1968	106,466	716	87	80	0	107,349
1969	180	0	0	0	0	180
1970	0	0	280	0	0	280
1971	79	86	0	0	117	282
1972	75,379	1,591	246	123	800	78,139
1973	1,241,232	2,903	0	1,369	6	1,245,510
1974	815	443	0	74	101	1,433
1975	397	290	28	26	169	910
1976	2,098	1,208	62	63	869	4,300
1977	0	161	81	0	0	242
1978						

* Data are for water year, October through September
** Wasteway abandoned in 1926
*** No records after December 1924

TABLE 5-2

TOTAL DISCHARGES TO SALT RIVER

IN ACRE-FEET IN ORDER OF MAGNITUDE

(Courtesy Salt River Project)

Years 1913 - 1977 Inclusive

Year	Total Discharge	Year	Total Discharge
1962	0	1936	9,333
56	58	39	10,771
53	86	14	11,200
69	180	13	11,710
48	196	67	14,261
70	208	31	15,669
77	242	40	17,312
71	282	59	18,169
33	623	28	18,225
47	732	51	20,511
75	910	26	33,323
42	1,076	24	52,449
34	1,204	18	53,570
74	1,433	32	62,005
29	1,513	72	78,139
50	1,527	23	87,810
44	1,541	15	91,280
63	1,588	35	91,694
58	1,664	17	99,570
57	2,000	68	107,349
45	2,045	21	110,876
46	2,327	16	113,470
49	3,038	19	128,730
52	3,950	22	190,429
76	4,300	65	195,700
60	5,002	38	212,744
30	5,151	20	360,670
25	5,176	66	381,534
54	5,399	37	415,129
43	7,332	41	915,487
64	7,785	73	1,245,510
55	7,957		

Table 5-3

TABLE OF SIGNIFICANT WATER RELEASES
BELOW GRANITE REEF DIVERSION DAM

In Cubic Feet Per Second

(* Indicates Largest of Two or More Releases)

Year	Peak Flow	Dates	Total Releases	Total Days
1911	(ROOSEVELT DAM-ROOSEVELT LAKE)		0	0
1912			0	0
1913	3,700 cfs	Feb. 26-Mar. 16*, Mar. 24-25, Apr. 1-9	3	30
1914	15,700 cfs	Jan. 28-30, Feb. 19-Mar. 1,* Dec. 19-26	3	21
1915	18,700 cfs	Jan. 30-Feb. 6*, Feb. 12-23, Mar. 18-Apr. 6, Apr. 18-May 24, Aug. 27, Sept. 3, Dec. 31	7	80
1916	79,100 cfs	Jan. 16-May 15*, Sept. 9-12, Oct. 8-10	3	128
1917	23,100 cfs	Jan. 21-Feb. 2, Feb. 24-Mar. 7, Apr. 18-May 1*	3	39
1918	28,400 cfs	Feb. 26-28, Mar. 8-16*, Aug. 7-13	3	19
1919	46,200 cfs	Feb. 2-3, Mar. 28-Apr. 4, Jul. 14-22, Aug. 2-4, Nov. 26-Dec. 3*	5	30
1920	87,800 cfs	Jan. 5-9, Feb. 9-16, Fib. 20-Apr. 16*	3	58
1921	15,900 cfs	Jul. 25, Aug. 1-2, Aug. 22-23, Dec. 28-30*	4	8
1922	24,100 cfs	Jan. 3-7*, Feb. 10-15, Feb. 21-22, Mar. 17-30	4	17
1923	42,800 cfs	Mar. 5-13, Sept. 19-20, Nov. 11-14, Dec. 27-31*	4	19
1924	5,990 cfs	Jan. 1-4, Apr. 3-4, Apr. 10-11	3	8
1925	(MORMON FLAT DAM--CANYON LAKE)			
	6,200 cfs	Sept. 18-23, Oct. 7-8	2	8
1926	28,800 cfs	Apr. 5-17, Apr. 20-21	2	15
1927	(HORSE MESA DAM--APACHE LAKE)			
	49,800 cfs	Feb. 15-Mar. 2*, Sept. 13-15	2	18
1928	7,820 cfs	Feb. 5-9	1	5
1929	17,200 cfs	Apr. 5-9*, Mar. 12-13	2	7
1930	(STEWART MOUNTAIN DAM--SAGUARO LAKE)			
	2,290 cfs	Mar. 23-24, Aug. 9-10*	2	4
1931	22,900 cfs	Feb. 13-19*, Dec. 10-11	2	9
1932	48,700 cfs	Feb. 10-Mar. 6*, Mar. 10-14, Mar. 19-22	3	35

Year	Peak Flow	Dates	Total Releases	Total Days
1933			0	0
1934			0	0
1935	6,827 cfs	Jan. 12-13, Jan. 16-17 Feb. 7-11*, Feb. 15-16, Mar. 4-5	5	13
1936	4,000 cfs	Feb. 25	1	1
1937	36,891 cfs	Feb. 7-11*, Feb. 15-21, Mar. 13-21	3	21
1938	57,554 cfs	Mar. 1-8*, Mar. 13-14	2	10
1939	(BARTLETT DAM--BARTLETT LAKE)		0	0
		Subtotal	72	603
	(No Releases May 19, 1941 - April 20, 1965)			
1946	(HORSESHOE DAM--HORSESHOE LAKE)			
1965	67,000 cfs	Apr. 20-23, Dec. 31*	2	4
1966	53,000 cfs	Jan. 1-11*, Feb. 12-Mar. 4	2	33
1967	2,950 cfs	Dec. 19-20	1	2
1968	3,703 cfs	Feb. 14-19*, Feb. 25-Mar. 1 Mar. 10-15, Apr. 15-22	4	26
1969			0	0
1970	15,000 cfs	Sept. 5-6	0	0
1971				
1972	10,000 cfs	June 22, Oct. 6*, Nov. 22 Dec. 26-31	4	9
		Subtotal	13	74
1973	1,000 cfs	Jan. 1-8	1	8
	4,100 cfs	Feb. 21-28	1	7
	22,000 cfs	Mar. 2-May 29	1	88
1978*	113,000 cfs	March, April	2	23
		Totals	96	899

* as of Nov. 22, 1978

Natural recharge characteristics of the Salt River are reviewed in the section: Existing Ground-Water Recharge Mechanisms in the East Basin.

5.2.2.2 Hydraulic Properties of Soils

5.2.2.2.1 General

The hydraulic conductivity of soils bordering the flood plain of the Salt River in the East Basin are (Adams, 1974):

Table 5-4

Soils and Related Permeabilities on the Salt River

	Soil	Hydraulic Conductivity (cm/min)
1.	Alluvial Land	0.03 - 0.85
2.	Antho sand loam	0.03 - 0.08
3.	Avondale clay loam	0.03 - 0.08
4.	Carrizo fine sandy loam	0.08 - 0.27 @ 0-38 cm
5.	Carrizo gravelly loamy sand	0.85
6.	Gilman loam	0.03 - 0.08
7.	Gilman fine sandy loam	--- ---
8.	Pinant very gravelly loam	0.008 - 0.03
9.	Pimer clay loam	0.008 - 0.03
10.	Rock Land	not estimated
11.	Vint loamy fine sand	0.08 - 0.27

The most permeable soils on the flood plain are those of the Carrizo series, particularly the Carrizo gravelly loamy sand. The surface 38 cm of this soil is classified as gravelly loamy sand. From 38 cm to 152 cm the soil consists of very gravelly sand (ibid.). As shown in the above list the hydraulic conductivity of the Carrizo gravelly loamy sand is greater than 0.85 cm/min. This soil is located south of the Salt River near Hayden Road and Alma School Road.

The infiltration rates of the soils are generally rated as good except for Rock Land which is probably poor and the Alluvial Land which is excellent. Subsurface caliche zones may reduce the infiltration rates of some soils. If the caliche layers are fractured, however, infiltration rates may not be reduced to a great extent.

5.2.2.2.2 Soils of the Project Area

The hydraulic conductivity of Alluvial Land soils, located within the channel of the Salt River and along the floodplain, ranges from 0.03 to 0.85 cm/min (ibid). Hydraulic conductivity values of Salt River material at three locations are given in Table 5-5 (Courtesy H. Bouwer, 1978).

Based on these observations, it appears that expected hydraulic conductivity values in spreading basins within the river should range from 0.02 cm/min to 0.64 cm/min. These values correspond to long-term infiltration rates ranging from 0.94 ft/day to 30.2 ft/day. Such rates compare favorably with the rates reported for spreading facilities in California.

Table 5-5. Hydraulic Conductivity of Salt River Material
(Courtesy H. Bouwer)

Laboratory Tests of Disturbed Samples - 35th Avenue

Soil Type	% Sand	% Silt	% Clay	No. of Tests	K cm/min
Medium Sand	95	3	2	7	0.47
Loamy Sand	85	9	6	4	0.14
Sandy Loam	61	32	7	6	0.05
Loam	38	53	9	4	0.02

Double Tube Permeameter

Soil Type	K	No. of Tests
Tempe Bridge		
Fine Sand	0.10 - 0.36 cm/min	20 tests
Average	0.2 cm/min	
Power House		
Loamy Sand	0.037 cm/min	1 test
Coarse Sand	0.64 cm/min	1 test

5.2.2.3 Hydraulic Properties of the Vadose Zone

Water movement and storage in layered vadose zone sediments such as those of the East Basin, are governed by a multitude of physical properties. Chief among such properties are: 1) the hydraulic conductivity of the media, 2) hydraulic gradients in the fluid, 3) specific yield, 4) field capacity (specific retention), 5) fillable porosity, and 6) textural variations. The hydraulic conductivity is a measure of the permeability of a porous media. Alternatively, the hydraulic conductivity is the factor of proportionately relating the flux of water and the hydraulic gradient in Darcy's equation. (Flux is defined as the volume of water passing through a unit cross-sectional area per unit time. The hydraulic gradient is the driving force causing water to flow from a region of higher potential energy to one of lower energy.) The hydraulic conductivity is strongly affected by the manner in which the layered sediments have been deposited. For example, the imbrication of gravel during deposition in alluvial basins causes groundwater movement to occur more readily in the horizontal than vertical direction (see Bouwer, 1978, p. 56 for a discussion of imbrication). Concomitantly, the horizontal hydraulic conductivity in such sediments is greater than the vertical hydraulic conductivity. In other words, the hydraulic conductivity is affected by anisotropy. For unsaturated sediments the hydraulic conductivity is also a function of water content, decreasing as the water content decreases.

The hydraulic gradient is generally determined by measuring the difference in hydraulic head between two points in a flow system and dividing by the distance between the points. For saturated systems, heads may be measured via open wells. For unsaturated systems, heads are measured by alternative techniques, such as by tensiometers.

The specific yield of water-bearing materials is defined as the volume of water released from storage per unit surface area of the formation, per unit drop in the water table (Bouwer, 1978).

Representative values of specific yield for unconfined aquifers range from 0.01 to 0.30 (Freeze and Cherry, 1979). When the specific yield of alluvium is related to grain size, it is typically observed that the value of specific yield increases from the clay-sized material to a maximum value for the sand-sizes. Thereafter, as the grain size increases into gravels and cobbles, the specific yield decreases.

As defined above, the specific yield refers to the change in water storage during a decline in the water table. During recharge it is more meaningful to refer to the change in storage resulting from a rise of the water table. Bouwer (1978) suggests that the term "fillable porosity" be used in lieu of "specific yield" for the recharge case. That is, fillable porosity represents the amount of water that an unconfined aquifer can store per unit rise of water table per unit area. As Bouwer points out, because of hysteresis the fillable porosity value of a given formation is less than the corresponding specific yield value.

The specific retention is defined as the volume of water which, during drainage, a unit volume of alluvium will retain against the pull of gravity. In the soils literature the synonymous term is "field capacity". The time for a soil to drain to field capacity depends on the texture and structure of the media. For example, field capacity may be reached in sandy soils within a few hours. For coarse textured soils two or three days may be required to reach field capacity and for medium to fine textured soils a week may be required. For poorly structured clays the time will be much greater (U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, and the U.S. Department of Agriculture, 1977).

It is commonly supposed that when a soil has reached field capacity internal drainage has stopped. In reality, drainage continues but at a much slower rate. Conversely, when water moves into a dry media during recharge, the flow rate is probably not significant until the water content behind the wetting front

increases to a value near field capacity (neglecting hysteresis). In other words, a certain amount of applied water is required to overcome deficits, if any, in water content between the initial value and field capacity. For deep vadose zones, the sediments of which have not been wetted subsequent to deposition, a substantial amount of recharge water may need to be "invested" in overcoming such moisture deficits. In the East Basin, a large amount of the area has been irrigated, so that the moisture deficit is probably small. Similarly, recent natural recharge events in the Salt River have undoubtedly brought the water content of underlying sediments into the range of field capacity.

Vertical variations in texture within the vadose zone lead to the formation of perched ground water during deep percolation of water. It is generally assumed that perched ground water is produced by a pronounced impedence to vertical water movement, such as when a clay or caliche layer underlies a gravel deposit. Although this concept is true, temporary perched ground-water bodies may also develop at the interface between layers of relatively high permeability, such as a gravel overlying a coarse sand. The requisite condition for perched ground-water development is that the hydraulic conductivity of the lower material must be less than the vertical flow rate of water through the overlying material. Inasmuch as the hydraulic conductivity values of sediments of the vadose zone are greater in the horizontal than vertical direction, perched ground water tends to spread laterally.

Two pronounced regional perched ground-water bodies exist in the East Basin (Laney, et al., 1978). The locations and areal extent of these masses are depicted on Figure 5-1. The largest mass comprises an elongated, northeast trending region, extending from Gilbert to about three miles northeast of Williams Air Force Base. The smaller mass, which is within the project area, underlies a region along and north of the Salt River, near the Tempe Buttes. The existence of these masses is evidenced by cascading water in irrigation wells and by shallow ground-water levels.

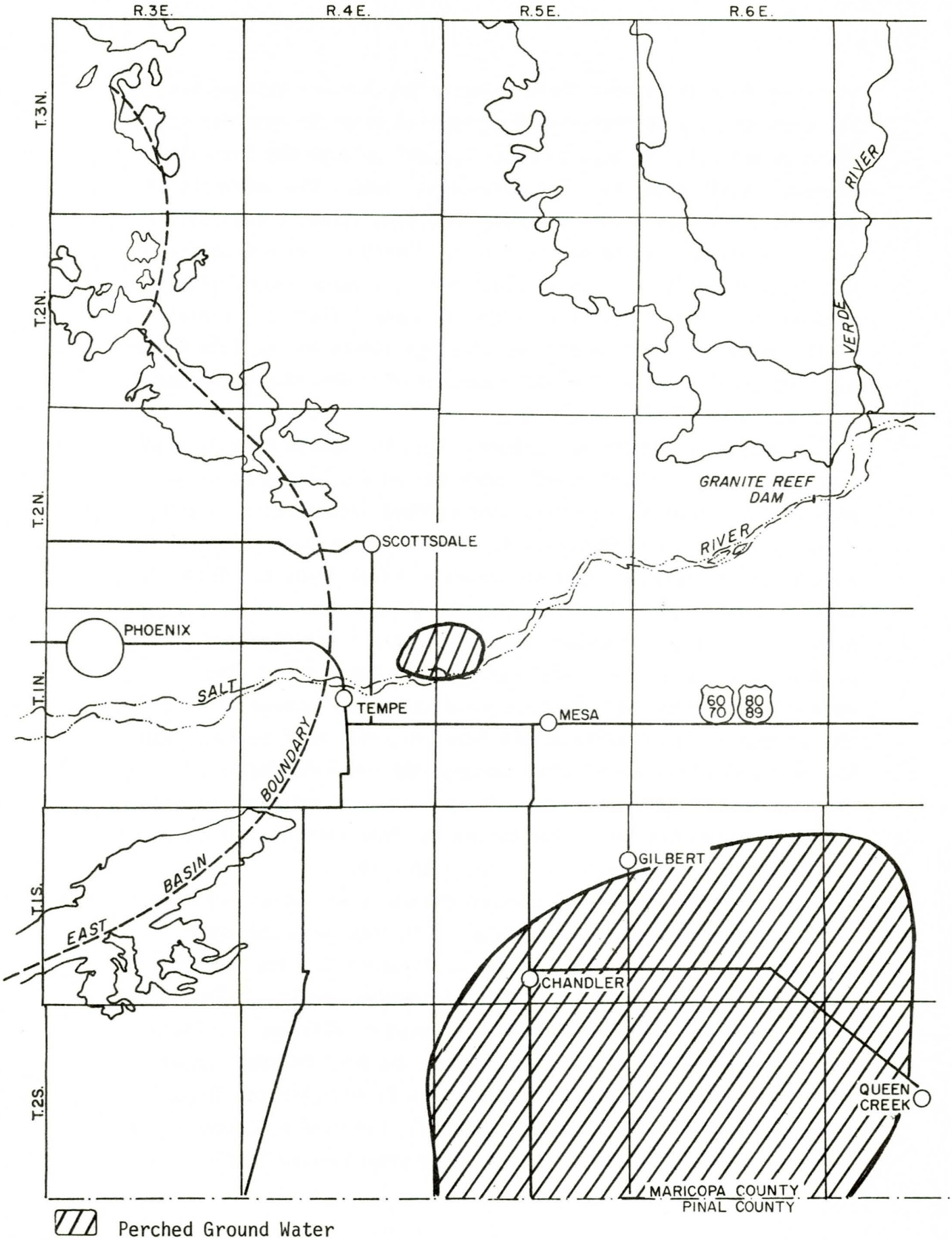


Figure 5-1. Perched Ground Water in the East Basin (After Laney, et al, 1978).

The larger perched ground-water mass in the East Basin appears to be caused by a sharp transition from coarse material to underlying silts. This mass is recharged by irrigation return flow and canal seepage. The smaller mass near Tempe may also be recharged during flows in the Salt River. The East Basin contains caliche layers at different depths in the soil profile. Depending upon their extent and vertical permeability, caliche beds will also impede the flow of water.

5.2.2.4 Ground Water Hydrology

5.2.2.4.1 General

The principal water-bearing units in the East Basin are the Upper Alluvial Unit and the Lower Conglomerate Unit (U.S. Bureau of Reclamation, 1977). The Middle Fine-Grained Unit may provide a small amount of ground water but generally is considered to be an aquiclude (ibid). Water bearing regions of the Upper Alluvial Unit are mainly unconfined, although local fine-grained zones may promote partial confinement and perching. The Lower Conglomerate Unit is confined where overlain by the Middle Fine-Grained Unit, and unconfined where the middle unit is missing (ibid).

Inasmuch as aquifer tests have not been conducted to a great extent in the East Basin, it has been necessary to estimate transmissivity (T) distributions. For example, Anderson (1968) developed an empirical relationship between the specific capacity of wells in Central Arizona and aquifer transmissivity. Specific capacity represents the drawdown in a well a certain time after pumping is started, divided by the discharge rate of the well. The distribution of T values in the East Basin derived by this approach is shown on Figure 5-2. T values ranged from about 10,000 gallons per day per ft (gpd/ft) to 200,000 gpd/ft. A band of high T values is shown extending from the Salt River, northeast of Mesa, through Chandler. Apparently, this region corresponds to the location of buried, ancient stream channel of the Salt River.

Prior to large scale pumping, ground water in the Paradise Valley generally flowed in a southerly direction toward the Salt

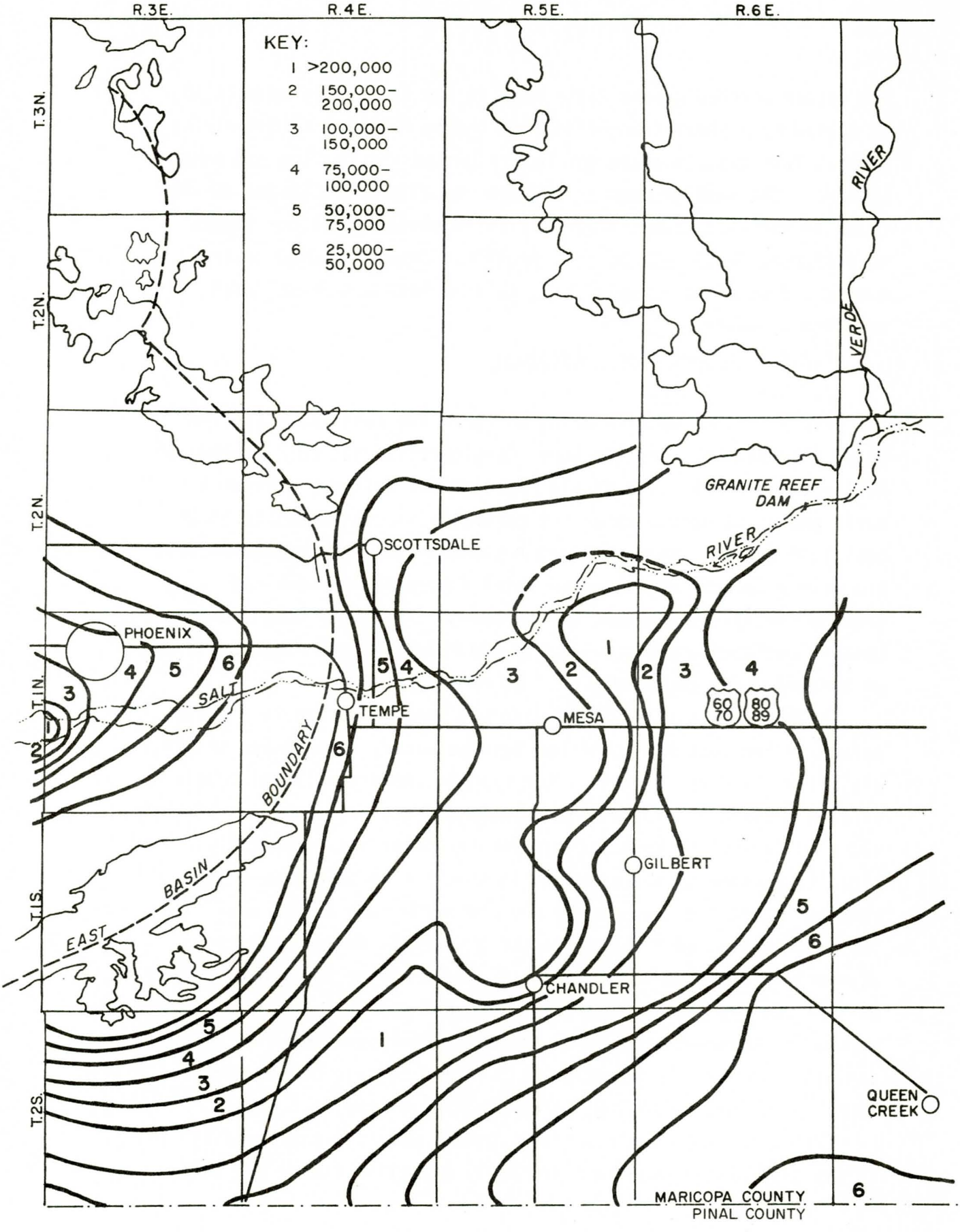


Figure 5-2. Distribution of T Values (gpd/ft) in the East Basin (After Anderson, 1968).

River (U.S. Bureau of Reclamation, 1977; Arteaga, et al., 1968). Subsurface outflow from the East Basin into the West Basin occurred beneath the Salt River. South of the river, ground water moved primarily in a northwesterly direction.

Extensive pumping after the Second World War profoundly affected ground-water levels and flow direction in the East Basin. Water levels throughout the Basin have receded from 50 to 400 feet. Near the San Tan Mountains, in the southern part of the basin, water levels dropped 400 feet (Laney, et al., 1978). Similarly, in a ground-water depression east of Mesa, water levels dropped 350 feet. In a ground-water trough under Scottsdale water levels have declined 300 feet. The cone of depression in Scottsdale resulted from widespread pumping from the conglomerates, which lead to dewatering of overlying sediments. The ground-water trough east of Mesa was produced by wells pumping from the Upper Alluvial Unit. The areal extent and influence of the depression east of Mesa is much greater than the cone underlying Scottsdale.

By 1964 the large scale cones of depression underlying Scottsdale and east of Mesa modified the natural flow patterns. Thus, in the region north of the river the orientation of ground-water flow was shifted generally into a south, southeast direction. Near Scottsdale the direction of ground-water flow became oriented primarily toward the large pumping trough underlying the city and environs. South of the river the flow direction was reversed by the pumping trough east of Mesa (U.S. Bureau of Reclamation, 1977). The principal direction of ground-water flow in the region between Mesa and the Salt River was south-easterly. Subsurface outflow into the West Basin was eliminated.

Plate 2 illustrates ground-water elevations in the region encompassing the project area in 1972. The plate shows that in addition to the depression east of Mesa and the depression underlying Scottsdale, a third cone of depression has developed beneath Mesa. South of the river, flow gradients continue to be directed toward the depression east of Mesa. However, flow in the vicinity of

Mesa is now oriented toward the depression underlying the city.

Plate 2 also includes the lines of equal elevation of perched ground water. The direction of flow of perched water is not necessarily the same as that for ground water in the main aquifer. North of the river perched ground water flows mainly in a southeasterly direction. South of the river, flow is in a more easterly direction, toward an incipient trough southeast of Mesa. The differences in elevation between perched ground water and the main ground-water body are greatest near Scottsdale.

Depths to ground water in the region encompassing the project area in 1972 are shown on Plate 3. North of the Salt River in the vicinity of Scottsdale water levels varied from 100 feet below land surface near the Papago Buttes to 400 feet beneath Scottsdale. Beyond the Scottsdale cone of depression water levels gradually decreased to 400 feet near the Sawik Mountains. South of the river, the depth to ground water in 1972 ranged from 60 feet below land surface south of Tempe to about 580 feet below land surface near the Usery Mountains (U.S. Bureau of Reclamation, 1977).

5.2.2.4.2 Ground Water in the Project Area

Examination of water level contours for 1972 on Plate 2 shows that depending on the location of a recharge site, recharged water could move in three possible directions within the main aquifer. Water recharged in the eastern one-third of the project area would likely flow toward the large depression east of Mesa. Water recharged in the central one-third of the area would probably flow toward the ground-water trough underlying Mesa. The southward flow of water would be enhanced by coarse, highly transmissive deposits of the ancient, buried stream-channel (see Figure 5-2). In the western one-third of the area, ground-water would probably flow toward the Scottsdale depression.

The above estimates of flow direction did not account for the effect of perching on water movement. Thus water recharged near Tempe and Mesa would probably merge with the shallow perched ground-water system in the western portion of the area. In that case,

recharged water would flow along the prevailing gradient of the perched ground-water, i.e., in a southeast direction, north of the river; and in a northeast direction, south of the river. In addition, water recharged in the central and eastern portions of the area could create new perched ground-water systems within the vadose zone. Water would then flow in directions concomitant with the particular hydraulic gradients established in each perched system.

Absolute values of the depths to ground water near Granite Reef Diversion Dam in the eastern one-third of the area are uncertain. As shown on Plate 3, the depths may be as great as 500 feet below land surface. In the central one-third of the area levels vary from about 240 feet below land surface to 320 feet below land surface. In the western one-third of the area, water levels range from about 100 feet to 240 feet. The shallow depth corresponds to the perched ground-water system near Tempe.

5.2.3 Ground-Water Quality

5.2.3.1 General Trends

Trends in the areal, vertical and temporal quality of ground water in the East Basin were identified by Schmidt (1979) during the U.S. Army Corps of Engineers Phoenix Urban Study and Maricopa Association of Governments 208 Program. The following information is summaried from Dr. Schmidt's report.

Schmidt used available values of the electrical conductivity (EC) of water samples from wells in the East Basin in 1975 as a gage of salinity. EC values in micromhos/cm may be converted into total dissolved solids by multiplying by an empirical factor. For the Salt River Valley this factor is about 0.65. Figure 5-3 shows the distribution of EC values in the East Basin during the sampling period. In the Paradise Valley EC values were generally less than 500 micromhos/cm except in a region extending diagonally from Scottsdale to the Salt River Pima-Maricopa Indian Community. In this region a band of EC values of 1000 micromhos/cm was observed. Schmidt surmised that the higher salinity in this region reflected

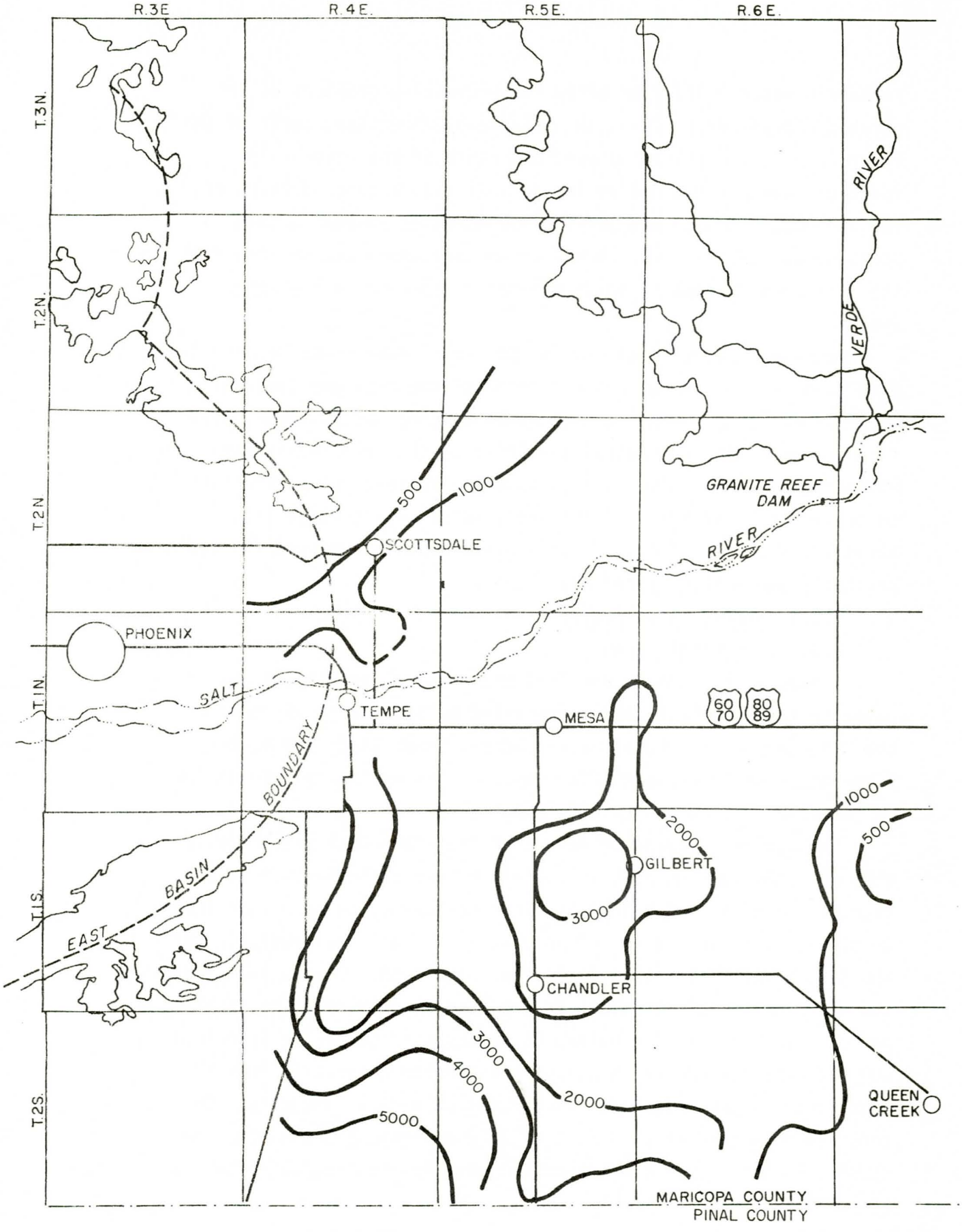


Figure 5-3. Distribution of Specific Conductance in the East Basin (After Schmidt, 1979).

recharge of Salt River water, which contains a higher salt content than sources to the north. Ground water within the Recent Alluvium Unit was historically of higher salinity than underlying ground water (ibid). Much of the Recent Alluvium Unit has been dewatered except southwest of Chandler.

In the Chandler Basin, south of the Salt River, two ground-water regions with EC values greater than 2000 micromhos/cm were observed in 1975. One of these regions extends diagonally across the southwest corner of the basin. In this region, EC values increase in a southwest trending direction, with a reported maximum of 5000 micromhos/cm. West of Chandler ground water still occurs in the Upper Alluvium Unit, which, as indicated above, contains water of higher salinity.

A ground-water region of high EC values occurs south of Mesa, northeast of Chandler, and encompasses Gilbert. In the central part of this region, EC values of 3000 micromhos/cm were observed. According to Schmidt, in this area finer grained facies occur in the formations underlying the Recent Alluvium Unit. The higher salinity ground water appears to be associated with those finer deposits.

Regions of the Chandler Basin containing the Upper Alluvium Unit correspond to an area with perched ground water. Cascading water in wells within perched ground-water regions effectively short circuit the vadose zone; directly recharging the ground water with higher salinity water. Along the margins of the basins ground-water salinity decreases with depth.

At greater depths (800-1000 feet) in the central part of the basin, however, the salinity of ground water increases, because of the presence of evaporite deposits within the fine-grained sediments (ibid).

In the Chandler Basin, ground water with EC values less than 1000 micromhos/cm was observed only in regions east of Mesa and near Queen Creek (ibid). In the area east of Mesa the Recent Alluvium Unit is absent and the salinity appears to be more constant with depth.

In examining historical changes in ground-water salinity within the East Basin, Schmidt (ibid) concluded that the predominant trend was one of constancy. He attributed such constancy to four possible factors:

> First, canals traverse much of the area and supply recharge by seepage. This recharge is of lower salinity than much of the ground water in the East Basin, and thus tends to counteract the expected salinity increase due to recharge from return flow from irrigation. Second, the declining water tables in some areas may not allow the detection of the full effect of return flow at present. Third, substantial precipitation of carbonates and sulfates which are major anions in water, may occur prior to percolation of return flow to the ground water. Lastly, pumpage of ground water and subsequent export through sewers or canals to other areas tends to remove salt from parts of the East Basin.

In contrast to the overall constancy of salinity in ground water of the East Basin, salinity has been increasing in the Chandler and Gilbert areas. In these areas it appears that higher salinity ground water from the Upper Alluvium Unit is moving downward into producing regions. In addition, in the Chandler area ground water of higher salinity has moved northward into ground-water regions of formerly lower salinity.

In addition to salinity, certain specific chemical constituents are of concern in ground water. Schmidt reviewed the recent distribution of chloride, sulfate, hardness, nitrate, fluoride, chromium and arsenic within the East Basin. Trends in nitrate, chromium and arsenic are briefly reviewed here. According to Schmidt's nitrate map for the East Basin in 1976, ground-water regions with nitrates more than 45 mg/l occurred in four areas: 1) Scottsdale; 2) along the Salt River, east of Tempe; 3) west of Gilbert, and 4) east of Gilbert. Overall, nitrate levels have decreased since about 1930 in the East Basin, apparently because of the dewatering of the upper region of the Upper Alluvium Unit.

Ground water containing concentrations of hexavalent chromium greater than 0.05 mg/l (The EPA maximum contaminant level for

drinking water) were observed only in the Paradise Valley. According to Schmidt (ibid), chromium contents in excess of 0.02 mg/l were found in ground-water samples from large capacity wells in a northwest-southeast trending region, 15 miles long and three miles wide extending through Scottsdale. An area containing 0.10 mg/l chromium was observed near the intersection of Scottsdale Road and Cactus Road. The large capacity wells in the area tap higher temperature ground water from the lower conglomerates.

Arsenic levels were also fairly high in the Paradise Valley. According to Schmidt (ibid), arsenic concentrations exceeded 0.02 mg/l in 1976 in a large area, mainly west of Pima Road and north of Indian School Road.

5.2.3.2 Relationship of Recharge Project to Water Quality

From the above review it appears that a full-scale ground-water recharge project in the Salt River could mainly impact upon the ground-water quality in the Chandler Basin. As an example, consider a recharge project in the Salt River located such that recharged water would move into the buried, ancestral channel of high permeability. After a prolonged period of time, and after recharging a large volume of water, the mass of high salinity water south of Mesa could be intersected and diluted by this better quality water. In light of the small amount of water which would be recharged, it is doubtful that a demonstration project in the river would have a substantive affect on ground-water quality.

A demonstration or full-scale recharge project could leach salts into the water table if the project is located, 1) on land previously irrigated, or 2) on virgin ground. During normal irrigation practice salts are leached below the root zone into the lower reaches of the vadose zone. Application of a larger amount of water for recharge would flush these salts directly into the ground-water zone. In areas which have never been irrigated, native salts may be dissolved and leached with applied recharge water. One constituent of particular concern is nitrate, which is commonly observed in high concentration in saturated extracts from virgin soils of arid regions.

5.2.4 Existing Ground-Water Recharge Mechanisms in the East Basin

A prime function of a demonstration recharge project is to answer a basic technical question: will a full-scale project be competitive with existing recharge mechanism with respect to the quantity of water recharged? Note that this question concerns only the quantity of recharge. In addition to quantity, other factors may be of equal or greater significance to the decision maker in weighing the merit of a potential project. Additional factors include such technical considerations as: water quality, proximity of the recharge source to recovery wells, and depth to ground water. A host of legal-institutional-economic considerations also need to be examined, such as those presented in the ensuing sections of the report.

Existing ground-water recharge in the East Basin is attributable to three principal mechanisms: flood flows in the Salt River, deep percolation of irrigation water, and canal seepage.

5.2.4.1 Natural Recharge

Observations of channel losses in the Salt River during floods in 1965, 1966, and 1973, and associated water level rises in nearby wells, attest to the efficacy of natural recharge in the river. (Data from the 1978-1979 floods are currently being examined). The observations of 1965, reported by Aldridge (1970), and those in 1973 reported by Babcock (1975), relate to recharge in the entire reach of the Salt River from Granite Reef Diversion Dam to Gillespie Dam, a distance of 74 miles. The 1965 observations by Briggs and Werho (1966) examined channel losses in the Salt River within the East Basin.

5.2.4.1.1 1966 Recharge Studies in the Salt River Valley

Intensive and copious precipitation in November and December 1965 within the Salt River Watershed generated excessive surface runoff into the Salt River. The system of reservoirs filled to overflowing and surplus water was spilled into the river over Granite Reef Diversion Dam. Flow over the dam occurred on

December 23, but the major discharges occurred between December 31, 1965 and January 11, 1966 (Aldridge, 1970). An additional amount of flow occurred between February 12, 1966 and May 5, 1966. According to Aldridge a large part of the water lost from surface flow during the Phoenix flood infiltrated into the ground water. Using estimates (Table 4, p. C2, Aldridge, ibid.) of inflow volumes from both the Salt and Gila Rivers, and arrival volumes at Gillespie Dam, it appears that recharge in the Salt River Valley during the period December 22, 1965 through March 1966 was about 155,000 acre-feet.

Recharge from the flood water reflected in water level rises in wells near the Salt River. For example, one well, near the river, and about 12 miles below Granite Reef Diversion Dam, manifested a rise in water level of about 21 feet during the period mid-December 1965 to mid-March 1966.

5.2.4.1.2 <u>1973 Natural Recharge Studies in the Salt River Valley</u>

Babcock (1975) described recharge during the 1973 floods as follows:

> --In 1972-73 the winter precipitation was 60 and 100 percent above average in the Salt and Verde River watersheds, respectively, and resulted in record snowpacks....The combined discharge of the Salt and Verde Rivers was more than 3 million acre-feet. The unusually large amount of runoff necessitated the release of water from the Salt and Verde reservoir system into the normally dry Salt River below Granite Reef Dam...The releases, which were intermittent from January through May 1973, amounted to about 1.2 million acre-feet; however, the total inflow into Painted Rock Reservoir on the Gila River 108 miles downstream from Granite Reef Dam...was only 700,000 acre-feet. Nearly all the 500,000-acre-foot loss in surface flow was recharged to the ground-water reservoirs along the river channels.
>
> In general, rises in water levels occurred throughout the areas near the rivers from spring 1973 to spring 1974. A maximum water-level rise of 52 feet occurred in well (A-1-4)2 near the Salt River. Part of the rise in water levels, especially in the Salt River Project area, may be attributed to a decrease in ground-water pumpage; in the Salt River Valley

ground-water pumpage was about 500,000 acre-feet less in 1973 than in 1972.

The general shape of the recharge mound underlying the Salt and Gila Rivers about the time that surface flow ceased was estimated using water-level measurements made before flow began and after flow ceased. The average rise in water level directly under the rivers was about 30 feet, and the mound was about 6 miles wide and about 108 miles long. The volume of water required to create a mound of this size indicates that recharge to the ground-water reservoir was about 500,000 acre-feet. By spring 1974, the recharge mound had spread laterally and had dissipated, which, combined with the decrease in ground-water pumpage, caused general rises in water levels in parts of the Salt River Valley and the Gila Bend basin. The water-level changes in these areas for 1969-74 reflect, in part, the water-level rises for 1973-74.

5.2.4.1.3 1966 Recharge Observations in the East Basin

Briggs and Werho (1966) observed flow characteristics and infiltration in the Salt River, and resultant ground-water recharge, resulting from an unusual flow event during April 19-25, 1965. The total amount of water released over Granite Reef Diversion Dam during the six day period was 20,000 acre-feet, at a maximum rate of 6100 cfs (ibid.).

The river was divided into three reaches: 1) Granite Reef Diversion Dam to 48th Street (19 miles); 2) 49th Street to 16th Street (4 miles); and 3) 16th Street to 7th Avenue (2 miles). The first reach includes the entire project area as defined herein. The lower 10 miles of the first reach contained several small gravel pits.

Flow hydrographs at Granite Reef Diversion Dam, 49th Street, 16th Street and 7th Avenue during the period April 20, 1965 through April 24, 1965, are shown on Figure 5-4. According to Briggs and Werho, about 75% of the total flow released at the dam was lost from the surface between the dam and 48th Street. About 10% was lost in the reach between 48th and 6th Streets, and the gravel pits in the final reach retained the remaining discharge.

Neglecting evapotranspiration losses, Briggs and Werho calculated total losses in reaches 1, 2 and 3 to be 12,000 acre-feet,

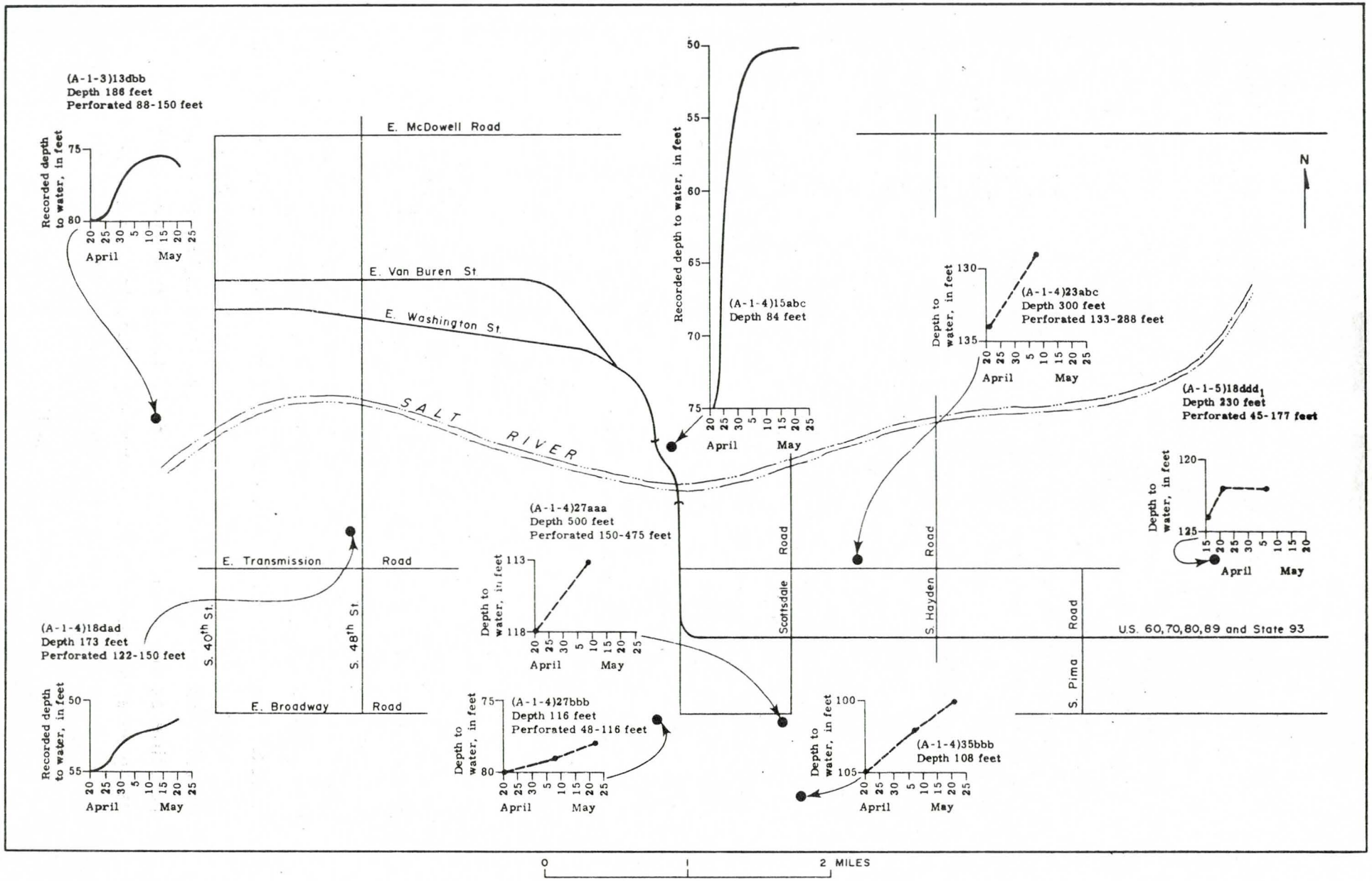


Figure 5-4. Changes in Water Levels in Wells Along the Salt River During 1965 Flood (After Briggs and Werho, 1966).

540 acre feet, and 1100 acre feet, respectively. The corresponding infiltration rates were: 1) reach #1, 2.5 ft/day average for 3.8 days; 2) reach #2, 1.4 ft/day average for 4 days and 3) reach #3, 1.5 ft/day, average for 4 days. Intake rates in the gravel pits between 16th Street and 7th Avenue varied from 1.5 ft/day to 1.1 ft/day during the period April 21-May 6.

Water level hydrographs from wells near the Salt River during the period April 20 - May 25, 1965, are shown on Figure 5-4. The observed rise in water levels in these wells indicates that recharge occurred as a result of channel losses. Note, however, that the wells measured were primarily shallow. No data were presented on water level response in deeper wells in the upstream reaches of the river.

Two general conclusions can be deduced from the observations of Briggs and Werho: 1) the Salt River between Granite Reef Dam and 48th Street (encompassing the project area) is a highly efficient recharge unit, and 2) gravel pits in the river are also effective recharge units. The relatively high intake rates in the pits indicate that suspended sediment did not completely inhibit infiltration, at least during the period of observation. However, because of clogging the infiltration rate was lower than the potential value of 5-10 feet per day (Bouwer, Personal Communication, 1978).

5.2.4.2 Deep Percolation of Irrigation Water

In the East Basin extensive irrigated agriculture is practiced on land north of the Salt River, on the Salt River Indian Reservation, and on land south of the river. Water in excess of the soil intake capacity runs off the field becoming tail water. Water infiltrating into the root zone may be consumed by evapotranspiration or percolate into the vadose zone. Water in the latter category may eventually recharge the underlying ground water system.

Inasmuch as field data are lacking on the volume of deep percolation from irrigated areas in the East Basin, it is not possible at the present to quantify recharge from this source. Using an approximate water balance approach, the Arizona Water

Commission (1975), estimated that about 41% of the applied irrigation water in the Salt River Valley may be recharged. In 1970 this amounted to 949,000 acre-feet. Using an inventory approach, the U.S. Bureau of Reclamation (1977) estimated that recharge from irrigation in the Paradise Valley-Chandler-Queen Creek Area (encompassing the East Basin) was 101,000 acre-feet in the period 1952-1964. The difference between the Arizona Water Commission estimate and U.S. Bureau of Reclamation estimate is attributable to differences in estimated return flow values (50% vs. 20%).

Despite variable estimates of the amount of deep percolation from irrigation, the fact that deep percolation is indeed occurring is evidenced by cascading water in wells near irrigated fields.

Although the quantity of incidental recharge from irrigation may be substantial, the chemical quality of water mixing with native ground water may be poor. In particular, irrigation water is a source of nitrate and possibly pesticide residues.

Canal Seepage

In addition to seepage in irrigated fields, canal seepage constitutes another form of "artificial" recharge in the East Basin. Principal canals in the East Basin are those shown on Plate 1, primarily those of the Salt River Project (SRP) and the Roosevelt Water Conservation District. As indicated in Section 3, the SRP contains 131 miles of canals, 61 miles of which were lined in 1977. Similarly, the Project contains 878 miles of laterals, 726 miles of which were lined in 1977. Substantial losses may occur in the unlined sections.

In their evaluation of ground-water conditions in the Paradise Valley-Chandler-Queen Creek subdivision of the CAP Project Area, the U.S. Bureau of Reclamation (1977) estimated that recharge from canal seepage amounted to 200,000 acre-feet per year in the period 1952-1964.

5.3 Technical Information Requirements for a Demonstration Recharge Project

Three technical elements of prime importance in selecting, designing, and operating either a demonstration or full-scale recharge project are: 1) infiltration, 2) storage, and 3) recovery. As apparent from the above hydrogeological review, these elements are defined only in a general sense within the project area and environs. Particular items within each element which should be defined for potential recharge sites are discussed below:

5.3.1 Infiltration

The long-term infiltration rates of soils at alternative sites are useful in selecting a final site, and in determining the areal requirements of a surface recharge facility. Data on long term infiltration rates are also useful in developing management plans to sustain intake rates in an operational facility. In addition to measuring the intake rates of a soil, data are needed to estimate the effects of shallow lenses (e.g. caliche) and clogging by sediment on infiltration rates.

5.3.2 Storage

Specific items which should be defined in characterizing the storage capacity of a ground-water reservoir include: 1) the overall storage capacity, 2) storage capacity of the vadose zone, and 3) storage capacity of the zone of saturation.

5.3.2.1 Overall Storage Capacity

Overall storage capacity of the vadose zone plus zone of saturation entails determining the vertical and areal extent of a ground-water reservoir. Depth to water table information indicates the vertical thickness of vadose zone deposits. Similarly, data on the depth to bedrock and bedrock configuration indicates the total capacity of the system.

5.3.2.2 Storage Capacity of the Vadose Zone

The storage capacity of the layered sediments of the vadose zone is defined by the saturation capacity. Theoretically, the saturation capacity is equal to the porosity of the media. In

reality, saturation is never attained because of the occlusion of air bubbles in the pore space. Saturation capacity is equivalent to the sum of the specific retention plus specific yield of a porous media. For recharge cases quantification of the fillable porosity may be more significant than values for the specific yield.

The overall thickness of the vadose zone may have an affect on intake rates of a surface spreading facility. In particular, if the vadose zone is relatively thin (or if shallow perching occurs) mounds created by recharge may merge with the surface. Intake rates will subsequently decrease. Hantush (1967) presented a method for determining the height of rise of a mound above a water table during recharge for rectangular basins (See Bouwer, 1978, p. 287-288).

5.3.2.3 Storage Capacity of the Zone of Saturation

Storage in unconfined aquifers is characterized also as the sum of the specific yield plus the specific retention. For confined aquifers storage is defined by the storage coefficient: "...the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Lohman, 1972)."

5.3.3 Disposition and Recapture of Recharge Water

A primary question in any recharge operation is: How much of the recharged water actually is recoverable (i.e., how much could be pumped back to the surface)? For a recharge well the entire vadose zone is bypassed during recharge, and virtually none of the recharge water is held back in storage within the vadose zone. Thus, a substantive amount of the recharge could be recovered by pumping either from the recharge well or from downgradient wells. Naturally, when recharge water becomes a component of the ground-water flow system, it is possible that a fraction may escape the cone of influence of pumping wells and move further downgradient. For spreading basins, pits, or "dry wells", water moves through the vadose zone prior to crossing the water table. Storage properties of both the vadose zone and ground-water zone could affect the ultimate amount of water recovered by pumping wells.

5.3.3.1 Vadose Zone Properties Affecting Recovery

Vadose zone properties which govern the flow and release of water include: 1) stratification, 2) hydraulic conductivity, 3) water content deficits and 4) specific retention (field capacity) and specific yield.

Stratification in the vadose zone may impede vertical water movement, retarding the flow of water into the main ground-water body. In addition, as discussed above, perched ground-water bodies may be produced. Flow paths in these bodies may be different from those in the main system. Thus recovery wells oriented on the basis of hydraulic gradients in the main ground-water system may recover only a portion of the recharged water. Shallow perched ground water may also reduce the intake rates of recharge facilities.

The hydraulic conductivity of vadose zone sediments is related to the water content of the layers. Except during flow in perched layers, flow is generally in the unsaturated state. The unsaturated hydraulic conductivity is less than the saturated conductivity.

The initial, drained water content of sediments in the vadose zone may be less than the field capacity, the presumed lower limit of water movement. A certain amount of water must be stored to overcome this deficit.

The field capacity is generally considered to be the water content of a porous medium after gravity drainage has "essentially" ceased. The specific yield represents the amount of water released during gravity drainage.

5.3.3.2 Saturated Zone Properties Affecting Recovery

Factors relating to the flow and recovery of recharged water from an aquifer include: 1) the transmissivity, 2) specific yield, and 3) hydraulic gradients.

The transmissivity (T) of an aquifer is defined as the product of the hydraulic conductivity and the aquifer thickness. T values are usually obtained by conducting pumping tests. The specific yield or storage coefficient represents the amount of water released from storage during pumping. Transmissivities in the East

Basin have been estimated only from specific capacities of wells. While there is a correlation between these two parameters, specific capacity also depends on well construction and efficiency. The distribution of transmissivity is required to define preferred flow paths of recharged water. The variability of the specific yield or storage coefficient of the aquifer system in the East Basin is also unknown.

The prevailing hydraulic gradients of the ground-water system will govern the direction of flow of recharged water. Knowing the transmissivity of the system, flow rates can be estimated from Darcy's Law.

5.4 Data Collection Techniques

During the initial stages of Phase III, the most viable site or sites for a demonstration recharge project will be selected from a number of alternative sites. Site selection will be based on an optimal combination of technical, environmental, legal, institutional, and economic factors. To facilitate site selection from a technical viewpoint, preliminary field investigations should be conducted at alternative sites, followed by intensive investigations at the chosen location or locations. The preliminary field investigations will probably focus on determining infiltration characteristics of alternative sites. Subsequent detailed investigations at a specific site will address the data needs, discussed in the previous section, relating to storage and recovery of recharge water.

5.4.1 Infiltration

A recent report by the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers and U.S. Department of Agriculture (1977) presents an excellent review of methods for estimating long-term infiltration rates. For water spreading operations the two most suitable procedures for determining long-term infiltration are double-ring infiltrometers and test basins. In the double ring infiltrometer method a metal cylinder from 6 to 14 inches in

diameter is driven to a depth of 6 inches into the soil at the test site. A larger ring, ranging from 16 to 30 inches in diameter, is placed concentrically around the smaller ring. The areas within inner and outer rings are flooded and the rate of recession of water level in the inner ring is measured via a hook or point gage.

By keeping the outer region flooded, flow in the inner region is restricted mainly to the vertical direction. Water to be used during actual flooding should be used during infiltrometer tests. Because of the spatial variability of soil properties, an inordinate number of ring tests may be required to ensure that results are within a certain percentage of "true" mean values (ibid., pp. C-25 to C-27). Even with care, however, experience has shown that double ring infiltrometers tend to over-estimate the true infiltration rate (Bouwer, Personal Communication).

The basin method represents a more realistic technique for measuring long-term infiltration rates. In this approach, a region of the proposed spreading area is enclosed by dikes; water is applied; and the rate of recession of the water surface is measured. Again, water intended for the actual flooding operation should be employed in the test. If the basin is large enough, spatial variations in the hydraulic properties of the surface soils will be offset, and a mean intake rate will be obtained. A problem with this method is that shallow impeding layers may promote lateral movement of water in preference to truly vertical flow. Lateral flow rates generally exceed vertical rates. Hence measured intake rates would tend to over-estimate the intake rates of a larger spreading area.

5.4.2 Total Storage Capacity

The overall storage capacity of a ground-water reservoir underlying a potential recharge site requires data on the thickness of sediments overlying non-water bearing bedrock. In the central part of the East Basin the base of the aquifer is massive evaporites not bedrock (Schmidt, Personal Communication). Direct techniques for determining depth to bedrock and bedrock configuration entail

inventorying available drillers well logs in the area or constructing special wells. The former method may not provide definitive information inasmuch as wells may not be constructed to bedrock. Similarly, construction costs for sufficient wells to characterize the vertical and area extent of bedrock could be prohibitive.

The most viable alternative to constructing wells is to use indirect methods, principally geophysical techniques. A thorough exposition of geophysical techniques applied to ground-water investigations was presented by Zohdy, Eaton and Mabey (1974). The principal methods discussed by Zohdy, Eaton and Mabey were electric methods, the seismic method and the gravimetric method. The interested reader should consult their review for details on the principles of each of these methods.

The electric methods rely upon electrical properties of rocks in the earth's mantle relating to the amount of water in the rocks, the salinity of water, the distribution of water and the presence of clays and conductor minerals (ibid.). The most common electrical technique is the direct current-resistivity method. Although the total depth to bedrock may not be detected via resistivity methods, the vertical location and lateral extent of buried stream channels and clay layers may be mapped. Zohdy (1974) used the combined technique of horizontal profiling and electric sounding to locate buried stream channels underlying an artificial recharge site at San Jose, California.

The seismic method measures the reaction of geologic bodies to artificially induced vibrations (Davis and DeWiest, 1966). The vibrations are generally created by setting off charges of dynamite and the response is detected via geophones. The function of the geophysicist is to separate and identify the waves arriving at the geophones, together with arrival times, into meaningful geological information (Eaton, 1974). The seismic method has been commonly used in hydrogeological investigations to determine the thickness of sediments overlying non-water bearing consolidated bedrock,

including the location of irregular bedrock surfaces. By appropriate location of charges and geophones the vertical and lateral extent of buried stream channels may be delineated. The method has been used to determine depth to water table and to determine gross properties of water-bearing sediments (e.g. between unconsolidated and semi-consolidated sediments). Other uses include mapping the lateral facies variations in an aquifer caused by lithological variations, and estimating porosity in clastic sediments. Davis and DeWiest (1966) rate the seismic method as the most accurate and potentially the most useful geophysical technique for hydrogeological investigations.

During gravimetric surveys the variations in the force of gravity are measured along a traverse or within a grid. Gravity variations are related to changes of density between various types of subsurface materials (U.S. Bureau of Reclamation, 1977). Inasmuch as a gravity meter measures only relative changes in gravity a base station of known gravity must be established. Before raw gravity data are used to interpret the geology of an area several corrections must be applied, including latitude corrections, the Bouguer correction, terrain corrections, drift correction, and regional gradients (Eaton, 1974). In light of the need to relate gravity data to density data it is important to obtain accurate values of the density of alluvium and bedrock. Consequently, construction of several pilot holes for procurement of samples, coupled with down-hole density logging, will be required. Detailed procedures for determining density are discussed by Eaton (ibid.).

According to Eaton, "The gravity method is a rapid, inexpensive means of determining the gross configuration of an aquifer, providing an adequate density contrast between the aquifer and the underlying bedrock exists. It is useful in locating areas of maximum aquifer thickness, in tracing the axis of a buried channel and in locating a bedrock high that might impede the flow of groundwater." Goodoff (1975) used the gravity method to locate bedrock highs at the entrance into and the exit from the Cortaro Basin in Southern Arizona.

Other applications of gravity methods are to estimate average total porosity and changes in water level elevations.

Any of these methods could be used to determine the thickness of alluvium and bedrock configuration at the site of a demonstration recharge project. As indicated above, the seismic method would probably provide the most accurate information. However, to provide a first estimate, resistivity or gravimetric methods could be employed. Inasmuch as the U.S. Bureau of Reclamation (U.S.B.R.) has already conducted gravity studies in the vicinity of proposed Central Arizona Project (CAP) structures, a base station has already been established. Results of a gravity survey could thus be correlated with previous U.S.B.R. surveys. Seismic studies could be conducted if more definitive geological information is required and results correlated with existing seismic data from the U.S.B.R. and other agencies.

In addition to determining on-site properties, geophysical studies should be conducted to more accurately define the location and extent of the buried stream channel extending from the Salt River through Mesa and Chandler (see Figure 5-1).

As indicated in the section on gravimetry, one or more test wells may be required to obtain data for the interpretation of geophysical data. Such wells would be installed during investigations on the vadose zone and zone of saturation.

5.4.3 Vadose Zone Properties

5.4.3.1 General Nature of Layered Deposits

The degree of stratification of the vadose zone, and the associated description of layers, may be estimated by examining available driller's logs or data from previous investigations. Such logs or data may not be available in the vicinity of a project site and a special investigation may be required. Alternative approaches for characterizing stratigraphy in the vadose zone include drilling test wells and/or using bore geophysical techniques.

In practice, construction of one or more wells will be required at the site of a recharge project in order to: 1) obtain representative samples from the vadose zone and zone of saturation for correlation with surface and bore hole geophysical tests, 2) permit conducting aquifer tests, and 3) facilitate monitoring. In the Salt River area either the cable tool or rotary methods could be used for pilot well construction. The cable tool method is preferred inasmuch as relatively clean samples can be obtained at discrete intervals. Drill cuttings could be examined in the laboratory for particle-size distribution and other geologic parameters. Knowing the vertical distribution of grain-sizes in the hole the location of potential perching zones may be delineated. The collected samples could also be used to estimate storage and transmissive properties of the vadose zone.

Following construction of a test well or wells, geophysical logging should be initiated. First the test hole(s) should be logged and subsequently nearby existing wells should be logged. The results of logging in the test well should be correlated with drill cutting analyses to delineate stratigraphy. Logs from other wells could thus be interpreted and the lateral and vertical extent of various layers (e.g., those favoring perching) could be defined.

Among the common bore hole logging techniques are the spontaneous potential method, resistance logging, acoustic logging and nuclear logging. The spontaneous potential method and resistance logging require an uncased well. Acoustic logging is conducted in a fluid filled cavity and is not applicable to the vadose zone. Only nuclear logging methods are suitable for logging in either uncased or cased wells above the water table. Inasmuch as the test wells in the recharge project on the Salt River will probably be drilled by cable tool (installation of casing progresses with drilling), only the nuclear methods are considered.

Common nuclear logging techniques include natural gamma logging, gamma-gamma logging, and neutron logging. The principles of and procedures in applying these techniques in ground-water investigations

are discussed thoroughly by Keys and Mac Nary (1971). Briefly, natural gamma logging comprises the detection of natural gamma activity of rocks. Keys and Mac Nary (ibid.) list the following sequence of sedimentary rocks in ascending order of natural gamma activity: anhydrite, coal, salt, dolomite, limestone, sandstone, sandy shale, shale, organic marine shale and potash beds. Natural gamma logs are particularly advantageous in characterizing the vertical extent of sediments and tracing them laterally from well to well (Kays and Mac Nary, ibid.; Norris, 1972).

Gamma-gamma logs provide a record of the intensity of radiation from a source in a down-hole probe, after it has backscattered and attenuated in the well and surrounding media (Keys and Mac Nary, 1971). The down-hole probe contains a source of gamma photons, such as cobalt 60 or cesium 137 and sodium iodide detector. The principal use of gamma-gamma logs is to identify the lithology and for estimation of bulk density and porosity of rocks (ibid).

Neutron logging comprises lowering into a well a down-hole probe containing a source of high energy neutron and a detector of thermalized neutrons. A common source is Americium-Beryllium. Lithium enriched BF_3 is a common detector. Neutron loggers provide information on the hydrogen content, and consequently water content, of sediments within the vadose zone and the porosity of sediments below the water table. Smaller units (primarily for water content measurements) with sources in the millicurie range require small diameter casing, e.g., two-inch. Larger units, with multicurie sources, such as those used in the petroleum industry for porosity determination, are used to log larger casing. Neutron logs are useful in detecting the presence of perched ground water. For example, Keys (1967) used a combination of gamma logs and neutron logs to delineate a clay perching bed at the national Reactor Testing Station in Idaho. Neutron logging between wells may indicate the lateral extent of perched ground-water bodies.

In light of the coarseness of deposits within the underlying the Salt River, and because of the great depth to ground water, it

would probably be extremely difficult to install small diameter casing for neutron logging. Consequently, large diameter casing should be used in conjunction with a large logger.

5.4.3.2 Water Retention and Release Characteristics of the Vadose Zone

In the upper soil layers of the vadose zone, techniques employed by soil scientists could be used to determine the saturation capacity, specific yield and specific retention (field capacity). Evaluation of these parameters could be coupled with infiltration studies. For example, shallow samples could be obtained via a King tube when the soil is saturated and subsequently oven dried to estimate saturation capacity. Similarly, samples could be obtained during drainage, and oven dried to estimate a range of values corresponding to field capacity.

An alternative field technique for estimating saturation capacity and field capacity is to log shallow access tubes with a neutron moisture logger when the soil is saturated and also during drainage.

Field soil samples could also be subjected to laboratory analyses to determine saturation capacity, specific yield and field capacity. For example, core samples could be saturated in the laboratory and the moisture content determined by oven drying. Similar saturated cores could be subjected to a suction of 1/3 atmosphere. The water content of the soil at this suction corresponds approximately to field capacity.

Inasmuch as the deposits underlying the Salt River channel are extremely coarse, of the techniques described above, only neutron moisture logging would probably produce meaningful results. Even then, wide variations in results would be expected from site to site because of spatial variations in soil properties.

Estimation of the saturation capacity, specific retention and specific yield in the deeper horizons of the vadose zone would probably rely upon indirect methods, principally neutron logging. Drill cuttings could be subjected to laboratory tests to determine

saturation capacity and the 1/3 atmosphere water content. However, because of the action of the drill bit the samples would no longer be "undisturbed" and laboratory results would be meaningless.

The ideal times to obtain neutron logs are before a major flood in the river and at intervals thereafter. The initial log would indicate the distribution of drained water content values in the profile. Subsequent profiles could indicate approximate saturated conditions in the layered media as recharge occurs. Subsequently, during drainage, water content values would be observed corresponding to the specific retention values of the layers. The difference in the values of the drained profiled and those for specific retention indicate the moisture deficit. In addition to estimating water content storage and release data, logging during recharge from floods may indicate the location of temporary perched ground water bodies.

The above approach must be used with a degree of caution. In particular, coarse sediments may be capable of transmitting water at a rate equivalent to the vertical flux. In such cases, water content changes would not occur; and estimates of storage capacity, specific yield and specific retention could not be obtained.

5.4.3.3 Transmission of Water in the Vadose Zone

The permeability or ease of water transmission is usally expressed as the hydraulic conductivity, K. The hydraulic conductivity is the proportionality factor in Darcy's equation relating flux and the hydraulic gradient.

A number of field techniques have been developed for estimating K in soils. Of interest for the recharge project area are methods for determining K in the absence of a shallow water table. Determination of the hydraulic conductivity, K, in the absence of a water table generally involves techniques which bring the soil at the measuring point to saturation or near-saturation. Bouwer and Jackson (1974) reviewed five possible methods: 1) the shallow well pump-in method; 2) the cylinder permeameter method; 3) the infiltration gradient technique; 4) the air entry permeameter technique;

and 5) the double tube method. The shallow well pump-in method measures K mainly in the horizontal direction and is suitable for stoney soils. The cylinder permeameter and infiltration gradient techniques measure K in the vertical direction and are not suitable for stoney soils. The air entry permeameter measures K in a vertical direction, and with care may be used in stoney soils. An important consideration in using these methods is to minimize entrapping air in the pores of the media: obviously occluded air will decrease the value of the measured K below the true saturated value. For additional details on these methods, including associated equations and techniques for determining K, the reader is referred to the excellent review of Bouwer and Jackson (ibid).

Laboratory and field methods are currently available for measuring the hydraulic conductivity in deeper unsaturated regions of the vadose zone. Laboratory related techniques which have been used to estimate K values from drill cuttings include permeameter tests, empirical relations between the grain-size distribution and K. Permeameter tests are not particularly meaningful because of the disturbance caused by the drilling process. In contrast, certain empirical relationships might exist between grain-size analyses and the hydraulic conductivity. Davis and DeWiest (1966, p. 375) present a table relating hydraulic conductivity to the dominant size of selected sediments.

The U.S. Bureau of Reclamation (U.S. Department of the Interior, 1977) has developed two alternative techniques for estimating the hydraulic conductivity, K, of unconsolidated, unsaturated sediment of the vadose zone. One approach entails pumping water into a bore hole at a steady rate such that a uniform water level is maintained within a basal test section. Knowing the dimensions of the hole and inlet pipes, the depth of water, and the constant inflow rate, appropriate equations and curves are consulted to calculate K. For depths less than 40 feet the hole is cased to the desired depth. A water inlet pipe and a separate water level measurement pipe are then placed inside the casing. Gravel is

then poured inside the casing to insure a gravel pack throughout the test section. Subsequently the casing is pulled back and a test is initiated. For depths greater than 40 feet it is necessary to use preperforated casing to isolate the test section. The total open area of the perforations must be known. An observation pipe is placed in the casing on a six inch bed of gravel. The use of preperforated casing permits driving the casing in depth-wise increments such that a profile of K values are obtained. The second method is used to determine K in the vicinity of a widespread lens of slowly permeable material. The method entails installing an intake well and a series of observation wells. Water is pumped into the well at a steady rate and the water level response in the observation wells is recorded. Appropriate equations and curves are consulted to calculate K.

Weeks (1978) presented a method for measuring vertical air permeability values of layered materials in the vadose zone. Basically, the method entails measuring air-pressure changes in specially constructed piezometers during barometric pressure changes at the land surface. By coupling pressure-response data with auxiliary information on air-filled porosity, and numerical solutions of the one-dimensional flow equation, an estimate of the air permeability is obtained. If the material is well-drained and permeable enough that the Klinkenberg effect is minimal, air permeability values may be converted to the corresponding hydraulic conductivity values.

Estimates of K within perched ground-water bodies of the vadose zone may be obtained by pumped hole techniques such as the auger-hole method; the piezometer method; tube method; well point method; and multiple-well methods (Bouwer and Jackson, 1974). The auger hole, piezometer and well point methods entail installing a single cavity (cased or uncased) below the water table; lowering the water level in the cavity by pumping or bailing; and measuring the rate of recovery of the water level. Knowing the geometry of the cavity and the known or assumed depth to an impermeable layer, suitable

equations, curves or nomographs may be used to calculate K. In the multiple well method, water is pumped from one well or set of wells into other wells until the difference in water levels between the wells becomes stabilized. Knowing the geometry of the cavities and flow system, appropriate equations or curves are used to determine K (see Bouwer and Jackson, 1974, pp. 612-627). All of the above methods, except the tube method, determine K primarily in a horizontal direction.

5.4.4 Saturated Zone Properties

The investigations conducted within the vadose zone should be extended below the water table. In particular it is recommended that the test wells be installed throughout the full extent of the major aquifer. Drill cuttings should be taken in discrete intervals or at depths corresponding to formation changes. The drill cuttings should be subjected to grain-size analyses. Again, it is presumed that the well will be constructed by the cable tool technique. Water samples should be bailed from the wells in incremental depths during construction to characterize vertical variations in chemical quality. Logging methods which could be employed include the natural gamma, gamma-gamma and neutron methods.

The specific yield of water-bearing sediments underlying the test site could be estimated if detailed information were available on: 1) changes in water level for a discrete period of time, 2) amount of pumping during the same period, 3) amount of recharge during the same period. Inasmuch as data are lacking on most of these items this method may have limited use in the project area.

The storage and transmissive properties of an aquifer may be estimated by conducting tests on core samples (e.g., permeameter tests) or by inference from grain-size distribution curves. The preferred technique is to conduct pumping tests (aquifer tests) on wells screened or perforated in the region of interest. Aquifer tests basically involve pumping a well; determining the discharge rate; and measuring the water level response in the pumping well and observation wells at various times. Step by step procedures

for conducting pumping tests under various test conditions are reviewed by Kruseman and de Ridder (ibid.), together with methods for analyzing data and calculating T and S. Pumping tests are also discussed by Lohman (1972). Lohman describes and presents examples for determining aquifer parameters for the following cases: 1) confined aquifers, using the Theis method and Jacobs straight line method; 2) leaky confined aquifers, using the Hantush method; and 3) unconfined aquifers using Boulton's method. In addition to these cases and others, Kruseman and de Ridder (1978) reviewed and presented examples of techniques for determining T and S in anisotropic aquifers. Neuman and Witherspoon (1972) presented a method for determining the hydraulic properties of aquitards and aquifers in leaky systems.

In conducting pumping tests at the recharge site, existing nearby wells could be used as observation wells. Alternatively, special wells may be required.

An alternative to pump testing for determining T is to construct a flow net for the ground-water system using potentiometric data. A flow net consists of two families of orthogonal curves, equipotentials and streamlines. Equipotentials represent contours of equal head in the aquifer, either on the potentiometric surface for confined aquifers, or on the water table for unconfined aquifers. Streamlines depict the direction that tagged particles of water would take during flow.

Assumptions for constructing a simple areal flow net include the following (Cooley, Harsh and Lewis, 1972): 1) no variation in the vertical hydraulic head distribution in the aquifer; 2) constant aquifer thickness and 3) the transmissivity is isotropic. Transformation methods are available for accomodating anisotropy. Techniques for constructing flow nets are presented by Cooley, Harsh and Lewis (1972), Lohman (1972) and Bouwer (1978).

5.4.5 Coordination of Hydrogeologic Studies with SWAB/RASA

The U.S. Geological Survey recently initiated a study entitled, "The Southwest Alluvial Basins, Regional Aquifer System

Assessment" (SWAB/RASA). Among the objectives of the studies are 1) to define the ground-water resources of southwest alluvial basins, including natural and modified recharge rates, and 2) to describe the present level of development of ground water and surface reservoirs in the state, including conjunctive operation of surface and ground-water reservoirs (Anderson, Personal communication).

TIME LINE - TECHNICAL

Task	First Year	Second Year	Third Year	Fourth Year
Infiltration Tests	→			
Surface Geo-physical Tests	→	→		
Test Hole Drilling	→	→		
Down-hole Geophysical Logging		→		
Grain-size Analyses		→		
Water Quality Analyses		→		
Pump Testing		→		

6. ENVIRONMENTAL CONSIDERATIONS

6.1 Introduction

Approximately one-third of the Phoenix area water supply comes from surface waters of the Salt-Verde watershed. A full-scale artificial recharge project has been proposed as a method to augment natural recharge processes to help alleviate groundwater overdraft resulting from this inbalance. Before a full-scale operation is implemented, a demonstration project will be needed to determine the environmental impacts assocated with a recharge facility. On the basis of information obtained from a demonstration project an Environmental Impact Statement (EIS) could be prepared in accordance with Council on Environmental Quality (CEQ) guidelines (40 CFR Parts 1500-1508; National Environmental Policy Act-Regulation; Proposed Implementation of Procedural Provisions; May 31, 1978).

The intent of this section is not to provide a rigorous assessment of environmental impacts. Rather, the over-riding purpose is to identify some of the important variables and potentially critical issues relevant to the environment of the study area. The variables and issues identified should serve to guide future in-depth investigations during the implementation of a demonstration facility.

This section has been prepared in accordance with guidelines from the CEQ to provide a preliminary review of the anticipated environmental impacts to be addressed in planning and implementing any site specific recharge project. By focusing on the real or projected environmental issues and alternatives this review will also assist decision makes in reducing the accumulation of extraneous background data. Based on Section 102.2(C) of the National Environmental Policy Act (NEPA) of 1969 this section shall describe:

1. The physical makeup of the study area before the demonstration recharge project;
2. Beneficial and detrimental effects which would be

associated with a recharge project;

3. Long and short term effects of artificial recharge and sources of water; and
4. Any irreversible of irretrievable commitments of resources if a recharge project is implemented.

When current information on potential effects is available it will be summarized and discussed. If no hard data are available the problem area will be identified for further research and discussion in future site specific environmental reports.

6.2 Physical Makeup of the Study Area

Within the study area there are three specific environments along the reach of the Salt River Channel from Granite Reef Diversion Dam to Tempe Butte. First, the undisturbed native environment which is seen only along non-urbanized sections of the flood plain, primarily along sections of the Salt River Indian Reservation. Second, the man-made agricultural environment, which primarily involves irrigation works and utilizes various agricultural chemicals. Third, the urban-industrial environment in or along the river channel proper.

It is recognized that the first category of environmental setting is precious and warrants special protective measures. However, the Salt River Channel, for the most part, has been and will continue to be a disturbed environment with or without the introduction of any artificial recharge project within its confines. The following sections constitute a basic description of the study area environment in terms of eight environmental categories.

6.2.1 Vegetation

The study area is located in the Lower Sonoran desert zone with typical desert plant species. Although the channel reach proper is devoid of permanent vegetation, vegetative growth in the flood plain warrants special considerations because it provides habitat for wildlife, bank stabilization, and aesthetic values to the area.

Riparian vegetation depends on surface water and is particularly sensitive to the depth of the water table. Vegetation is most prevalent near the Granite Reef Diversion Dam, due to higher ground-water levels and minor spills from the dam. The vegetation is characterized by cottonwood and willow in the wetter areas and palo verde, mesquite, and iron wood in the drier areas. Much of the vegetation on the lower flood plain was destroyed or altered by the floods in 1978 and 1979.

Much of the flood plain of the Salt River is used for irrigated agriculture and native vegetation has been replaced by agricultural crops such as cotton, milo, barley, sorgum, alfalfa, grapes, and nuts (U.S. Army Corps of Engineers, 1975). Many former agricultural lands have become urbanized and now support a wide variety of native exotic vegetation. In the channel area and surrounding flood plain, industrial activities (primarily sand and gravel mining) and landfills have completely disrupted normal vegetative growth.

6.2.2 Wildlife

Wildlife exists in relative abundance in all three environments of the study area. The native riparian community is especially critical because of its limited areal distribution and aesthetic properties. Areas with heavy growth of riparian vegetation are likely to support larger and more varied populations of wildlife than areas devoid of vegetation partly because of the increased cover. Environmental Impact Statements on file with CEQ for the Central Arizona Project (1972), Granite Reef Aqueduct (1974), Orme Dam (1976), and Buckhorn-Mesa Watershed (1978) provide lists of the species to be expected in the study area. A summary of these lists is included in Appendix D.

Of the wide variety of mammals, birds, amphibians, insects, and reptiles that occupy the Salt-Verde watershed, three species are on the endangered list, one species is on the threatened list, four species are peripheral, and two species are of undetermined status. Of the protected species, only the Gila Monster would be expected to

be present in the immediate area of the Salt River Channel between Granite Reef Diversion Dam and Tempe Butte; the lower, hotter, more highly developed sector of the watershed.

6.2.3 Cultural Resources

Because of the long-standing importance of the Salt River to local settlers within the study area there are twenty-four archaeological and historical sites. Communities of the earliest sedentary inhabitants of the Salt River Valley, the Hohokam Indian culture, flourished on the flood plain of the river approximately 1000 years ago. The river flowed freely for most of the year and the channel was never utilized for purposes other than fishing, diversion of water into canals and domestic uses. Therefore, it is highly improbable that any archaeological or historical sites would have been located directly in the channel of the Salt River. Even if a site had been situated in the channel or flood plain it would likely have been destroyed by the 1978 flood (200 year event) or other previous flood events.

Professional archaeological consultants were contracted by the Corps of Engineers to locate and classify archaeological sites on the Salt River flood plain which could possibly be impacted by construction of access roads or maintenance facilities associated with recharge activities in the channel. Burt and Pewe (1978) emphasize that the Lehi Terrace, the lowest floodplain terrace, being five feet above the Salt River Channel near Lehi, has various pot shards and artifacts indicating occupation by Hohokam culture residents. Known archaeological sites in the study area contain pot shards and historic houses for the most part. Descriptions and locations of known sites in the study area are presented in Appendix D and Plate 4, respectively.

6.2.4 Health and Safety

The only apparent health-related features of the study area are numerous solid waste and sludge disposal sites in and along the lower part of the Salt River Channel (Douthit, Personal communication, 1978). Locations of these landfills are presented in

Plate 4. These disposal sites have received discarded material (including sludge) from industrial, commercial, mining, agricultural, and other community activities. Some unknown inactive landfills may exist on the Salt River-Pima-Maricopa Indian Reservation land within the study area (Evans, Personal communication, 1978). The known locations are described below:

1. The active Tri-City landfill, co-managed by the cities of Mesa, Scottsdale, and Tempe under contract with the Salt River-Pima-Maricopa Indian Community, is located on the Salt River Indian Reservation east of Beeline Highway, north of Oak Street, adjacent to the Salt River Channel. It was placed in operation three years ago. The disposal site has a maximum depth of ten feet and is approximately one square mile in area.

2. An inactive Tri-City landfill was previously used for general municipal refuse and is bordered by Country Club Road on the east, McDowell Road on the north, the Salt River Channel on the south, and the Evergreen Golf Course on the west. It has a maximum depth of 10 feet and is one-half to one square mile in size.

3. The Mesa landfill was operated for twenty years prior to its inactivation. It is located on the Salt River Channel adjacent to and west of Center Street to the Salt River Channel. This location was flooded in 1978 causing the solid waste to be saturated. It is twenty feet in depth and covers forty acres, fifteen of which are unused in the river channel.

4. The city of Mesa sewage treatment plant, located at 2500 W. 8th Street, has been in operation since the early 1930's. It is comprised of two holding ponds for on-site disposal. The plant has a capacity of 3.5 to 4 million gallons per day (MGD). This system uses a trickling filter for secondary treatment but does not work too efficiently (Balmer, Personal communication, 1978). Disposal practices include utilization of effluent for irrigation of corn fields near the plant. Plans to phase out plant operations over the next two years have been abandoned and it can be expected to be used for at least the next five years.

5. Tempe has one inactive solid waste disposal area which, until 1972, was used for street sweepings and rubble. It is thirty feet at maximum depth and measures one-half mile by 1000 feet in size. It is located on the south bank of the Salt River Channel, one-half mile east of Hayden Street between Pima Street and the Salt River. This area is a maximum of thirty feet deep and is thirty acres in size.

6. The City of Tempe has a sludge disposal area located east of Hardy Drive at the Salt River Channel. A 2.5 MGD plant operating at the site was closed in the mid-1960's.

7. An inactive sludge disposal settling pond is located at the southeast corner of Miller and McClintock Roads. The facility served the City of Scottsdale prior to 1970. There is no knowledge of any past or present landfills in Scottsdale.

8. Inactive landfill used by Arizona State University is located south of First Street and north of Sun Devil Stadium one-half mile east and west of Scottsdale Road. The one-half mile wide area involves a random system of shallow burial holes used for paper, tree limbs, and flood wastes. It was discontinued in 1975 and the Packard Baseball Stadium was built on a portion of the landfill.

9. A new landfill on the Salt River-Pima-Maricopa Indian Reservation is located just south of Beeline Highway approximately 100 to 150 yards west of the confluence of Evergreen Drain and the Salt River. Dimensions of the landfill are unknown but it appears to be relatively large.

6.2.5 Aesthetics

Aesthetics is a term commonly used in reference to the rather ambiguous, subjective, and seemingly unquantifiable properties of beauty. The aesthetic characteristics of the study area are particularly difficult to measure. Throughout most of the year the channel of the Salt River is in reality nothing more than a wide sandy wash. Its greatest apparent aesthetic value is that it provides the appearance of open space and occasionally a glimpse of flowing water. From Country Club Road to Tempe Butte the channel has been

dominated by the presence of man and his social and technical activities. Authorized and unauthorized landfills, sludge disposal areas, and sand and gravel mining facilities are common sites along the flood plain and immediate channel. The remainder of the channel from Country Club Road to Granite Reef Diversion Dam is dominated by natural features, although it is dotted with high tension towers and utility platforms. Water flows in the channel only during peak flow periods, and has become associated with large scale inconveniences for commuters.

6.2.6 Soils

Soils in the study area are within the Alluvial land association, an excessively drained, very gravelly sand alluvium in stream channels and adjacent lowlands, according to the Soil Conservation Service (1974). Detailed information on soils can be found in Section 5.

6.2.7 Surface Hydrology

Runoff from the Salt-Verde Watershed originates primarily in the mountains north and east of Phoenix and is stored behind six dams operated under the authority of the Salt River Project. Major diversions for agricultural, industrial, and municipal uses are controlled at the Granite Reef Diversion Dam. The normally dry Salt River runs from the diversion dam through the Phoenix metropolitan area to where it merges with the Gila River Channel.

Above the Granite Reef Diversion Dam, the Verde River contributes a significant amount of runoff. The drainage area is approximately 13,000 square miles at the Salt-Verde confluence (U.S. Army Corps of Engineers, 1977). From the confluence the drainage area continues west to the Gila River covering an additional 800 square miles of which contributing flows are negligible. Elevation ranges from 12,000 feet near the headwaters to 1,300 feet at the confluence of the Salt and Verde Rivers. The land changes from dry deserts in the Salt River Valley to pine forests in the higher elevations. Winter snows in the upper basin are a significant portion of the annual flows of the Salt and

Verde Rivers. Additional detail concerning hydrology of the study area can be found in Section 5.

6.2.8 Socio-Economic Environment

The principal socio-economic features of the environment are the presence of significant residential, commercial, and industrial development within the study area. Heavy and growing demand for water resources, both within and outside of the study area, serves to highlight the social and economic significance of large-scale water resources development projects.

6.3 Beneficial and Adverse Environmental Effects

Because of the pervasive and integral importance of water resources to the vitality of any environment, the potential scope of beneficial and adverse environmental effects associated with a recharge facility can theoretically be expanded indefinitely. For the purposes here, beneficial effects are those changes to the physical, social, economic, or environmental character of the study area which are caused by the project and result in the gain of some value or values. Conversely, adverse effects are changes which result in the depreciation of a value or values within the study area resulting from the demonstration project.

The costs and impacts of water resources development within the Salt-Verde Watershed are documented in a number of Environmental Impact Statements filed with the Council on Environmental Quality. Included in the file are statements for Orme Dam (Bureau of Reclamation, 1975), Granite Reef Aqueduct (Bureau of Reclamation, 1975), Buckhorn-Mesa Watershed Flood Management Plan (Soil Conservation Service, 1978), Queen Creek Watershed Flood Management Plan (Soil Conservation Service, 1978, and Roosevelt Water Conservation District Channel Expansion and Improvement (Bureau of Reclamation, 1978).

The following sections present a summary of potentially significant environmental impacts of a demonstration recharge project located within the study area.

6.3.1 Vegetation

Aquatic and channel vegetation would stabilize and flourish around the proposed recharge facilities. The vegetation would provide food and shelter for species expected to be reintroduced to this reach of the Salt River Channel. At the same time excessive vegetative growth could clog the soil, decrease the water quality, and provide food, shelter, breeding grounds for insect vectors. Excessive vegetative growth on dikes and levees would need to be controlled by physical or chemical means.

6.3.2. Wildlife

The use of recharge basins as the principle recharge mechanism in the Salt River Channel would result in the presence of standing pools of water for periods of time varying with facility type and methods of operation. The presence of additional sources of water could attract wildlife species, particularly waterfowl, not regularly seen in this portion of the Salt-Verde Watershed. But standing pools of water also have negative environmental aspects. If water depth remains constant for long periods of time, spreading basins will more resemble bogs than open pools of water. Algae and weeds may choke the basins and insect vectors could find thriving breeding grounds. The specific effects of standing water should be addressed in the demonstration project.

6.3.3 Cultural Resources

None of the 24 archeological sites within the study area are located in the Salt River Channel proper and only the sites at the confluence of Evergreen Drain and the Salt River Channel hold the possibility for immediate adverse impact from construction of a recharge facility. But these sites have already been disturbed by landfill operations; hence, any additional effects of a demonstration project on cultural resources are likely to be peripheral at worst. Any disturbances which might occur will most likely be associated

with alignment of access roads and location of service facilities. While all the answers to the problem are not known, it is likely that potential adverse impacts can be minimized through proper site selection and careful positioning of service roads and facilities.

6.3.4 Health and Safety

Potentially adverse effects could be felt from the presence of solid waste and sludge disposal sites within the study area. Unless these sites are taken into account so as to reduce the chance that wastes (and residues thereof) will enter the water environment, they may create vector, leachate, and ground-water contamination problems. Furthermore, such consideration is required under provisions of the Resource Conservation and Recovery Act of 1976.

Vector control appears to be a problem associated primarily with facility operational procedure. Control of insects is a management problem inherent with water spreading facilites. In the Rio Hondo spreading grounds control of insects has been effected by imposing wet-dry cycles. The procedure is described by Milne (1975):

> In general, the district (Los Angeles County Flood Contol District) has found the best control to be the interruption of the life cycle of the insect. Most of the problems have originated with chronomic midges. These insects readily develop in moving water. (Mosquito problems have been minimal because they propogate best in stagnant-water conditions). The life cycle is interrupted by an operation termed "battery spreading". This simply involves operating only one portion of the spreading grounds at any time; generally one-third of the grounds is wet, one third is drying and one third is dry; the period of each lasting from seven to ten days. This has been very effective for insect control, much better than the application of insecticides. In fact, it seems that insecticides also tend to kill off the natural enemies of the midges, thereby disrupting the ecological balance, with the usual result that the midges return much more quickly than their natural enemies, thereby creating a greater infestation than existed before the application of insecticides. This battery spreading also seems beneficial in maintaining infiltration rates which tend to drop off under long-term wet conditions.

It is possible that with the use of low quality water for recharge microbial and salinity problems may develop within shallow

aquifers.

In this period of concern for public safety, it should be recognized that pools of standing water could pose an unusual attraction to the general public. To provide adequate public safety at the project site, facility security and posting of warning notices should be considered.

6.3.5 Aesthetics

The aesthetics of the study area are likely to be impacted only insofar as the introduction of standing bodies of water enhance or detract from the study area's beauty, or lack thereof.

6.3.6 Soils

With the application of large volumes of water to small areas of land such as occurs in a recharge project, the possibility of water logging soils may present a problem. Because water logging is a function of specific soil parameters, any problems would be site specific and localized.

The problems of soil compaction, sediment sealing, and potential for aerobic conditions have also been recognized as potential impacts associated with recharge activities. For further details, refer to Section 5 for a description of soils in the study area.

6.3.7 Surface Hydrology

At the time of the original settlement of the Salt-Verde Watershed, the surface water system was developed for domestic and agricultural use. The surface and ground-water systems were in dynamic equilibrium; the system as a whole being effluent with a constant baseflow. With the development of efficient high capacity irrigation pumps capable of meeting growing agricultural demands, the area's ground water was developed intensively. Through the years, increased demand from municipal and industrial users has placed additional stress on the system and contributed to the development of a deep cone of depression centered in the areas around the Salt River flood plain (see Section 5). Because the surface water portion of the system has been diverted, stored, and controlled at upstream facilities operated under the authority of

the Salt River Project, natural recharge has been greatly decreased in the stretch of the Salt River Channel below Granite Reef Diversion Dam.

While the proposed system of recharge is not a flood control method, it is possible that flooding problems in the greater Phoenix metropolitan area could be reduced somewhat in magnitude if recharge facilities in the Salt River Channel were used for the capture of releases from upstream facilities. Although current upstream structures are neither designed for, nor operated with, flood control as a major function, flood control and conjunctive use operations could theoretically be coupled. For example, the volume in storage in surface reservoirs could be reduced to accommodate a portion of snowmelt runoff from upstream watersheds. Water released could be recharged in downstream facilities. Alternatively, flood waters could be diverted from a stream channel into off-stream recharge reducing downstream flood peaks. The demonstration project should be designed to answer these questions. The quantity of water lost to evaporation annually from Arizona reservoirs has been estimated as enough to supply the municipal demands of Tucson for a full year (Tucson Urban Study, 1979). Subsurface storage of water, via recharge facilities, offers the potential of reducing evaporation losses. However, the precise quantity of water which may be saved from evaporation and other losses by storage in subsurface reservoirs is not yet known.

It is possible that salts and chemical pollutants could increase in concentration with evaporation during storage in surface reservoirs. If so, water with higher salinity levels would be recharged and water quality in the immediate vicinity could deteriorate. The demonstration project should be designed to answer these questions.

6.3.8 Socio-Economic Impacts

The construction of demonstration recharge structures may result in minor inconveniences to local residents and commuters. The noise associated with construction could temporarily disturb

local businesses and residents. Dust pollution levels can be expected to increase temporarily with the presence of heavy earth-moving equipment in the construction area, but can be minimized by spraying with water.

It is possible that sewer line connections would be temporarily disconnected during construction.

Possibilities of the raised water table adversely impacting sand and gravel operations in the Salt River Channel is a concern. As such it must be addressed in any site specific assessment. Also, with the raised water table it is possible that water users in the area would have less incentive to practice water conservation methods.

6.4 Short and Long-term Effects of Artificial Recharge

For assessing the anticipated short-term or long-term environmental effects of a recharge project the following distinction is made: short-term effects are those effects associated with facility installation and operation which can be corrected by using proper management techniques over a relatively short period of time; whereas, long-term effects are those effects which are either permanent or could be corrected only during the course of the full-scale project.

6.4.1 Anticipated Short-Term Effects

6.4.1.1 Vegetation

It is anticipated that vegetation in the immediate area of spreading activities will be periodically inundated. Species less tolerant of such environmental conditions would not be expected to survive in the immediate spreading area. The major short-term effect on vegetation would be the possible disruption caused by construction of well and water transport systems.

The major question concerning vegetation which will need to be addressed in a detailed environmental assessment for a full-scale recharge project, is whether the vegetation will return to the area by natural processes. If not, replanting would be required to stabilize structures and enhance aesthetic quality. The

demonstration project is small scale and would be located in the river channel which essentially is devoid of vegetation.

6.4.1.2 Wildlife

It is expected that there will be short-term adverse impacts upon local wildlife habitat in the immediate area of activities associated with facility construction and maintenance. Consider, for example, the consequences of contructing monitoring wells. Because percussion well drilling is loud and tends to vibrate the immediate area, any animals which live in the area, particularly burrowing rodents, will be temporarily disturbed. The loss of vegetative cover would strip some species of food and shelter but species would be expected to return once construction ceased and revegetation is completed. Burrowing rodents, however, will have to be eradicated to protect earthen levees.

6.4.1.3 Cultural Resources

Construction activities, especially the construction of access roads, could have a major disruptive impact on archeological and historical sites. Because of the site specific nature of the impacts, care should be taken by planners to learn the locations of cultural resources. Consultation with a trained archeological consultant or the state historic preservation officer is recommended.

6.4.1.4 Health and Safety

Short term health considerations focus on the surface spreading area becoming a possible breeding ground for insect vectors. The use of biological controls, technical spreading mechanisms, and chemical pesticides could alleviate the vector problem. If chemical pesticides are selected, additional environmental impacts associated with water contamination would become important.

6.4.1.5 Aesthetics

The local landscape will be altered by the presence of additional structures. The degree to which landscapes will be altered during project construction depends on the nature and design of the facilities used.

Problems may exist if storage facilities are required to retain

and deploy water to be recharged. Stored water or effluent water used for recharge may have negative aesthetic properties of color and odor to an extent dependent on the quality of the water to be recharged and the proximity of the project site to urban or industrial areas.

6.4.1.6 Soils

It should be anticipated that an acceleration of soil erosion will accompany construction activities. The effect upon erosion rates would be dependent on the degree of disruption and the soil type of the specific site. Revegetation and/or land treatment measures could minimize any adverse surface erosion impacts.

Soil sealing by algae and cattails could become a serious problem under particular soil conditions. Methods for control include site selection, herbicides and algicides, biological means, and physical removal. Any additional impacts of chemical contamination of recharged water should be investigated during a site specific environmental assessment.

Subsurface short-term impacts of soil sealing and compaction can be expected from the use of heavy machinery. The impacts would be greatest upon silt and clay type soils.

6.4.1.7 Surface Hydrology

The installation of recharge structures in the river channel could temporarily obstruct river flows during releases from Granite Reef Diversion Dam. Consequently, flood water could spread laterally onto adjacent flood plain. Also, a back-water effect might be produced in the water surface profile. In all probability, however, recharge structures such as levees would be quickly washed away by river flows of any significant magnitude.

A second short-term effect is that during prolonged spreading operations, clogging of the surface occurs, resulting in a reduction of intake rates. Consequently, the amount of streamflow depletion by infiltration during floods would be reduced in the project area compared to that occurring in other sections of the channel. A concomitant amount of water would move downstream,

possibly adding to flooding problems. Moderating effects include: 1) the surface area of the spreading basins affected by reduced intake rates would be miniscule compared to the total surface area of the channel, and 2) river flows actually scour surface impeding layers, resulting in augmented intake rates.

6.4.1.8 Socio-Economic

Short-term adverse effects would be felt as temporary nuisances and inconveniences associated with construction activities. These effects are discussed earlier in this section.

6.4.2 Anticipated Long-Term Effects

6.4.2.1 Vegetation

Anticipated long-term effects on vegetation will be primarily on the micro-environment scale. Nevertheless, they may be significant. Aquatic vegetation is expected to thrive in the recharge basin basins and such species as algae, cattails, and grasses could pose problems. Specific micro-environmental issues which need to be addressed in the demonstration project include the following:

1) Possible impact on wildlife,
2) Possibilities of soil sealing,
3) Secondary effects on agricultural activities, and
4) Impact on downstream vegetation.

6.4.2.2 Wildlife

Aquatic wildlife can be expected to invade the micro-environment around the recharge basins. Reptile and amphibian populations would increase around standing pools. Bird species, including migratory and sedentary waterfowl and songbirds, would be expected to return to this reach of the Salt River Channel, below Granite Reef Diversion Dam and above Tempe Butte, on a regular basis.

Fish, primarily goldfish and carp, could be expected to thrive in standing pools of water. Microbial populations would also be expected to increase. The effects upon other types of wildlife, including hunting and exotic species, and possibilities for stocking game fish warrant additional investigation.

6.4.2.3 Cultural Resources

Destruction of archeological and historical sites can be minimized through proper site selection, and care taken when locating access roads. A detailed analysis should be included in any site specific environmental assessment.

6.4.2.4 Health and Safety

The possibilities of health hazards exist if sewage effluent is used for recharge purposes. Principal concerns relate to the introduction of nitrates, toxic organics, and microorganisms into ground water. Further study should be directed to the scope and magnitude of the problem and to the Federal, State and local water quality standards that must be met.

The possibilities of seepage from known landfills and sludge disposal sites could pose a potential health hazard. Landfills and disposal sites should be located and care should be taken to avoid project location in their environs. Once again, the main problem would be associated with high flows on the Salt River.

6.4.2.5 Aesthetics

Since the facility would be located in or near the Salt River Channel it has the potential for standing in stark contrast with the natural conditions of the channel. Because aesthetic quality is such a variant, the question of the appealing or degrading aesthetic characteristics of a facility are a matter of individual preference and design expertise.

Small areas of desert could be permanently scarred if care is not taken during construction. Small tracts of land would be permanently used for spreading basins; however, most land will be in the barren low-flow channel. Swamp conditions within the recharge basins are a potential aesthetic problem if vegetative growth is not properly managed.

Long-term beneficial effects would also include the cooling and attractive benefits of observing water in a normally dry river channel.

6.4.2.6 Soils

Soils could be permanently sealed due to heavy siltation, although periodic floods may promote scouring. Unless banks are reinforced and/or vegetated, accelerated erosion could become a severe problem. Anaerobic soil conditions are possible if flooding is not periodic. Total dissolved solids (TDS) and alkalinity problems could arise if evaporation rates from basins are high.

6.4.2.7 Surface Hydrology

Long-term effects on surface hydrology which may occur include the creation of standing pools of water and a rise in the water table. One purpose of an artificial recharge facility is to restore the balance to the hydrological system disrupted by ground-water pumping and surface water storage projects.

6.4.2.8 Socio-Economic Impacts

Significant long-term impacts may be adversely felt by sand and gravel operations in the channel if the water table is raised. A raised water table may also reduce an awareness of the need for water conservation. A long-term beneficial affect might result from recreational uses of the facility.

6.5 Summary of Resource Commitments

The demonstration and full-scale ground-water recharge projects will involve full commitment of several resources. They include the following:

1) The desert land utilized for the project.
2) The vegetation, wildlife, and archeological sites associated with this land.
3) The water used for recharge in the project.
4) The aesthetics associated with the undeveloped site.
5) Energy and construction materials expended in site development and maintenance.

6.6 Summary of Additional Investigations Needed

The following is a list of investigations which would be conducted during the demonstration project:

1) The affect of the project on wildlife habitat, the attraction of new species, and vegetation including downstream riparian vegetation.
2) Impacts on cultural resources.
3) The quantity of water lost to evaporation.
4) Effects of salinity and microbial activity on water quality.
5) Vegetation types best suited for bank stabilization.
6) Soil problems of sealing, compaction, anaerobic conditions, microbial activity and accelerated erosion.
7) Effects of raised water tables on agricultural and industrial activities.
8) Recreational use of the facility and associated service facilities.
9) Potential health problems, including seepage from landfills, flooding from Salt River and vector control.

6.7 Compliance of a Demonstration Recharge Project With Federal and State Environmental Regulations

The operation of water spreading basins, pits, or a recharge project may need to comply with regulations presently being promulgated by the U.S. Environmental Protection Agency. For example, the Resource Conservation and Recovery Act (RCRA) is concerned, in part, with the disposal of hazardous wastes, including municipal wastes, via pits, ponds, and lagoons. Thus, the project management agency may need to obtain a permit to recharge sewage effluent via spreading basins or pits.

The operation of a recharge well falls within the aegis of the Safe Drinking Water Act. In particular, a recharge well would be classified as a Class V injection well, according to proposed EPA regulations under the State Underground Injection Control Programs (Federal Register, April 20, 1979, Part III, pp. 23738-23767). Class V wells inject "...non-hazardous fluids into strata that contain underground sources of drinking water. It includes but is not limited to the following types of injection wells: waste

disposal wells...and recharge wells....". Particular criteria and standards which a management agency may need to comply with during operation of a recharge well are presented below (ibid.):

Section 146.51 General

This subpart sets forth requirements for underground injection control programs to regulate all injection not regulated in Subparts B, C, D, and E. Generally, wells covered by this Subpart inject non-hazardous fluids into strata that contain underground sources of drinking water. It includes but is not limited to the following types of injection wells: waste disposal wells, such as dry wells, non-residential septic system wells, and sand backfill wells; and recharge wells, such as drainage wells, cooling water return flow wells, air conditioning return flow wells, salt water barrier wells and subsidence control wells (not associated with oil and gas production).

Section 146.52 Inventory and Assessment

a) The owner or operator of any Class V well shall, within six months of the effective date of an underground injection control program, notify the Director of the existence of any well meeting the definitions of Class V under his control, and submit a description of:

1. The construction features of the well;
2. The nature and volume of injected fluids;
3. The alternative means of disposal available to the operator, and
4. The environmental and economic consequences of well disposal and its alternatives.

b) Within 2 years of approval of the State program the Director will make and report to EPA:

1. An assessment of the contamination potential of the Class V wells using information supplied by the operator and hydrogeological data available to the State;
2. An assessment of the available corrective alternatives where appropriate and their environmental and economic consequences; and
3. Recommendations both for the most appropriate regulatory approaches and for remedial actions where appropriate.

Section 146.53 Requirement

If at any time the Director gains knowledge of a Class V well which presents a significant risk to the health of persons, he/she shall, under 40 CFR 122.46(b), prescribe such action as necessary (including the immediate closure of the injection well) to remove such risk.

6.8 Estimated Budgetary Requirements

The total budgetary requirements estimated for completion of additional investigations is $38,503. The total time required is estimated to be 29 months of full-time work. The following diagram (time line) represents the time requirements and sequence for completing tasks involved in additional investigation of environmental considerations.

TIME LINE - ENVIRONMENTAL CONSIDERATIONS

Task	First Year	Second Year	Third Year	Fourth Year	Fifth Year
Wildlife Studies	→	→			
Vegetation Studies		→	→	→	→
Vector Control	→	→	→	→	→
Soil Sealing Studies	→	→			→
Air Quality Monitoring	→				
Water Quality Monitoring	→	→	→	→	→
Monitoring of Water Levels	→	→	→	→	→
Recreational Use of Basins if used		→			
Noise Monitoring	→				

7. INSTITUTIONAL CONSIDERATIONS

7.1 Introduction

Before an artificial recharge project can become an integral part of a regional water resource management plan, certain institutional factors should be taken into consideration. For example, the attitudes, whether positive or negative, of various key agencies in the region toward artificial recharge should be determined and evaluated. Institutional attitudes indicate the degree of support which exists in the area for a recharge project, and, thus, the probable degree of success of such a project. In addition, the institutional requirements imposed by a recharge project should be determined, and the capabilities of existing institutions evaluated in terms of those requirements. Another consideration should be the amount of institutional change required for the implementation of a recharge project, and the ability of existing institutions to make those changes. Institutional analysis is necessary to ensure that technical plans for artificial ground-water recharge projects are implementable in terms of the institutional framework of the region. Such analysis should be completed prior to implementation of either a demonstration or full-scale project.

The institutional analysis in this report is a planning device which will provide the implementing agency with information about the institutional framework within the Phoenix metropolitan area so that legal and political factors will be adequately considered in formulating implementable water resource management plans, and more specifically, in designing an implementable artificial ground-water recharge project for the Salt River Valley. Such an analysis has several components: (1) the identification of institutions directly or indirectly related to water resource planning in the area; (2) an evaluation of the organizational structure, legal authority, financial capabilities, interdependencies, and attitudes of these insti-

tutions; (3) a determination of the institutional requirements imposed by alternative artificial ground-water recharge project plans; (4) an assessment of the capabilities of existing institutions to implement those alternatives; and (5) a presentation of any institutional changes required to implement project plans.

Institutional analysis, however, is not limited to the identification and evaluation of the capabilities of governmental and private organizations. It also explores the policy variables, local customs and values, legal constraints, and other factors which may affect the planning and implementation of a recharge project. Institutional analysis is thus structured to assist a planning agency to determine feasibility, design and implement artificial ground-water recharge projects which best fit local characteristics and requirements without sacrificing technically, economically, and environmentally feasible solutions.

7.2 Objectives

The institutional analysis in this report has 3 major objectives. The first is to make a preliminary inventory of the existing institutional framework of ground-water management agencies in the Phoenix metropolitan area. The purpose of this inventory is to determine which institutions will be involved in, or impacted by, an artificial ground-water recharge demonstration project in the Salt River Valley. The inventory includes the history, purpose, organizational structure, legal authority, financial resources, and attitudes of these institutions. The inventory also includes an evaluation of important political trends which may have an impact on the recharge project.

The second objective is to determine the institutional incentives and constraints which may influence the implementation of a recharge project. These incentives and constraints are considered in terms of their impact on the planning, design, construction, and operation

of both a demonstration and a full-scale artificial ground-water recharge project. As part of the second objective, this report suggests an analytical process for assuring that such institutional considerations are examined during all of the phases of an artificial recharge project.

The third objective is to estimate the staff and time which are required to incorporate an institutional analysis component into an artificial ground-water recharge demonstration project. Institutional analysis should be included in each phase of a demonstration project. Thus, the estimation includes both the minimal and optimal levels of staff and time necessary to incorporate institutional analysis throughout the demonstration project.

7.3 Specific Study Approaches

Several general analytical principles were utilized in the institutional analysis presented in this report. The first principle was that collection of data was viewed as an iterative process; no attempt was made to collect full and complete information at the outset. Instead, as important information emerged, it was integrated into the initial data set. Thus, the collection and evaluation of data were ongoing, continuous processes.

The second general principle was to make maximum use of existing reports, information and publications. The utilization of existing information enabled the researchers to build on past efforts and to concentrate on filling data gaps.

The third principle was to evaluate carefully each type of information in terms of its potential usefulness. The purpose of institutional analysis is to assess and evaluate the institutional feasibility of various technical alternatives. Thus, the researcher must determine what information is useful and what is not in achieving that purpose. The biggest problem in institutional analysis is deciding what data to collect and what data will be useful in the analysis. Much care

must be exercised in order to avoid getting caught up in merely completing the institutional inventory.

The fourth general principle was to select a prototype of the institutions under consideration. Rather than attempting to collect information from each unit in a similar group (i.e., all municipalities, or all irrigation districts), a prototype from each group was selected. This prototype served as a representative for that group. Later, if additional information is required, other members of that group can be contacted.

Two specific approaches were also utilized in the prepartation of the Institutional Section of this report. The first was literature search and review. In addition to utilizing the results of the RECON search, the following indices were consulted: The Index to Legal Periodicals, September 1967 to date; The Index of Periodicals Related to Law, Vol. 1 to date; Environment Index Vol. 1 (1971) to date; and Environmental Periodical Bibliography, Vol. 1 (1972) to date. The objectives of the literature review were threefold: first, to establish the general policy framework and institutional setting for water resource planning and management in Arizona; second, to identify institutions with water management authority in the Phoenix metropolitan area; and third, to identify the major institutional variables which have affected the implementation of ground-water recharge projects in other areas of the country.

The information that was obtained from this bibliographic search has been incorporated into the remainder of this section. Those studies and articles which could not be obtained and examined during the study period are included in the bibliography. These materials may provide useful information concerning legal-institutional aspects of artificial ground-water recharge, and should be consulted by project planners at a later date.

The second specific approach utilized in the formation of this section was a personal interview procedure. From the literature re-

view, several institutions emerged as being influential in the project area. A number of these institutions were contacted and key personnel with them interviewed. The interviews were used to fill gaps in the data obtained from the literature search and to determine the attitudes of the institution toward artificial ground-water recharge. A more detailed description of the process utlized in this interview procedure is discussed later in this section of the report.

7.4 Site Specific Implications

7.4.1 Institutional Inventory

7.4.1.1 Introduction

The first objective of this institutional analysis is to make a preliminary inventory of the institutions in the Salt River area which will be involved in or impacted by an artificial ground-water recharge project. Such an inventory should indicate which institutions are most involved in water management, planning and use, and provide a broad picture of the specific institutional framework of the Salt River Valley. The next section of this report will outline the procedures used to determine the key institutions in water resource management in the Phoenix area. The subsequent section will briefly describe these institutions.

7.4.1.2 Analytical Process

The first step in forming an initial list of institutions was to examine existing reports and information on the various federal and state institutions involved with water. Three documents were especially useful in this procedure: OEPAD's (Arizona Office of Economic Planning and Development) Arizona's Role in Water Quality Management (1977), OEPAD's The Federal Role in Water Quality Management (1977), and the U.S. Army Corps of Engineer's Draft Institutional Inventory, (1977). These documents provided the information needed to compile an initial list of the possible important institutions relative to a demonstration recharge project.

The second step (which took place concurrently with the first) was to classify these institutions into governmental and private groups. The governmental institutions were further classified according to level: federal, state and local. The private institutions were classified according to their major function, e.g. business, civic environmental, or agricultural.

The third step was to determine which of these institutions might have impact or be impacted by a recharge project. The degree of impact was divided into three categories: direct or primary impact, indirect or secondary impact, and no obvious impact. The decision as to the kind of impact of a specific institution was made on the basis of its area of authority, area of jurisdiction, and regulatory authority. Table 7-1 lists the institutions involved in water management, planning, and use in the Salt River Valley and further classifies them according to the above criteria.

After this list was compiled and the institutions classified, certain organizations and agencies were selected for further study and analysis. The decision as to which institutions were selected was based on two criteria: (1) how direct an impact an institution might have on a demonstration recharge project, and (2) the "prototype principle" mentioned earlier in which a representative from a particular group is selected. In this study, most of the directly impacted governmental institutions at all three levels were analyzed. However, due to time constraints, not all of the possible private interests could be notified. Moreover, none of the private organizations were analyzed.

Those institutions selected for further analysis were contacted, and key personnel within them interviewed. The purposes of these interviews were to inform the institutions of the need for a demonstration project, to solicit their attitudes toward artificial groundwater recharge, and to assess in more detail the kind of impact they might have on the project. The areas covered in the interviews were:

(1) general role in water management and use in Phoenix metropolitan area, (2) responsibility over ground water, (3) concerns regarding artificial recharge, and (4) potential role in a demonstration project.

Table 7-1

INSTITUTIONS INVOLVED IN WATER MANAGEMENT IN SALT RIVER VALLEY

Institution	Direct Impact	Indirect Impact	No Obvious Impact
Governmental:			
A. Federal			
*1. Bureau of Indian Affairs	x		
2. Bureau of Land Management	x		
*3. Bureau of Reclamation	x		
4. Environmental Protection Agency	x		
5. U.S. Forest Service		x	
6. Department of Commerce			x
7. Department of Health, Education and Welfare			x
8. Department of Housing and Urban Development			x
9. U.S. Geological Survey		x	
10. Bureau of Outdoor Recreation		x	
11. National Park Service			x
12. Fish and Wildlife Service		x	
13. Water Resources Council		x	
14. Soil Conservation Service			x
15. Federal Housing Administration			x
16. U.S. Army Corps of Engineers	x		
B. State			
*1. Arizona Water Commission	x		
*2. State Land Department	x		
3. Department of Health Services	x		
4. Water Quality Control Council	x		
+5. OEPAD		x	
6. Game and Fish Commission		x	
7. Outdoor Recreation Coordinating Committee		x	
8. State Parks Board		x	
*9. Groundwater Management Study Commission	x		

*Interviewed +Contacted

Table 7-1
(continued)

Institution	Direct Impact	Indirect Impact	No Obvious Impact
Governmental:			
10. Oil and Gas Conservation Commission		x	
11. Office of the Governor		x	
C. Local			
*1. Maricopa Assn. of Governments	x		
*2. Tempe	x		
*3. Scottsdale	x		
*4. Mesa	x		
5. Phoenix	x		
*6. Salt River Project	x		
7. Roosevelt Water Conservation District	x		
8. Flood Control District of Maricopa County		x	
9. Maricopa County	x		
10. Central Arizona Water Conservation District	x		
Private:			
A. Environmental		x	
1. Sierra Club		x	
2. Audubon Society		x	
3. Arizona Wildlife Federation			
B. Business			
1. Sand and Gravel Operators	x		
C. Agricultural			
+1. Farm Bureau	x		
D. Civic			
1. Valley Forward Association	x		
*2. League of Women Voters		X	

*Interviewed +Contacted

The next section outlines the history, purpose, area of jurisdiction, functional authority and attitudes of each of the institions selected for analysis.

7.4.1.3 Federal Institutions

7.4.1.3.1 Bureau of Reclamation

The Bureau of Reclamation is an agency within the Department of Interior. Its original mandate was to "locate, construct, operate, and maintain works for the storage, diversion, and development of waters for the reclamation of arid and semi-arid lands in the Western States" (Federal Role, p. 911). Its area of jurisdiction is limited to the seventeen contiguous western states, Hawaii and Alaska. Its traditional area of concern has been the development of irrigation projects for agriculture. However, the Bureau has been moving out of this traditional role and into other areas such as energy related projects, municipal and industrial supplies, recreation, fish and wildlife enhancement, total water management, water quality enhancement and water efficiency as it relates to farmers and cities. According to a spokesman for the Bureau there has been a definite shift in emphasis from traditional areas of concern to other areas, especially water and energy conservation (Burbey, personal communication, 1978).

The functional authority of the Bureau is limited to the construction, maintenance, and operation of projects which it has built. It has no regulatory authority beyond those works for which it is responsible. Its main concerns in the Phoenix area are construction of the Central Arizona Project (CAP)--a major reclamation project designed to bring Colorado River water to central and southern Arizona--and the investigation of other potential water resource projects.

The Bureau has no legal mandate giving it direct authority over ground water. However, the Bureau may have some responsibility over ground water as it relates to land drainage works, such as those in the Wellton-Mohawk area, and total water management plans, such as the Lower Colorado Management Program. Another indirect Bureau authority over ground water is its responsibility to administer the contracts for CAP water. The CAP legislation states that agricultural water users

who contract for CAP water must reduce their use of ground water by an amount equal to project water received. The Bureau's responsibility is to ensure compliance with this regulation. However, this management of ground-water use is limited to users of CAP water only; it cannot extend to basin-wide ground-water management.

The importance of the Bureau relative to a demonstration project lies in two areas. First, CAP water may be a possible source of water for the full-scale recharge project. If CAP water was contracted and paid for, the Bureau would be the agency responsible for delivery. However, because CAP water will not come to the Phoenix metropolitan area until 1985, it would not be available for a demonstration project prior to 1985. A second area in which the Bureau might assist is the provision of staff and funding. It may be possible to use CAP money for the construction of a long-term recharge project for the Salt River. One problem with the use of CAP money is that the Bureau must demonstrate that a substantive relationship exists between CAP water and any artificial ground-water recharge project (Burbey, personal communication, 1978).

In general, the Bureau feels that artificial ground-water recharge is an important component of any total water management plan in Arizona. It should be viewed in conjunction with surface water reclamation projects and water conservation measures as a device useable to solve one part of the total water problem. However, to maximize artificial ground-water recharge from local floodwaters, storage is needed to regulate the floodwaters. Artificial recharge has its own niche in any water management plan and should be carefully investigated as to its technical feasibility (Burbey, personal communication, 1978).

However, the Bureau does see two institutional problem areas. First, the beneficiaries, those using the recharged ground water, need to be identified. The beneficiaries need to be identified so that they can be charged for the benefits received. Second, legislative changes are needed if the Bureau were to sponsor a recharge project (Burbey, personal communication, 1978). To date , no institution exists in Arizona which would have ultimate authority over a recharge project.

Overall, the Bureau of Reclamation was supportive of the concept of artificial ground-water recharge. It indicated a willingness to provide technical assistance and, possibly, funding. If technical problems can be overcome, the Bureau feels that artificial ground-water recharge can be viable water management technique for the Phoenix metropolitan area.

7.4.1.3.2 Bureau of Indian Affairs - Salt River-Pima-Maricopa Indian Community

The Bureau of Indian Affairs (BIA) has the responsibility "to actively encourage and train Indian . . . people to manage their own affairs under the trust relationship to the federal government" (Federal Role, p. 74). The BIA is authorized to use funds "to extend, improve, operate and maintain existing irrigation systems and to develop water supplies" (Rich, p. 19). The BIA is also authorized "to effect a just and equal distribution of the water among Indians on the reservation" (Rich, p. 19). In relation to water management, the BIA is responsible for the development and operation of irrigation projects on Indian lands.

However, most of the authority for everyday Indian affairs resides with the individual tribes. Each tribe has a tribal council which establishes the laws and policies which will govern the people of the Indian community. Thus, in analyzing the impact of Indians on a recharge project, the individual Indian tribes in the area should be contacted. In this case, the Salt River-Pima-Maricopa Indian Community is the tribe which would be most directly involved in a demonstration project.

The Salt River-Pima-Maricopa Indian Community is a principal water user in the Salt River area. Its primary use of water is for irrigated agriculture. The Indians are attempting to institute some water management techniques on community land, such as recycling ponds (used for recycling tailwaters from the fields). In addition, the Community is attempting to institute some type of regulation or inventory of ground-water use on Indian land. Participation of the Salt River Indians in other water management functions, such as 208 water quality planning or flood control district meetings, is severely limited by a lack of staff (Evans, personal communication, 1978).

The Community's primary concern about water is the amount available for irrigation. Heavy pumping on the borders of the Community is causing the ground-water table to drop. The Indians are concerned that their water is being pumped from underneath them. In addition, the Community is trying to secure surface water rights from the Salt River Project for available land north of the Arizona Canal (this land does not now have any surface water rights) (Evans, personal communication, 1978).

The Salt River-Pima-Maricopa Indian Community would be important in a demonstration recharge project because of the extent of its land, the location of potential reservoirs, and its interest in recharge. Almost the entire northern portion of the project area and the Salt River itself is on Indian land. Any recharge project is bound to have an effect on the Indians.

The Salt River-Pima-Maricopa Indian Community is very interested in artificial recharge for two reasons. The first is a desire to restore the declining ground-water table. Due to heavy pumping, both inside and outside the Community, the water table is dropping. Recharge may be able to halt or reverse that trend. The second reason is the possibility of utilizing the recharge basins (if that is the method selected for use) for recreation. The Indians are desirous of using the basins for fishing, boating, and other water-based recreation for their community (Evans, personal communication, 1978).

The Salt River-Pima-Maricopa Indian Community is very supportive of an artificial ground-water recharge project. If the technical aspects are suitable, the Community may be able to provide a site and/or water for a recharge project. However, if such a project were located on Indian land, the Community would want to retain control of it.

7.4.1.4. State Institutions

7.4.1.4.1 State Land Department

The Arizona State Land Department (ASLD) is a powerful institution in the State of Arizona. It is "responsible for the planning, development and protection of all forests and natural resources located on State land" (State Role, p. 36). In addition, it is "empowered to ad-

minister laws relating to waters of the state" (Draft Institutional Inventory, p.28) as well as "laws relating to the lands owned by, belonging to, or under the control of the state" (State Role, p. 36).

The ASLD's water authority is of primary importance to this study. The department is authorized to "formulate and prescribe rules and regulations governing the appropriation and distribution of water" (State Role, p. 36). This authority includes the recording of appropriated water rights as well as the administration of application procedures for the appropriation of public waters. The State Land Commissioner (appointed by the governor) is ultimately responsible for approval or regulation of these applications.

The State Land Department is also the major state agency involved in ground-water regulation. Under the Groundwater Code of 1948, it is authorized to designate critical ground-water areas. Construction of new wells for the purpose of irrigating lands not under cultivation at the time of designation as a critical area is prohibited (Allen, personal communication, 1978). Anyone wishing to drill new wells for non-restricted purposes, or to replace or deepen existing wells in the area, must be issued a permit by the department.

A new responsibility over water was recently added as a result of the 1977 Groundwater Transfer and Management Act. Under this legislation, the department may issue certificates of exemption which allow the transfer of water from a critical ground-water area to another location. The courts have not clearly defined a "transfer of water"; however, the department's working definition is "the removal of water from its original place of use to another place foreign to its original area" (Allen, personal communication, 1978).

The State Land Department has expressed two concerns regarding ground water. The first is the lack of knowledge about the actual amount of ground water that is being pumped out of the Salt River Basin. No comprehensive system exists which monitors all of the existing wells in the area. Without this knowledge, it is difficult to determine the actual ground-water level and to evaluate the rate at which it is dropping. A second concern is the department's inability to require full compliance with existing ground-water laws. Since many of these laws only carry

misdemeanor penalties, county attorneys are often unwilling to prosecute offenders (Allen, personal communication, 1978).

The State Land Department will be important in a demonstration project in three ways. First, if the project were located on state land, the department would be very concerned about any effects it might have. In addition, the department may want to retain control over a recharge project on state land. A second impact the ASLD may have on a demonstration project is in the actual operation of the project. Since the department is responsible for administering the water rights for the water in the state (both surface and ground-water), it would be concerned about the source of water, the quality of the water, and the methods of injection and extraction. It will likely have some regulatory authority over the project. The third impact may be actual technical assistance in determining the best method of recharge (Allen, personal communication, 1978).

The Arizona State Land Department is somewhat supportive of a recharge project for the Salt River; however, a department spokesman expressed some concern over the practicality of recharge. The first concern deals with the legal questions involved with artificial recharge: whose water is used? what happens to the water once it's injected? who has legal ownership of the water after it is injected into the ground-water aquifer? The second concern is the technical questions: how to inject the water? where does the water go after it is injected? is it retrievable? The third concern is the economic aspect: is it economically practical? (Allen, personal communication, 1978).

The principal role of the State Land Department would be technical assistance. The department is unsure as to any other role it might have, such as regulating or managing the project.

7.4.1.4.2 Arizona Water Commission

The State Legislature established the Arizona Water Commission (AWC) in 1971 in an effort to centralize state water responsibilites. The Water Commission has "responsibilities for the development, management, conservation, and use of watersheds and waters in the State" (State Role, p. 65). It is also "responsible for acquiring, preserving, publishing, and disseminating information, and for making studies of the waters of the state" (State Role, p. 65). Other duties of the Water Commission

include supervision of dam safety, dispersal of flood control assistance monies, and investigation of flood control projects at the request of any public agency.

The primary role of the Water Commission is in the area of water planning. The AWC is "authorized to plan for development and utilization of interstate, intrastate ground and surface waters and to consider aspects of both water quality and quantity" (Draft Institutional Inventory, p. 27). Currently it is preparing the Arizona State Water Plan which is designed to "provide the physical and economic information required for decisions concerning management of the waters of the state" (State Role, p. 65). In Part I, Phase 3 of the Arizona Water Plan, for example, the Water Commission recommends that Arizona water law be amended to "permit the formation of replenishment districts authorized to develop the works necessary to increase recharge of ground waters from flood waters and from the Central Arizona Project and to impose charges on ground-water users in proportion to benefits received" (Part I, Phase 3, Arizona Water Plan, p. 4). In addition, the AWC works closely with and provides technical support to the staff of the Groundwater Management Study Commission.

The AWC is also conducting a series of studies on a contractual basis for the Groundwater Management Study Commission. The first is a baseline study which analyzes eleven water basins in the state and asks the question "what would happen in these basins if various trends continued with no changes in the law?" The second study involves evaluating several water management options. Each management option includes both a management goal (safe yeild, planned depletion, or prolonged basin life) and a management method including such techniques as pump tax, artificial recharge and land retirement. (Ferris, personal communications, 1978).

The Arizona Water Commission has no direct regulatory power over the waters of the state. Rather, it is a water planning agency. However, it does have some quasi-regulatory powers. The AWC is required "to evaluate the adequacy of water supplies for proposed subdivisions in

the state and to forward a copy of the evaluation to the Real Estate Commission" (State Role, p. 65).

The Water Commission feels that artificial ground-water recharge is one piece of a comprehensive water management plan. However, artificial recharge is not an overwhelmingly important piece of that water plan. A spokesman for the agency expressed concern that the feasibility and desirability of recharge has not yet been demonstrated. Until the desirability (technical and economic) of recharge can be demonstrated, other more serious problems cannot be resolved (Clark, personal communication, 1978).

A major problem which the AWC sees with artificial recharge is in the legal area. According to the agency spokesman, the Salt River Valley is one of the worst problem areas in the state in terms of legal and institutional problems. However, the technical desirability of recharge should still be demonstrated before these institutional problems are tackled.

The Water Commission has several reservations about the desirability of an artificial ground-water recharge project. However, it would be willing to provide technical data for the planning and construction of such a project. Any other participation in the project would be minimal.

The impact of the AWC on a recharge project would not be as great as the other institutions mentioned previously. The primary role of the Arizona Water Commission would be technical assistance in planning, constructing and testing a recharge project.

7.4.1.4.3 Groundwater Management Study Commission.

The 1977 Groundwater Transfer and Management Act established the Groundwater Management Study Commission. The Commission is composed of twenty-five persons: fourteen members of the Arizona House and Senate; two representatives each from mining, municipal and agricultural interests; one representative each from Indian communities and the utilities; and three members of the general public. The Commission's statutory mandate is "to make findings and recommendations and prepare legislation to provide for the best development, utilization and conservation of

ground-water in the state, including utilization of alternative sources of water, methods of management of ground-water resources throughout the state, limiting depletion to reasonable rates, and establishment of incentives to encourage efficiency, conservation, reuse and importation of ground-water" (Rich, p. 50). By December 31, 1979, the Commission's final report, which will contain the recommended constitutional or statutory amendments, is due. If the state legislature fails to act on the Commission's recommendation by September 1981, the Commission's recommendations become law.

The Commission faces a formidable task. It is the fourth such study commission to be formed for the purpose of revising Arizona's ground-water laws. The members of the Commission, especially those representatives of the major interest groups, are interested in seeing some real changes in Arizona ground-water laws. However, the major problem facing the Commission is how to develop meaningful standards for ground-water management without being too restrictive that is--how to bring flexibility into the law and yet be comprehensive. The informal consensus of the Commission at this point is that it favors the creation of ground-water management districts to provide for localized solutions to local problems.

The major impact of the Commission on a recharge project will not be felt until its recommendations are submitted to the Legislature. At that time, legislation may be enacted which could help or hinder development of a recharge project. However, the Commission is interested in the feasibility of artificial recharge and could formulate its recommendations so as to eliminate many of the existing legal barriers to recharge.

7.4.1.5 Local Institutions

7.4.1.5.1 Salt River Project

The Salt River Valley Water Users Association was created in 1903 as a result of the federal government's request for an organization which represented "owners of a majority of the acreage suitable for irrigation" (Draft Institutional Inventory, p. 112). The National Reclamation Act of 1902 made federal aid available for construction of recla-

mation projects. The Association was a corporation that would guarantee the repayment of construction costs for reclamation facilities along the Salt and Verde Rivers, collect from landowners, and insure an equitable distribution of water and water rights to landowners in the reclamation area.

In 1937, the Association founded the Salt River Valley Project Agricultural Improvement and Power District in order to receive the privileges and immunities of a municipality. All property rights were transferred from the Association to the District. Both organizations, although legally distinct entities are commonly referred to as the Salt River Project (SRP).

The Salt River Project is a major supplier of water and power to landowners and public utilities in the metropolitan Phoenix area. It is responsible for the operation, maintenance and construction of power and irrigation systems.

In order to provide water to its customers the Project utilizes a form of conjunctive water use. When surface runoff is high, little ground water is used. Conversely, when surface runoff is low, more ground water is pumped.

The Project sees artificial ground-water recharge as only one of many alternatives for dealing with ground-water problems in the Salt River Valley. Some of its major concerns are: 1) technical: is artificial ground-water recharge technically possible, and how much is actually recoverable?; 2) economic: how expensive will recharged water be compared to other types of water; 3) legal: who owns the water after it has been recharged?; and 4) quality: how "good" does the water used in recharge have to be in relation to existing ground water? (Small, personal communication, 1978).

The Project is generally supportive of a demonstration recharge project. A spokesman for the Project indicated that it would probably be able to provide technical assistance to a demonstration project. However, the Project believes that other alternatives, such as recycling of sewage effluent, should also be investigated (Small, personal communication, 1978).

7.4.1.5.2 Maricopa Association of Governments

The Maricopa Association of Governments (MAG) was created as a voluntary association in January of 1967. The regional council, consisting of elected representatives from the Maricopa County Board of Supervisors and from each of the county's nineteen incorporated cities and towns, serves as the policy-making body. MAG is a planning and coordinating agency for its members. In addition, it assists them in obtaining federal and state grants.

The basic philosphy of MAG is to "keep the decision-making authority at the level closest to the people and to preserve the integrity of the local decision-making process" (Draft Institutional Inventory, p. 49). Thus, MAG has no regulatory authority over the county or cities. However, even though MAG's plans and suggestions are not legally binding on its members, members do try to adopt and implement those plans whenever possible.

MAG is the designated wastewater management planning agency for the Phoenix metropolitan area under Section 208 of the Federal Water Pollution Control Act Amendments of 1972. Funds have been provided by the U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers to prepare an area-wide wastewater management plan. Plans have also been made to study point and nonpoint pollution source management aspects for Maricopa County.

In addition, MAG and the Corps of Engineers have undertaken a joint water planning effort. The Corps, under provisions of its urban studies program, is involved in the areas of wastewater, flood control, floodwater conservation, water related recreation, and fish and wildlife within the Phoenix metropolitan area. MAG's 208 activities and the Corps' Phoenix Urban Study are closely coordinated (Draft Institutional Inventory, p. 49).

In addition to water planning, MAG is involved in land use planning for the entire county. MAG has recently completed its Guide for Regional Development, Transportation, and Housing (1978). The Guide is "the basis for MAG's regional planning activities, including regional development, transportation, housing, wastewater management, and open space."

(Guide, p. v). This report also includes MAG's goals and objectives for physical development in the county as well as "the policies for achieving them, the regional development plan, and highlights of the long-range transportation and housing plans" (Guide, p. v). An artificial ground-water recharge project may be able to fit into MAG's regional plans.

MAG's contribution to a recharge project would be primarily in the area of planning. In developing a long-term recharge project, MAG may be able to assist in designing the management component. In addition, MAG may also be able to provide technical assistance for the project.

MAG is generally supportive of an artificial recharge project, although it has not directly addressed recharge in any of its land use plans. A spokesman for MAG indicated that recharge would probably fit into MAG's land use plan and would be a beneficial component in MAG's regional development plan. Although MAG lacks the regulatory authority needed to be the managing agency for a recharge project, it could make a significant contribution in providing planning and technical assistance (Neblitt, personal communication, 1978).

7.4.1.5.3 Municipalities

The three cities which would be most involved with a recharge project are Tempe, Scottsdale, and Mesa. Scottsdale and Mesa are heavy users of ground water. The ratio of ground water to surface water use is sixty-forty, respectively. In addition, all three cities are involved with the 208 wastewater management program. Each city is concerned with providing good water and adequate sewer facilities to its residents. However, each city has its own special concerns with water.

Tempe's major water concern is with implementation of the Rio Salado project. It is planning a moderate water use park which would be constructed on the banks of the Salt River within the Tempe city limits. The park would consist of 250 acres of lakes which would be used for boating and fishing. The Tempe City Council has approved a

design study for the project.

According to a Tempe planner, an artificial ground-water recharge project could be designed to fit in with Tempe's Rio Salado project. If recharge basins are used, they could be used as recreational lakes. Tempe may also be able to receive federal funds for developing its Rio Salado plan, funds which could also be used to finance a recharge project. In addition, Tempe may be able to participate in a geological survey of the area. There may be geological problems in the Salt River which would adversely affect both a recharge project and the Rio Salado plan. Thus, Tempe would probably participate, either with funding or staff, in a geological survey of the Salt River (Harmer, personal communication, 1978).

Tempe is somewhat supportive of an artificial recharge project. However, it is concerned that such a project does not adversely affect its Rio Salado plans. If recharge were made a part of Tempe's Rio Salado plan, Tempe would probably be a major participant in the project.

Scottsdale's major water concern is water quality. Many of Scottsdale's wells yield a very poor quality water. Thus it is looking for economical ways of improving the quality of its water. In addition, it is developing a linear park along Indian Bend Wash which will serve as a flood control device as well as a recreational area.

Artificial ground-water recharge may benefit Scottsdale in several potential ways. According to a city spokesman, it may be a way to clean up poor quality water in the water table. Good water could be recharged which could eventually dilute poor quality ground water, bringing it up to more acceptable levels. Second, the Indian Bend Wash may be a site for recharge, and the water used for recharge could also be used for recreation. Third, recharge may have the potential benefit of reducing subsidence problems in the future.

In theory, Scottsdale is somewhat supportive of recharge; however, a spokesman for the city expressed some reservations about the economic practicality of recharge. The benefits from recharge must be convertible

into dollars, and economic incentives must be provided for recharge. A second reservation was the necessity of ensuring that if Scottsdale put water into the underground storage, it could retrieve it or retain ownership of it. If these concerns area dealt with and answered, Scottsdale could be a major participant in a recharge project (Smith, personal communication, 1978).

Mesa's major water concern is its wastewater treatment plant. The plant is scheduled to be phased out in five years. At that time, Mesa will connect with Phoenix's 91st Avenue Treatment plant. Currently the Mesa plant is processing three million gallons per day (mgd). The treated wastewater is used by an adjacent farmer under a contract with the City.

A spokesman for the City of Mesa indicated that the City would have a great deal of interest in a recharge project. Water from the wastewater treatment plant may be available for use in a demonstration project. However, Mesa's participation would be limited by the fact that it has very little access to the Salt River due to the new boundaries of the Salt River-Pima-Maricopa Indian Reservation (Balmer and Sloan, personal communication, 1978).

7.4.1.6 Conclusion

The purpose of this inventory was to describe and evaluate those institutions which would have the most impact on an artificial recharge project in order to determine the institutional framework within which a demonstration project would operate. Some institutions, such as the Salt River-Pima-Maricopa Indian Community and the Bureau of Reclamation, appeared eager to get involved with such a project. Others, such as the Arizona Water Commission, were more cautious in their evaluation of recharge. Most of the institutions contacted in this study were in favor of the development of a demonstration project; however, many expressed various concerns or reservations about artificial recharge in general. In order to evaluate properly the institutional feasibility of the project, these concerns must be carefully examined and answered. The next section of this report outlines the most common

concerns discovered in the study.

7.4.2 Institutional Incentives and Barriers

7.4.2.1 Introduction

The second objective of the institutional analysis is to outline the institutional incentives and barriers involved in implementing an artificial recharge project in the Phoenix metropolitan area. Incentives are those factors which will positively encourage individuals or institutions to participate in a recharge project; whereas, barriers will negatively influence the willingness to participate. The mix of incentives and barriers represents the general political and legal parameters within which site-specific plans must be developed if they are to be implementable.

This section of this report discusses the general institutional incentives and barriers for an artificial ground-water recharge project in the Salt River project area. (The specific institutional advantages and disadvantages of the five alternative sites selected for further investigation are outlined elsewhere in this report.) It identifies past developments in water law and policy, and prevailing policy values, attitudes and issues which may affect the planning, design, construction and operation of an artificial recharge project. It also indentifies a number of political demands and conditions which are challenging the current policy and legal situation. These challenges, the analysis concludes provide opportunitites, or leverage points, for change that may facilitate project development.

7.4.2.2 Incentives

Throughout the interview process, several individuals pointed out that the general attitude of people and institutions toward water in the proposed recharge area has changed (Lofgren, personal communication, 1978; Small, personal communication, 1978). People are becoming more aware that water is a scarce resource in the desert and can no longer be wastefully used. They are more willing to compromise in order

to achieve workable solutions.

Another change in attitude is the increased willingness of the major ground-water users to work together to solve the problem of the declining water table. In the past ground-water users in the Salt River Valley would not readily provide information on ground-water pumping. Each pumper was afraid that by giving out such information, he would be helping someone else and hurting himself. However, because of the steady decline of the water table and the attendant problems of rising pumping costs and subsidence, many of these individuals now recognize the need to work together to solve the ground-water management problem. They are beginning to work toward a common goal (Small, personal communication, 1978). In order to avoid more frequent and more intense political and legal conflicts over questions of water use and transfer, the major ground-water pumpers are anxious to see some real changes in the state's ground-water laws.

President Carter's commitment to comprehensive water policy reform and his decision to eliminate several major water reclamation projects is another indication that attitudes toward water and water management are changing - that is - the popular choice of water management projects over water development. There is growing concern about the environmental and economic costs of large-scale water supply projects. Large, expensive reclamation and irrigation projects, such as dams and storage reservoirs are being more critically examined, and other less capital intensive and less environmentally destructive projects are being considered. There is increased interest in water conservation alternatives. The solution to water shortage or flood control problems is no longer simply to build a dam; rather decision-makers are looking for other solutions. A new policy framework in which federal, state and local interests must operate may have been created (Mann, 1978).

The creation of the Groundwater Management Study Commission is also an indication of the desire on the part of the State of Arizona to revise its water laws. While the extent of change the Commission will recommend or the Legislature will subsequently accept is uncertain,

the existence of the Commission does provide a forum for discussing (and possibly effecting) the legal and institutional changes required to implement artificial recharge projects.

Several other factors and conditions have also prompted greater public and governmental awareness that change in Arizona's water law and policy are requisite if solutions to water supply and allocation problems are to be devised. They include, for example: rising water costs; uncertainties about the extent to which water may need to be reallocated to satisfy Indian claims; the water requirements of increased energy production activities; the demands of environmental groups and public interest groups for greater citizen involvement in water planning and decision-making processes; and federal requirements for state program development and management in the area of water quality (Cortner and Berry, 1977; Mann, 1978). Thus, new political demands and conditions have added new items to the agenda of government, and have made action on items long neglected, such as revision of the state's ground-water law, more imperative.

Artificial ground-water recharge is one device which might be able to help deal with the problem of a declining water table. Many individuals interviewed asserted that recharge should be a component in any total water plan for the Salt River Valley. However, other individuals expressed several reservations about artificial recharge and outlined some problems which must be overcome before recharge is a viable option in a water management plan.

7.4.2.3 Barriers

These problems can be calssified into five general areas: legal, economic, management, water quality, and technical feasibility and engineering design. The first problem, which almost every individual interviewed expressed, was the legal problem of ownership of the water - that is - who owns the water once it is in the ground? Current water law in Arizona conveys the ownership of percolating waters to the overlying landowner. It does not (and cannot) take into consideration

a situation in which an individual recharges the water table. Another problem related to ownership is the legal identification of the beneficiaries of a recharge project. Under existing law, for example, a landowner may pump water from a recharge basin without assuming any of the costs for the recharge program (Arizona Water Commission, 1978, p. 15). Thus, there is a need for new state ground-water law which will allow the benefits of artificial recharge to be controlled and the costs equitably distributed.

Revision of Arizona's basic ground-water law has repeatedly been urged and several special study commissions have specifically been formed to correct legal deficiencies (Dunbar, 1977). As previously mentioned, the current Groundwater Management Study Commission is the fourth special study commission to attempt revision of the state's ground-water law. Since revisions in ground-water laws threaten to remove or significantly alter the benefits that the State's major water users have traditionally received, there is great resistance to change. Whether the Groundwater Management Study Commission can successfully accomplish its mandated tasks--especially in light of the meager accomplishments of its predecessors--remains to be seen. However, the make-up of the present Commission is designed to help insure that its recommendations will be acted upon by the Legislature and will eventually become law.

The second problem area mentioned by most individuals was the economics of an artificial recharge project. Artificial recharge may be too expensive to be feasible. Many institutions, especially the City of Scottsdale, expressed the need to transform the benefits of recharge into dollars. In order for recharge to be supported it must be proven to be economically competitive with other water management options. However, this attitude may be changing in degree and recharge may in the future become a more economically viable alternative of water management.

Another aspect of the economic concern is the proportion of federal to local cost assumption. Projects which place a greater cost burden

on the federal taxpayer than that placed on the local beneficiary have traditionally been favored in the West (Mann, 1975; Mann, 1978; Ingram, 1972). If recharge projects demand a greater cost contribution from local sponsors than other traditional water supply and flood control projects, they may lose some local support.

The third problem area is management of a recharge project. Arizona's administrative arrangements for water decision-making are fragmented with several agencies sharing responsibility for water policy development. Each of the state's water agencies has a narrow legal mandate to concentrate on specific management tasks and serves its own particular clientele interests. In turn, clientele interests exert considerable influence in agency decision-making (Mann, 1963; Null, 1970). No agency has overall administrative responsibility for water policy (Arizona Academy, 1977, p. 65), and few mechanisms exist to coordinate existing programs, While recommendations to reorganize these decentralized and disjointed administrative arrangements have frequently been advanced (Cook 1968; Null, 1970; Arizona Academy, 1977), there has been strong resistance to the various reorganization proposals by agencies which fear losing their institutional identity and clientele groups which fear their access to and influence in, decision-making will be diminished.

Within this fragmented administrative structure, there is no existing state agency with the clear authority to plan or implement artificial ground-water recharge programs. The Groundwater Management Study Commission is; however, considering the possibility of creating ground-water management districts. These districts could be designed with the capability to manage a recharge project (Ferris, personal communication, 1978). Moreover, the Arizona Water Commission has recommended that the study commission discuss legislation which would allow the formation of ground-water replenishment districts (Arizona Water Commission, 1978, p. 19). Without the creation of such an effective management structure, an equitable recharge program will be nearly impossible.

Water quality is a fourth problem area. Those institutions which deliver drinking water will want to be sure that recharge does not cause water quality to deteriorate. The State Health Department's Bureau of Water Quality, the U.S. Environmental Protection Agency, cities in the Phoenix metropolitan area, and environmental groups are all likely to be concerned about the water quality aspects of artificial recharge.

Almost every individual interviewed expressed concern as to the technical feasibility of artificial recharge. Many people stated that although recharge looks like a good idea on paper, its technical practicality is uncertain. They question, for example, how much water can actually be recovered. If recharge can be shown to be technically feasible, then these individuals and institutions would be more likely to support a recharge project. Yet, there may still be some disagreement over the particular engineering techniques chosen to implement a recharge project. One environmentalist, for example, criticized the use of spreading basins for recharge, believing that other non-structural solutions were preferable (Witzeman, presentation, 1978).

7.4.2.4 Conclusion

In this survey of the relevant institutions in the Salt River Valley, community support for artificial recharge was high. The political climate of the entire state is one of looking for new alternatives for water management. People are beginning to realize that water is a scarce resource and shouldn't be wasted. The declining water table, with the associated increased pumping costs and danger of subsidence, are motivating farmers and other ground-water users to work together toward a common goal of better ground-water management. Artificial recharge is viewed by many to be a way to help solve, or at least deal with, the problem of a declining water table. It is thus seen as part of an overall management plan for ground water. Changing attitudes and political challenges to the existing institutional framework for

water decision-making should facilitate the planning agency's attempts to obtain a consensus among affected institutions over the direction and nature of the legal and policy changes needed to implement artificial ground-water recharge projects.

However, support for artificial recharge is influenced by several reservations which various individuals have expressed in regard to the feasibility of a recharge project. The concerns are: legal questions of ownership and beneficiaries; cost; management; water quality; and technical feasibility and engineering design. These reservations should not be interpreted as an unalterable opposition or resistance to change. Rather, the individuals expressing these concerns voiced them as areas that should be dealt with before they could fully support a recharge project. Nevertheless, the difficulties of achieving institutional changes which threaten institutional survival, or require an alteration in traditional and accepted patterns of behavior and group relationships, must still be recognized as significant, albeit not insurmountable, barriers to change.

7.4.3 Recommendations for Further Study

The institutional analysis for an artificial ground-water recharge demonstration project is by no means completed. More information and additional evaluation of data are needed. This section of the report briefly outlines the remaining steps which must be taken in order to complete the institutional analysis.

The first step is to complete the institutional inventory. The inventory in this report needs to be expanded, both quantitatively and qualitatively. More institutions need to be contacted and evaluated. The institutions which were classified as having a secondary impact on a recharge project should be re-examined to determine if their impact will be significant. Institutions associated with water quality should definitely be contacted in order to discover which regulations might

affect an artificial recharge project. In addition, as the recharge project proceeds, other institutions may be added to the initial list of potentially important institutions. These also should be evaluated in terms of their impact on the recharge project.

The inventory should also be expanded qualitatively. Additional information is needed on the fiscal and management capabilities of the various institutions. Proposed or planned changes in authority, organization, or policy need to be determined. Interrelationships among existing agencies should be evaluated in terms of overlapping responsibility and potential areas of conflict. In addition, the specific legal authority (that is, an agency's ability to plan, manage, and regulate) should be carefully assessed in order to discover any legal or administrative constraints which would bar an institution from actively participating in a recharge project.

A complete institutional inventory is needed in order to assess the institutional conditions which must be considered in formulating alternative technical plans. The impact of technical alternatives on the institutions, as well as the impact of the institutions on the technical plans, must be evaluated. An expanded inventory, such as the one described here, would be essential in determining the capabilities of existing institutions to meet the institutional requirements of the technical plans.

The second step which should be initiated concurrently with the first step, is the formation of a technical advisory committee. This committee would include representatives of environmental groups and business concerns as well as representatives of governmental organizations likely to be affected by short and long term plans for artificial ground-water recharge projects. The purpose of the committee would be to monitor the progress of the demonstration project and to advise the managers of the project on important technical, legal, economic, or institutional changes which may affect artificial recharge.

The third step which should be initiated concurrently with the first and second steps, is the creation of a citizen participation

program. Citizen participation is closely related to institutional analysis activities in that early participation and coordination may identify potential conflicts. In addition, an ongoing citizen participation program may help to preclude or minimize later conflicts that could adversely affect the development of otherwise feasible plans. A public involvement program could include public meetings and workshops, citizen committees, opinion polls, brochures and newsletters, and speakers. Whatever method is used, the purpose of a citizen participation program is not merely to "sell" the public on artificial recharge. Rather, the purpose is to determine what the public's desires are and to keep people informed regarding the status and progress of the project.

Both the technical advisory committee and the citizen participation program are necessary for the development of a recharge project which conforms to the desires and best interests of the public. They will provide mechanisms for groups interested in artificial recharge or likely to be impacted by the project to be kept informed of the progress of the project. They will also provide a vehicle for conveying to project managers the attitudes of these groups toward artificial ground-water recharge projects in the Phoenix metropolitan area.

The fourth step is to specify the institutional requirements of the various technical alternatives. The technical plans should indicate what kinds of institutional arrangements are necessary for the implementation of a recharge project. For example: what kind of management is needed for a demonstration project?; what kind of legal authority is necessary?; who can provide the water and land, and what obligations do the providers of these resources have?; what planning and coordinating mechanisms are needed? The institutional requirements should be established for all of the various phases of a demonstration project: construction, operation, maintenance, surveillance, monitoring and enforcement.

The fifth step is to assess the capabilities of the existing institutions to meet the requirements of a demonstration project. In conjunction with this step, an extensive financial analysis of these institutions should be made in order to determine their ability to

finance and support a recharge project. The institutions included in the institutional inventory (which would contain all of the pertinent information on institutions in the project area) should be analyzed in terms of the requirements established in the previous step. This analysis should reveal those institutions which could best meet the institutional requirements. It should also indicate those requirements which cannot be met.

The final step is to devise a system whereby the project can be evaluated and monitored within the institutional setting. As the project progresses, the institutional environment will change. The project may have to be altered in order to fit in with these changes. In addition, the institutional requirements of the project may change as additional technical and economic information is obtained. Thus, a monitoring system will be needed in order to ascertain and evaluate these changes and to determine their impact on the demonstration project.

The purpose of an institutional analysis is to ensure that technical plans and alternatives for an artificial ground-water recharge project are implemented. The legal constraints, local customs, characteristics and attitudes of important institutions, and the attitudes of the general public must be monitored and evaluated as the project progresses. Institutional analysis should be an ongoing procedure, continuing throughout the project.

7.5 General Implications - Full-Scale Project

7.5.1 Introduction

Since artificial recharge is being practiced in many areas of the United States, the problems and successes of these other projects may provide useful information on the implementation of a recharge project in the Salt River Valley. Even though each recharge attempt is essentially a unique phenonoma, there may be some common factors which, if known, would greatly assist the planners of this project.

This section identifies the major institutional variables which have affected the implementation of ground-water recharge projects in other areas of the country.

In order to identify these factors, a limited and cursory bibliographic search was undertaken to discover materials addressing the institutional implications of artificial ground-water recharge. However, this search revealed a relative paucity of materials. There was little documentation of the institutional incentives and barriers associated with the development and implementation of artificial ground-water recharge projects. There were few case studies describing the institutional arrangements used to implement recharge projects.

The bibliographic search did reveal two areas in which some study has been done. The first is the management of artificial recharge projects. The second is the recreational use of recharge basins.

7.5.2 Management

Wanyoung Yu and Yacon Haimes, in their article, "Multilevel Optimization for Conjunctive Use of Groundwater and Surface Water," (1974), suggest that management of ground and surface water be divided into two levels: local and regional. The regional water authority would regulate artificial recharge operations in the common aquifer basin. The local agency would maintain its rights to develop and manage all water resources activities in its operating area except those controlled by the regional authority.

According to Yu and Haimes, "coordinated planning through regional management is essential to improve the allocative efficiency of the limited water resources," (Yu and Haimes, 1974, p. 625). In order to achieve this planning, they suggest that a regional management scheme be developed according to three principles: overall optimum, decentralized decision-making, and equity of policy. Under the first principle, the regional authority is responsible for "all activities that will enhance the public interest but are too big or inadequate

for any local agency to deal with or that anyone is reluctant to undertake" (Yu and Haimes, 1974, p. 626). Decentralized decision-making entails the division of the overall regional problem into two levels. Each local agency optimizes its own sub-regional problem independently of the other local agencies. "The regional authority. . . influences the optimal situation of the local agencies so that the overall optimal situation for the region is obtained" (Yu and Haimes, 1974, p. 626). Equity of policy is attained by using the pumping tax or ad valorem tax to finance the activities of the regional authority.

A second management alternative is the creation of public districts. This alternative is similar to Yu and Haimes' solution in that decision-making is decentralized. However, it differs in that the public district concept does not require the division of the area into regional and local levels. Rather, regional and local authority are combined in one agency.

Stephen Smith has written extensively on the subject of public districts. One of his articles, "Problems in the Use of the Public District for Groundwater Management" (1956) deals with public districts for general ground-water management. Another article, co-authored by Morton W. Bittinger, "Managing Artificial Recharge through Public Districts" (1962) deals more specifically with artificial ground-water recharge.

Smith and Bittinger maintain that group action is necessary in order to manage ground water effectively, including the management of artificial ground-water recharge projects. "Development of ground-water reservoirs is largely privately financed. . .(with) individual pumpers in competition with each other" (Smith and Bittinger, 1962, p. 2). The initiation of a recharge project, while beneficial to the individual, requires group action. The most common type of organization for achieving this kind of group action is the public district.

"The public district is a public corporation which receives its

powers from a state enabling act" (Smith and Bittinger, 1962, p. 3). The enabling act usually contains provisions for "(a) the establishment of the district, (b) the election or appointment of a governing board, (c) the taxation or assessment of those benefiting from the district services or charges per unit of service rendered, (d) the issuance of bonds, and (e) the owning of property, making contracts, hiring employees, and performing those functions necessary for achieving the district purposes" (Smith and Bittinger, 1962, p. 3). In addition, public districts often have the power of eminent domain and other police powers.

Public districts have several advantages and disadvantages relating to their use for ground-water management. One major advantage is their flexibility. Powers and boundaries may be designed to perform specialized functions. Flexibility is desirable in the management of artificial recharge in order to cope with "changes in development, changes in water use, and an increasing understanding of the physical conditions influencing the occurrence, recharge and movement of the groundwater within a basin" (Smith and Bittinger, 1962, p. 4). Since ground water occurs under a wide variety of physical, economic, and political conditions, flexibility of organization is essential.

However, the major disadvantage is the fragmentation of function and authority which may occur with the use of public districts. "Coordination of local taxes, budgets and programs is complex if those special units proliferate in a haphazard fashion with each going its own direction" (Smith and Bittinger, 1962, p. 4). Districts may operate duplicating facilities. If citizens become bewildered and apathetic about the maze of districts with which they must deal, effective public control is lost. The public districts can be an effective management tool for an artificial recharge project. "Its geographic flexibility, inter-temporal flexibility, concentration upon a single problem, ability to reflect local interests to obtain program adjustments, and ability to relate project costs to benefits" (Smith, 1956, p. 269) make the

public district a viable management option. However, care must be taken in the creation of the public district to avoid splitting water management into too many pieces.

7.5.3 Recreation

The second area in which some study has been done relative to the institutional variables affecting artificial recharge is the recreational use of recharge facilities. Artificial recharge in urban areas suggests the possibility of multi-use facilities. However, multi-use of recharge projects poses several questions: "Is multiple use of the recharge facilities feasible? Can an existing facility be economically modified to include multipurpose uses? What does it cost to plan, develop, and operate a multipurpose artificial recharge facility in an urban area?" (Scott, et al., 1974, p. 2). Verne Scott, Warren Johnston, and Joseph Scalmanini, aim at seeking answers to these kinds of questions in a report entitled Engineering, Economic, and Environmental Factors in Urban Artificial Groundwater Recharge Facilities (1974). They look at the role of artificial recharge in urban water resources management.

On the surface, it seems reasonable to utilize recharge ponds for recreational purposes. However, when recharge and recreation are combined, conflicts often arise in the design and operation of the ponds. A design which is ideal for recharge may be unacceptable for recreation and vice-versa. According to Scott, et al., "a prime question is the trade-off among infiltration rates, pond design, and allowable recreational activities" (Scott, et al, 1974, p. 19). The planners of multipurpose facilities must determine the costs and benefits of multiple use. If a recharge basin is designed to accomodate recreational activities an infiltration loss may occur. This loss, or cost, must be compared with the benefit gained from including recreational activities.

Whenever recharge and recreation are combined into one facility,

a potential problem arises if one of the interests "takes over." Recreational demands can become so great that other functions of the ponds, whether recharge, storage, or conservation, are subjugated to recreational uses. In order to avoid this "take over", careful planning and operation must occur, coordinating recharge requirements with other purposes.

Scott, et al. consider the biggest barrier to the multipurpose use of artificial recharge facilities to be the fact that "most of the older facilities were planned and designed for a single purpose by those professionals and others who either had no experience or training in multipurpose planning" (Scott, et al., 1974, p. 26). These facilities are often unsuitable for conversion into multipurpose uses. Ideally, in order to avoid this problem, the recharge facility should be designed from the outset as a multiple use facility. Access, landscaping, and recreational facilities should be incorporated into the planning and design of the recharge ponds.

In planning and designing a recreational area, several variables need to be considered. Estimates need to be made on the volume, types, and times of use. Data on the relationship between the types of various user populations, their demands, and the proposed facilities will assist in making these estimates.

Scott, et al. document a study done in July of 1971 which examined the current usage of artificial recharge facilities and assessed the importance of various factors in allowing or disallowing such use. The study consisted of a questionnaire which surveyed various water districts as to experiences and attitudes toward recreational use of recharge facilities. The study surveyed both residents near facilities and the managers of the facilities. Of special importance were four concerns expressed by managers: 1) public liability, 2) willingness of recreational authorities to assume costs and liability, 3) limitations of fiscal resources to finance landscaping and recreational facilities, and 4) seasonal variation in water supply (Scott, et al., 1974, p. 32).

If multiple use is to be considered for a recharge facility, these concerns should be examined, and answers provided.

The Santa Clara Flood Control and Water District exemplifies the importance of artificial ground-water recharge in the management of metropolitan water resources. The district typifies some of the problems involved in recording conflicts between recreational and. . . recharge uses (Scott, et al., 1974, p. 27). Other districts throughout the county have also attempted to design and operate multiple use recharge facilities. The experience of these districts should be closely examined before attempting to include recreation in a recharge project.

7.5.4 Recommendations for Further Study

Planning, constructing, and operating a full-scale artificial ground-water recharge project may differ substantially from the same procedure for a demonstration project. This observation may seem obvious; however, it is necessary to keep in mind the differences in scale. A full-scale project may involve the entire Phoenix metropolitan area; whereas, a demonstration project may affect only a few hundred acres. This difference in scale will affect the management and finances of a recharge project, and the attitudes of various institutions toward it. For example, institutions that may be in favor of a demonstration project may oppose a more expensive full-scale project.

More information is needed on institutional variables which have affected other recharge projects. There are several recharge facilities in the states of California, Oregon, and Texas. These projects should be visited, and the management structure and multiple use of the facilities analyzed in terms of the applicability of their experience to the Salt River area. Further literature review could be undertaken to discover data in these and other areas related to artificial recharge.

During the demonstration project the institutional requirements for operating a full-scale project should be determined. Alternative

institutional arrangements should be considered. The amount of institutional change needed to implement these alternatives should also be specified. Finally, the capability of existing institutions to meet requirements to make the necessary changes should be determined. This procedure will enable planners of a full-scale recharge project to assess the difficulties which might be encountered in implementing such a project and to make plans for handling these problems.

Public participation and a technical advisory committee should remain important components in every stage of implementing a full-scale project. It is important to not only keep people informed of the progress of the project but also to solicit their input into various aspects of the project. Changes in attitude and institutions are as important for planners to be aware of as changes in water level and use.

The value of institutional analysis is the input it provides planners regarding the institutional framework within which a recharge project must operate. Technical plans must be compatible with the political situation of the area. Therefore, institutional analysis should be an integral part of a demonstration and a full-scale artificial ground-water recharge project.

7.6 Estimated Budgetary Requirements

The third objective of this section is to estimate the staff and time required to incorporate an institutional analysis into an artificial ground-water recharge demonstration project. Thus, it is recommended that one planner (equivalent to the Civil Service rating GS 9) be retained to coordinate the institutional analysis components of both the demonstration and the full-scale recharge project. It is further recommended that, except for the preparation of background working/research papers or external review of project documents, outside consultants not be retained to perform basic institutional tasks. It is important that institutional analysis be an ongoing, iterative

process. If outside consultants are employed there is less likelihood that their analyses can be modified, redirected, or expanded as new information needs are identified or as the institutional setting itself undergoes change. It is also important that the staff person be able to gather, analyse and evaluate information from the technical advisory and the citizen participation activities and to integrate that information into project planning and decision making. As noted above, a technical advisory committee and a citizen participation program can serve as useful mechanisms, providing project planners with information concerning the institutional requirements of technical alternatives and the appropriateness of proposed institutional changes. Close staff involvement with these activities will ensure the maximum effective use of these information sources. Outside consultants will be unable to perform these essential tasks, because they are not part of the day-to-day working staff making continuous contacts with governmental and community leaders.

Outside consultant services can therefore be kept at a minimum. Such services could perhaps range from a minimum of $7,500 to a maximum of $50,000 a year, depending on whether a full or half-time staff person is employed.

The following diagram (time line) schematically represents the time needed by staff to develop additional information for a demonstration and full-scale project. Time is plotted along the horizontal axis, and the tasks remaining to be completed are listed vertically. The arrows represent the approximate time each task requires and where the task fits into overall project development.

TIME LINE - INSTITUTIONAL CONSIDERATIONS

Task	First Year	Second Year	Third Year	Fourth Year	Fifth Year
Technical Advisory Committee	→	→	→	→	→
Public Participation Program	→	→	→	→	→
Financial Analysis	→				
Complete Institutional Analysis	→				
Determine Inst. Requirements of Tech. Plans and Assess Capabilities of Institutions to Implement	→				
Monitor and Evaluate Project within Inst. Setting		→	→	→	→
Formulate Alternative Institutional Arrangements	→	→			
Project Review and Consultation	→	→	→	→	→

8. LEGAL CONSIDERATIONS

8.1 Introduction

Four primary legal concerns of artificial recharge are (1) the right to storage space, (2) the right to recharge that space with procured water, (3) the right to retain ownership of the stored water, and (4) the right to recapture the co-mingled stored water. Legal aspects are examined because of the loss of legal ownership which may occur in the artificial recharge demonstration area. Loss of ownership could occur because Arizona has no statutory or case law concerning the legality of a recharge system. Consider the following illustration. In the planned recharge system, the procurement of water results in personal property ownership for the procurer. The personal property is a claim to a specific body of water. Loosely speaking, it is a common property commodity. When the procurer uses it to artificially recharge a ground-water area, he replenishes the common ground-water supply. This results in a co-mingled source. Once it is co-mingled, he loses personal property ownership, ownership which should ideally become a property interest in the common ground-water supply to the extent of the actual replenishment.

Examination is also necessary to update current developments, especially in light of pending revision of Arizona's water law. Further examination is needed to insure that legal issues do not preclude the feasibility of recharge. For example, enforcement of subsurface injection regulations under federal water pollution laws may impact implementation of a feasible project. To explore these concerns, the legal analysis in this section presents a summary of current Arizona water law, a survey of California's and Washington's approaches to recharge, a discussion of alternative legal approaches to recharge that could be utilized in Arizona, an identification of needed additional legal information, a sequential format (time line) to secure this information, and an estimated budget.

In overview, significant portions of the proposed recharge area are located within or near the Salt River-Pima-Maricopa Indian Reservation. Thus, the potential exists for Indian water rights to have a significant impact on both a demonstration project and the ultimate implementation of any full-scale recharge program. A general discussion of Indian water rights in relation to artificial recharge within the study area was prepared by Dr. Michael D. Bradley, a faculty member of the University of Arizona, and is presented as Appendix B.

8.2 Objectives

The legal analysis has six objectives including:

1. To provide a background guide to Arizona water law;
2. To determine the extent to which existing Arizona law allows for artificial recharge;
3. To examine the extent to which the law of other jurisdictions provides applicable legal guidelines for artificial recharge;
4. To highlight possible means to implement artificial recharge in both long and short-term periods;
5. To indicate the legal issues that should be explored during the demonstration project; and
6. To suggest additional legal areas to research before full-scale project implementation.

8.3 Specific Study Approach

Preparation of this section followed eight steps. In sequence, the procedures were:

1. To physically examine the study area;
2. To review literature encompassing the selected bibliography.
3. To discuss issues with representatives of the Corps of Engineers;
4. To discuss issues with the study group;
5. To interpret existing statutes;

6. To analyze judicial decisions;
7. To solicit comments of legal counsel associated with study institutions; and
8. To solicit comments of legal scholars.

A draft report of the legal section was circulated to the study group and to legal scholars. Thereafter, a final revision was prepared and included in this report.

8.4 Site Specific Implications - Demonstration Project

8.4.1 Summary of Arizona Water Law

8.4.1.1 Introduction

There are three general sources of water within the study area: in-basin surface water, Colorado River water delivered through the Central Arizona Project and ground water. Each source is examined in turn. Surface waters and water in definite underground channels belong to the public under Arizona law. Public waters can be appropriated for beneficial use under the prior appropriation system. Main stream waters of the Colorado River are excluded. Except for early rights they do not belong to the public under Arizona law, but belong to the state under federal law. They are purchased by contract with the federal government. Ground water is the private property of the owner of the overlying land and does not belong to the public. Ground water means water under the surface of the earth regardless of the geologic structure in which it stands or moves. It does not include water flowing in underground streams with ascertainable beds and banks. If any project area for demonstration of recharge were defined in such a fashion, the recharged waters would be subject to the prior appropriation system. In this regard, the State Land Department records of water registration indicate several appropriation claims based on defining the Salt River drainage as an underground channel. Those claims remain unadjudicated. In addition, those waters which slowly find their way through the sand and gravel constituting the bed of the stream and the lands under or immediately adjacent to a stream constitute the

subflow of a surface stream and are a part of surface waters. The test for determining such subflow is whether any drawing off of subsurface water diminishes appreciably and directly the flow of the surface stream (U.S.vs. Smith D. Az. '77, on appeal 9th Cir. Ct.). Again, such water would be within the appropriation doctrine. Both underground stream and subflow will be included in the term "surface waters" for the remaining portion of this section. Nevertheless, underground water is presumed ground water, and water entering this structure becomes ground water. Thus, regardless of the initial source, recharged water is ground water.

Limited ground-water legislation is provided in Arizona Revised Statutes (A.R.S.) Title 45. Under these provisions, the State Land Department may designate critical ground-water areas. A critical ground-water area is an area which does not have sufficient ground water to provide a reasonably safe supply for irrigation at the current rates of withdrawal. Nonetheless, critical ground-water area designation affects not just water use for irrigation but all uses within an area where irrigation occurs. Hence, recharge facilities within such an area would be affected. Ten such areas are designated at present. The study area lies within the Maricopa Critical Ground-Water Area (U.S. Army Corps of Engineers, 1977). A moratorium exists on future designations until the Ground Water Management Study Commission's recommendations are finished. Completion of their report is scheduled in December 1979 (Chapter 29, Section 8, Laws of 1977).

In a critical ground-water area, no person can construct an irrigation well for irrigation of lands which have not been cultivated within five years prior to the date the area is declared critical. A permit system exists for non-prohibited persons to drill new wells. There is no restraint on existing wells, or exempted wells. An exempt well is a well with withdrawals for domestic, municipal, or industrial uses, or for transportation, agriculture schools, or stock watering. Any well used for recharge to be exempt must fall within one of these purposes.

The absence of comprehensive ground-water legislation encourages judicial determination of ground-water rights. A background knowledge of surface rights is a prerequisite to discussion of such judicially determined ground-water rights. Moreover, recharge involves both surface water, at one point, and ground water at another. Thus, the separate systems developed will interact in the recharge context. Consequently, the legality of recharge means indirectly both systems. This is the subject matter of the remaining portion of this section.

Under the surface appropriative rights doctrine, prior use is superior to any right of subsequent use. The claimed appropriative rights must be registered. The Arizona appropriation doctrine bases the right to the use of water on application of the water to a beneficial use. The time the right accrues is the day of the actual beneficial application of waters. If there exist conflicting applications by water owners of equal dates of acquisition, then one owner has preference over another according to the relative values to the public of the proposed uses. These preferences have been statutorily determined. The preference is: first, domestic and municipal; second, irrigation and stock watering; third, power and mining; and fourth, recreation and wildlife.

Beneficial use is not defined in Arizona's statutes. For the purposes of the Water Rights Registration Act of 1974, beneficial use included, but was not limited to, use for domestic, municipal, recreation, wildlife (including fish), agricultural, mining, stock watering, and power purposes. At a minimum, these uses are beneficial uses. If recharge is a means to accomplish such a purpose, it logically is a beneficial use. Thus, if appropriation is necessary for recharge, beneficial use is not a locial constraint to registration.

One statutory section and one case, Kovacovich (Az 1966) provide further explanation. A.R.S.45-172 permits severance and transfer of surface water from land to which it is appurtenant for beneficial use elsewhere without loss of priority unless the

appurtenant land was used for irrigation. In Kovacovich (and without discussion of section 45-172, enacted in 1962) the Court held that the doctrine of beneficial use precludes the transfer of appropriated waters gained by water conservation practices to lands other than those to which the water use was originally appurtenant. The decision links beneficial use to the purposes of the appurtenant land and not the ultimate advantage of encouraging conservation. The case, however, leaves open the possibility that water users, as an aspect of beneficial use, must adopt conservation practices even though the excess water accrues to junior appropriators.

The doctrine of beneficial use is also a part of the common law rule of reasonable use which limits a property owner's use of ground water. The principles of beneficial use are thus applicable to ground water. The reasonable use doctrine is also an Eastern water law doctrine analogous to concepts governing riparian surface uses and ground-water withdrawal announced in Restatement Second of Torts (Arizona Law Review, 1974). Some factors suggested are purpose of the respective uses; suitability of the uses to the source of supply; economic values; social values; extent and amount of harm; the practicality of avoiding harm by adjusting uses and methods; and protection of existing values of land, investments, and enterprises. Court decisions on ground water are not numerous. However, the principles advanced so far are significant to recharge legality.

It is a reasonable use to mine the ground-water appurtenant to the land, provided it is put to a beneficial use upon the land. Under the circumstances there is no liability for any resulting damage to anyone. However, the substantial portion of legal decisions concerning reasonable use involves transfers of water from the land where it is pumped to other lands. In this context, it is a reasonable use for an individual user to pump and transport ground water off the appurtenant land for any beneficial use elsewhere unless the withdrawal causes damage to the wells of individual user(s) of the common ground-water pool.

Several judicial decisions were modified in 1977 by the Arizona Legislature in order to allow certain designated critical areas transfers when the decisions jeopardized the economy of Arizona (A.R.S.45.317.01 et seq.). New judicial decisions concerning transfers within and from non-critical areas were also codified by the Legislature. According to the legislation, transfers prior to January 1, 1977, for reasonable and beneficial use within or from the critical area cannot be enjoined: 1) if they are for the same purpose; and 2) if they do not exceed current withdrawal amounts or are equal to amounts used on retired land as of June 1, 1977. Transfers after January 1, 1977 cannot be enjoined if they do not exceed annual use of ground-water on appurtenant land. A certificate of exemption is required. A person transferring from permitted or exempt wells prior to January 1, 1977, for irrigation of historically grown crops is exempt from procuring a certificate. City and public corporations transferring for domestic purposes and existing political sub-divisions for irrigation purposes are also exempt as long as the transfer is within their service area.

An industrial user, in critical or non-critical areas, can withdraw additional amounts of ground-water not to exceed an amount necessary to use maximum industrial capacity existing on January 1, 1977, but a special certificate is required. Another facet of the legislation allows a city contracting for the exchange or disposal of municipal treatment water in a critical ground-water area to pump an amount equivalent to the decrease of pumping by the waste water recipient. In this case, no certificate is required.

If the recharged water is construed as ground water, under current Arizona law, an adjacent landowner could pump the recharged water of a demonstration project without payment or liability. The critical point is the lack of any statement to guarantee such prevention. Consequently, a full-scale recharge system must at some point in time challenge the legality of withdrawals of recharged water by non-sponsors. Even if such pumpage could be prevented or

taxed, a finding that recharge is a reasonable use is a first step to preservation of recharge rights. The current Arizona law leans in favor of such a finding. Nonetheless, general advantages such as conservation would not be a sufficient reason as demonstrated in Kovacovich. However, in adopting Section 1242 of the California Water Code, the California Assembly found that the underground storage of surface water constituted a beneficial use where the water was applied to the beneficial purpose for which originally appropriated. In addition, California courts have recognized ground-water recharge as a reasonable use (San Fernando Cal,1975).

On the other hand, it is possible that a recharge project located within the Salt River Valley would fall under the current appropriative rights doctrine. In such a case, use of the surface runoff could be construed as a transfer, albeit beneath the sub-surface of the river by means of an underlying channel. Moreover, compliance with the Arizona Water Registration Act would insure a better claim to retention of the recharged water. One final caution against over reliance on either doctrines of surface and ground-water rights is as follows: a court in the absence of legislation or clear analogy has the power to claim the facts warrant a new doctrine. Arizona courts may take the flexible alternative. Less likely interpretations or modifications of Arizona law to accomplish recharge are considered in the section on Alternative Approaches (see Section 8.4.4).

8.4.1.2 Selected Arizona Cases

Four court decisions are reported in this section. These cases would serve as points of argument in any action seeking a declaration of rights for recharge. Accordingly, their implications merit close scrutiny.

8.4.1.2.1 Vantex vs. Schnepf 82 Az 54, 308 P2d 254 (1957) - Critical Ground Water Area

Facts:

Plaintiff Vantex owns low and high land, while the defendant Schnepf owns low land. A drainage ditch which roughly follows the

contour of a historical dry wash cuts across both lands. Lisbonbee and Ellsworth own high land. All are irrigating their lands with ground water. The artificially generated waste water flows into the wash, across the defendant's land, and re-emerges on a lower portion of the plaintiff's land. Plaintiff secured a permit to appropriate the water of the wash. The defendant, who had an informal arrangement to take and use the waste waters of Ellsworth and Lisbonbee, built a dam. The plaintiff sought to enjoin the stoppage of his flow of wash water under the appropriation right he had established.

Decision:

The court held the defendant was burdened by an easement in favor of the plaintiff only for the natural surface water, not for artificially created equivalents. At page 57 it was stated:

> "There is discussion of whether plaintiff can appropriate artificial waste water. This question is immaterial to a disposition of this case."

The importance of the decision is its implied recognition that artificially created equivalents of water sources are not subject to legal principles applicable to natural sources. In the context of recharge, if litigation is sought or arises, one could argue that recharge waters being artificial fall neither under the doctrine of appropriation nor the concepts applicable to ground water but, rather, within a new category, uniquely suited to promoting recharge.

The dissent contended that section 45-101 as then enacted, included the flow among the waste water as public water subject to appropriation; consequently the defendant had no right to stop the appropriated water since it was in fact waste water which had turned into public water. The dissent could find no distinction between natural and artificial water. The only condition, according to the dissent, was that the water be found in a natural channel.

8.4.1.2.2 Lambeye vs. Garcia 18 Az 178, 157 P 977 (1916)

Facts:

Lambeye captured the surface waste water from the property of a member of the Salt River Valley Water Users Association. He did not file an appropriation for the water. The Association intercepted

the waste water before it reached Lambeye. Lambeye sought an injunction. The member was not a named participating party to the suit.

Decision:

The court nontheless found the waste water was not Lambeye's because of the superior right of the owner of the property who was represented by the Association. In effect, the transfer of water from the Associaton to a member did not change the ownership of the water. In addition, the decision implies Salt River Project's (SRP) ability to retain control of an artificially generated source. In light of Lambeye, if the SRP were the sponsoring agency it is less likely that any entity could pump the recharged water without compensation to SRP.

8.4.1.2.3 Brewster vs. the Salt River Valley Water Users Association 27 Az 23, 229 P 929 (1924)

Facts:

Irrigation of 50,000 acres of SRP lands resulted in water logging. SRP contracted to have the area drained. Members of SRP objected to the "sale" as an act beyond the legal powers of the project.

Decision:

The court found questionable whether in fact the water was sold. The court concluded; however, should it be conceded a "sale" the project having recovered such water, has the right to dispose of it. Thus, the water was not subject to appropriation since ARS 45-101 as enacted at that time did not include drainage water. The court stated:

> "The waters involved in this litigation were put into the ground by means of artificial irrigation. They are not naturally in the ground and a part of it, in the sense of coming from a source unknown. They are therefore not subject to appropriation under any of the provisions of the statutory law. The person or corporation recovering such waters has the legal right to dispose of them by sale or otherwise if he so chooses."

The case is analogous in that recharge is not drainage subject to

appropriation but ground water. Under current law as interpreted in Brewster, recharge water is likely to be treated as ground water. Again, the court recognizes the uniqueness of artificially created water sources. However, there is no implication the SRP retained ownership of the artificially generated water.

8.4.1.2.4 Fouzan vs. Curtis 43 Az 140, 29 P2d 722 (1934)

Facts:

A boggy area without outflow was developed by a tunnel and an open cut to produce water. Plaintiff owned the land, while defendant claimed prior appropriation. Plaintiff claimed in the alternative prior appropriation and absolute ownership.

Decision:

The court found for the plaintiff on the absolute ownership theory. In analyzing the predecessor of ARS 43-101, the court stated:

> "The word 'natural' was meant by the legislature to limit all of the different sources of water subject to appropriation and that, if any of those mentioned are of artificial origin, the law does not authorize their appropriation. While any appropriable waters may be collected, stored, or carried in artificial reservoirs, channels and conduits, the test of the right to appropriate, both in quantity and quality, depends on their natural condition, and not on what may occur after that condition is artificially changed."

This case carries the same implication as Brewster, that recharge, being an artificial source, is not subject to appropriation. Because there may be some future contentions that the area of the Salt River is an underground channel, these two cases may still allow an exception to application of the appropriation doctrine.

8.4.1.2.5 Hurley vs. Abbott (Kent Decree) 4564 Az. Territorial Ct. (1910)

Facts:

The Kent Decree of 1910 establishes relative water rights for lands which used water beneficially from the Salt and Verde Rivers from 1869 to 1909. The decision instituted the doctrine of normal flow water rights. Land owners with such rights may receive normal

flow water when it is available in addition to their entitlement of stored and developed water. Generally, the decree states that the land where water was first used has the first right to water flowing in the river. Thus, the rights were established chronologically based on continuous beneficial use of water.

The structure of water rights operating under the Kent Decree, directed primarily toward agricultural uses, is summarized by Kelso (1974) as follows:

> "The principle of normal flow rights was established by the Kent Decree (Arizona Territorial Court, 1910) and refers to water that would be carried by the rivers were they not restricted by impounding. The right is based upon the concept of priority, and lands which held water rights established between the years 1869-1909 were granted normal flow rights. These lands were given the right to the use of normal flow in order of priority of the time of the establishment of their respective rights."
>
> "Another type of water right is stored water rights. This right is based upon the stored waters in the reservoir system. Owners of member lands who have filed the proper applications and have paid their annual assessments are entitled, as a stored water right, to an allotment of water annually in an amount determined by the Project Board. Water required for fulfilling the annual assessments is referred to as "assessment water." Water which is stored over and above the quantity required for annual assessments is referred to as excess water and is made available on an equal basis to Project members."
>
> "Additional water is available through the development, by the Salt River Project, of underground water sources. The pumped water right permits member lands to receive an additional quantity of water in one-half acre-foot increments to a maximum of two acre-feet per acre by paying a charge set by the Project Board based on net pumping costs."
>
> "The Board of Governors of the Salt River Project determines the actual amount of water apportioned among those lands with normal flow rights, stored water rights, and pumped water rights. The Board also determines the relevant assessments and charges."

Decision:

The decree purportedly settles Indian claims to the river water by small allocations to the Salt River Indian Community and the Fort McDowell Reservation. The State and current water users take

the position that the decree includes determination of Winters rights in the river flow. The Bureau of Indian Affairs (BIA) has proposed that the Department of Interior, as trustee, recommend to the U.S. Attorney General that the decrees be reopened to adjudicate water rights of the five central Arizona tribes. The State's position is that any claim of loss as a result of the Kent Decree is against the federal government for failure to adequately represent the Indians in the original suit. Similar issues are raised in U.S. vs. Truckee-Carson Irr. Dist. (Civil #R-2987 JBA, D. Nev.). In U.S. vs. Ahtanum Irr. Dist. 236 F2d321 (CA 9 '56) the Bureau of Indian Affairs' earlier non-judicial agreement with non-Indian users was not a bar to assention of Winters rights in derrogation of the original agreement because of the lack of explicit Congressional ratification. A similar decision is possible in central Arizona with respect to the Kent Decree.

8.4.2 California Approach to Recharge

8.4.2.1 Introduction

California has complementing statutory and judicial responses to the issue of artificial recharge. They are discussed separately following a background discussion of California's ground-water law. These laws could easily serve as a model for the Arizona Legislature or courts.

8.4.2.2 Background

California has four basic types of ground-water rights: 1) Overlying; 2) Appropriative; 3) Prescriptive; and 4) Pueblo (Gleason, 1976). Overlying rights grant the owner of the overlying soil ownership of the ground water beneath to use in any amount on the appurtenant land (Hutchins, 1966). These rights are limited to non-malicious uses, and by the judicial doctrine of correlative rights. Each landowner may extract all the ground water needed on the overlying land, but, in times of shortage, the extractions are limited to amounts that are reasonable with respect to other landowners' water needs. This judicial procedure involves calculating the safe yield of a particular ground-water basin, i.e., the average

annual withdrawal from the basin that can be maintained indefinitely (Aikens, 1977). The measure of current withdrawal is the average annual withdrawal during the previous five years. In addition, the practical definition of safe yield accounts for temporary surpluses. A temporary surplus is the amount of water that can be pumped from a basin to provide storage space for service water that would be wasted during wet years if it could not be stored in the basin. Once safe yield and the amount of current withdrawals are determined, the court reduces proportionately the amount of withdrawals of all ground-water users.

In California, appropriative rights apply to surplus ground water after exercisable overlying rights. Appropriative rights are also subject to the doctrine of correlative rights. Public ground-water supplies are primarily secured by these appropriative rights. Governmental units overlying ground-water basins can also claim overlying rights. A Pueblo water right is the paramount right of the city, as successor of the Spanish or Mexican Pueblo, to historic water sources for the inhabitants within the city's expanding boundaries.

Appropriative and overlying rights of private owners are subject to prescription. For a prescriptive right to ground water to mature, it must be established that the taking of non-surplus ground water was actual, open, notorious, hostile, adverse to the other party, continuous, uninterrupted for a statutory period of five years, and under claim of right. Private pumpers cannot gain prescriptive rights against a public entity (Schneider, 1977). The doctrine of mutual prescription is an expansion of the doctrine of prescriptive rights. Under mutual prescription all parties are restricted to a proportionate reduction in the highest continuous amount each had pumped and put to beneficial use in any five-year period after an overdraft began and before a complaint was filed. The prescriptive period does not start until the party who is prescripted has filed notice that an overdraft exists. The mutual prescription doctrine will not be used in the future unless agreed

to by all the parties (San Fernando Cal, 1975). The elimination of the mutual prescription doctrine as a judicial resource should not affect the correlative rights doctrine which achieves the same objective of a proportionate reduction of use in an overdraft basin.

8.4.2.3 California Water Code

Water districts appear to be the most frequently used solution in California (Schneider, 1977). Three general district acts specifically authorize replenishment programs with pump taxes. The three acts concerned are 1) the Water Replenishment District Act (California Water Code 60300 et seq); 2) the Water Conservation District Act of 1931 (California Water Code 75500 et seq); and 3) the Municipal Water District Law of 1911 (California Water Code 71682 et seq). In addition, several special districts also have similar powers. This legislation supercedes judicial decision only with respect to recharge districts. Thus, such legislation is an easy model to adopt without disrupting water rights beyond what is necessary to implement recharge.

The Water Replenishment District Act will serve as an example. Such a district may be organized both within incorporated and unincorporated lands and across counties. Orange County, California, is exempted since it is covered by the Orange County Water District Act. The Orange County Water District Act Water Code provides among the enumerated powers, the same powers as a water replenishment district. A district cannot include areas within the control of any existing agency which functions to replenish ground water and which has the power to levy charges for the production of groundwater supplies. Production means extraction by any method for domestic, municipal, irrigation, industrial or other beneficial use except incident to oil and gas extraction or construction. Ground water is defined as non-saline water beneath the surface of the ground, whether or not flowing through known and definite channels.

A district is formed by filing a petition. Thirty days following a hearing held by the state, the state shall determine if the district will benefit the persons or property within the

proposed area. If the petition is approved, an election of five directors is ordered by the board of supervisors of the principal county involved. The principal county is the county containing the greatest portion of land in a proposed district. The board of directors then serves as the governing body of the district. Further elections are managed by the board of directors.

A district may initiate any action necessary to replenish the ground water. This power includes buying and selling water; exchanging water; distributing water in exchange for cessation of withdrawals; spreading, sinking, or injecting water underground; storing, transporting, recapturing, reclaiming, purifying, treating, or otherwise managing or controlling water for beneficial use; and building necessary works. The district may take any action necessary to protect or prevent interference with water quality or the water rights or persons or property within the district. It can sue and be sued. It can also deal in all kinds of property within or without the district. A district has the power of eminent domain, and the ability to act jointly with any federal, state, or local agency. It can borrow money, incur debts, issue bonds, tax, and fix the rates at which water is sold.

The key power of the district is the water replenishment assessment. A public hearing in which findings must be determined is required. If the board of directors determines that a replenishment assessment should be levied, it is levied on ground-water producers within the area of the district. This provision indicates the importance of the district boundaries. If water moves outside the district into uncovered or exempt areas, the district without bringing suit loses the ability to manage and control the replenished waters. Thus, California districts often do not have adequate jurisdiction over the basin area. The assessment is levied uniformly on water producing facilities. Amendments passed in 1975 eliminate the requirement of water charges being assessed only to raise operating revenue, providing that assessments can be levied for any purpose consistent with the purposes of the act.

(Section 60230 (10) supercedes Section 60245, as formerly enacted.) The Orange County Water District (OCWD) under its Special District Act can also tax for any purpose. However, its power is required to be explicitly stated between either an operation cost or a "basin equity assessment." From an institutional standpoint, taxpayers are told the amount and purpose for each tax.

In effect, the replenishment assessment is a pumping tax. If a ground-water user withdraws more than his judicially allocated share, he must pay the replenishment tax. The assessment allows the district to control ground-water withdrawals. In supplementing court allocated shares, a ground-water user has the option to increase pumpage and pay the tax, or pay for imported surface water. By charging the tax, the district thereby influences the ratio of surface to ground-water use.

The district legislation is augmented by judicial interpretation. A replenishment district can enjoin quarry operations that interfere with the storage of water in an underground basin (Niles Sand and Gravel Cal, 1974). The district's underground storage right is based on the existence of a public servitude. An overlying property owner cannot exercise the property right in a way that would impair a public ground-water storage program. The district's underground storage servitude is limited to a public water supply service and by the height of the historical ground-water level. The latter is defined as the condition which would have existed without diversion from the watershed and/or extractions from the basin. Consequently, the overlying property owners have compensable rights for seepage damage to surface and near surface land and structures which are caused by ground-water levels rising above natural elevations. This would constitute an unreasonable use under the doctrine of correlative rights. A replenishment district is not subject to inverse condemnation claims for damages below the natural level. Thus, underground storage operations under these circumstances represent non-compensable police power regulation.

8.4.2.4 The Judicial Response in California

Entities in California other than those explicitly provided for by statute can rely on judicial authority to carry on artificial recharge. Thus, in San Fernando (Cal 1975) a city has the exclusive right to recapture imported water it has stored in an underground basin. This includes both the right to store and the right to recapture, because there is no court distinction between storage and recapture components. The basic right is described as "a right to all basin ground water derived from water imported by each city from outside the overlying area and either spread or delivered within that area." In addition, the city has the exclusive right to recapture imported water that customers allow to percolate into the ground as return flow from agricultural uses. Thus, both direct and indirect artificial recharge rights are recognized. Indirect storage occurs when water users dispose of the residue or create return flow of purchased imported surface water in a manner that permits residue to percolate into the underground basin. Indirect storage includes any artificial augmentation of the natural groundwater supply; no prior storage intent is necessary. The importation of water inherently implies intent to recapture all amounts so imported.

The storage right is limited to not impairing native groundwater rights. It may also be limited in order to provide adequate underground storage for other competing political subdivisions, although the issue of storage priority is undecided. It may also be limited by requirements not to impair native water quality, although this issue is also not yet judicially decided. However, it may be limited as one commentator suggests, to public agencies (Gleason, 1976).

The amount of water is not limited to a specific identifiable body of water, but rather a right in a co-mingled supply. The measure of the recapture right is the net amount of ground-water augmentation, not the net amount of imported water. Thus, the storer bears the risk of loss.

Moreover, whereas San Fernando establishes underground storage right as an extension of the public right to transport imported water in natural water courses and competing interests of public agencies, Niles establishes underground storage rights as a limitation on any overlying private property rights. The Niles decision provides several analogous principles to non-district areas. One commentary summarizes the following rights as judicially established by the Niles and San Fernando decision (Gleason, 1976):

1. The right to store water in natural underground basins without compensating overlying owners to the extent of natural storage space.
2. The right to protect the stored water from expropriation by others.
3. The right to recapture the stored water when it is needed.
4. The public's priority to store water underground when there is a shortage of underground storage basins.

These rights may be protected by appointment of a watermaster (Gleason, 1976).

8.4.3 Washington Approach

Washington has adopted a statutory solution (Revised Code Washington 99.44 et seq.). Like the California response, the Washington approach could serve as a model approach for the Arizona Legislature or courts. The operative provision distinguishes natural and artificial ground waters. It provides that water that exists in underground storage owing wholly to natural processes is natural ground water; whereas, water that is either intentionally or incidentally recharged during irrigation, and that otherwise would have been dissipated by natural waste, is artificial ground water. All natural ground waters and all abandoned or forfeited artificial ground water are public ground waters subject to appropriation for beneficial use. Artificial ground water is owned by the person able to demonstrate that the water claimed is, in fact, the water that would have been dissipated naturally except for artificial improvements. Ownership is recorded by the filing of a certificate declaration to that effect. The declaration must contain 1) a description of the works by which recharge is effected;

2) a description of the overlying lands; 3) the date of earliest storage; and 4) additional information as determined by the managing state agency. The declaration is reviewed in the same manner as an application to appropriate public ground water. If approved, the owner can withdraw the water by applying for a permit to withdraw in the same manner as approved appropriations.

The Washington statute was not motivated by development of systems such as those being contemplated in the Phoenix metropolitan area. Rather, the motivation was the development of the Columbia River Basin Project by the U.S. Bureau of Reclamation (Aikens, 1977). Seepage of the Bureau's irrigation water in the upper project area is recaptured in the Potholes Reservoir. However, the statutory language was foreseeably intended to encompass something more than incidental irrigation. This conclusion is evident since at the time of the last revision of the Revised Code of Washington, annotated in 1973, several projects similar to the Phoenix proposal were in operation in California and known to Washington legislators.

The protection of the ownership of that seepage was the primary motivation. Moreover, 1975 state regulations recognized the Bureau's right to concurrent approval of all ground-water withdrawals in the upper project area. In addition, the regulations recognize the Bureau's claim to artificially stored waters. It is unclear whether this is an alternative or supplmemental means to declare ownership. There are no significant cases interpreting any provisions of the Washington statutes affecting artificial ground-water recharge.

8.4.4 Alternative Approaches

8.4.4.1 Modification of Enabling Legislation of an Existing Water Related Agency Which Could Sponsor Recharge

The modification would be a legislative exemption to existing Arizona water law and judicial decisions which would recognize the sponsoring agency's right to retain ownership of intentionally recharged water. It would clearly separate the water and land ownership.

Given the technical difficulty of tracing a specific body of water, it must necessarily provide that ownership is in the form of a claim to the general pool of ground water within the basin. The proposal has an institutional advantage because the limited change in the status quo does not interfere with existing or disputed water claims. Further administrative control in efficiency could be added by the power to levy a pumping tax or assessment for the persons exceeding pumping in the recharge area. An example is California's Orange County Water District (OCWD) has four different assessment powers: an advalorem tax on all property owners; replenishment tax; pump tax for all purposes other than irrigation; and a basin equity assessment (Schneider, 1977). This proposal allows the agency to sell the water.

This proposal currently is ineffective in Arizona because a land owner can pump as much water for use on his own land as he desires. Ownership is not set at a specific quantity. Thus, the limits of water use lie at the practical use level. Further, given the permissive transfer policies of the current statutes there is no way to claim ownership against such persons under the reasonable use doctrines. In effect, the statutes define such transfers as reasonable use. The adjacent owner can simply pump and transfer the recharger's water. The reason California entities can recharge is because ownership is fixed at a safe yield level by the doctrine of correlative rights or mutual prescription. However, the doctrine of correlative rights was rejected in Arizona. Thus, adoption of a California system without accompanying change in judicial doctrines is ineffective.

An interim solution would be to grant a power to impose a general tax on all ground-water users in the reasonably discernable area of water dispersion. The tax would be sufficient to equal the cost of the replenishment operation. A disadvantage of the tax is the disparity of benefit between users closer to the source of recharge and those more distant. As a user the amount and quality of water increases while pumping costs decrease. A general tax would

be at the expense of the more distant users. Consequently, a partial solution is the flexibility to impose the pumping tax at graduated rates based on monitored ground-water rises.

8.4.4.2 Contracts with Ground-Water Users within the Area of Dispersion Recognizing the Recharger's Ownership

Recognition of ownership by the foreseeable group of adverse appropriators would allow sufficient control. One necessary element of a contract is consideration (Restatement of Contracts, 1975). Consideration is more than a unilateral promise. It is a forebearance; the creation, modification or destruction of a legal relationship; or a return promise. Consideration for recognition of a legal right to recharged waters could take the form of one or all of the following: decreases in pumping costs, guarantees of water quality, flood control guarantees, recreation, wildlife, and guarantees against subsidence. The consideration could also take the form of payment for use of facilities or payment for leases of storage space, or promises to recharge excess pumpage, or to recharge imported waters of the ground-water user. These factors also form the basis for persuading water users to contract not to pump and transfer the recharger's water.

Once establishing the right to ownership, infringement would allow a civil suit for breach of contract claiming damages or equitable relief, i.e., forcing compliance with the agreement. In addition to recognition, an agreed payment for the services similar to the graduated tax discussed above could be negotiated to sustain operating costs. Given large areas of land, small areas of dispersion, and small numbers of overlying owners, it would be effective in the Salt River area. The necessity of gaining a broad base of political support for legislation would be avoided. Another advantage is that the terms of the contract rather than court decisions would govern the course of conduct between the parties to the agreement.

8.4.4.3 Define Ground-Water Pumping of Water Replenished by Another as an Unreasonable Use

The judicial determination could be initiated by beginning a declaratory judgment action. It would name, as defendants, all ground-water uses within the foreseeable area of dispersion. It would be a lengthy court case -- two years at a minimum -- involving significant cost. The recharger would seek a declaration that pumping replenished water was not a reasonable use unless adequate compensation was provided to the recharger. It would be necessary either to trace adequately the replenished water or set a limit on the amount of water than can be withdrawn by all the overlying owners within the area of dispersion. The latter restriction is unlikely given the Arizona courts' rejection of California's correlative rights doctrine. The former restriction is a current technological impossibility. Moreover, such a suit would not be allowed by the courts until the Arizona Legislature has tried and failed to provide comprehensive ground-water legislation. In light of the Groundwater Management Study Commission's timetable, 1981 would be the earliest practical time at which such a suit would be considered.

8.4.4.4 Intergovernmental Agreements

Intergovernmental agreements would be an interim solution. Given the extensive public ownership of lands within the proposed recharge area and given the fact that government subdivisions are the largest producers of ground water, an agreement to respect the ownership of replenished water arranged between such water related agencies would be substantially effective.

California specifically allows for this type of agreement. The statutory authority is the Joint Exercise of Powers Agreements Act (California Government Code, Section 65000 et seq.). This act allows public agencies to join together in the exercise of any powers that each has already. They can agree to contribute funds to the common agency. One party can act for all or a new agency

can be formed to exercise their joint powers. Arizona does not currently have a joint exercise of powers agreements act.

A principal advantage of the use of intergovernmental agreements is to avoid a showdown on water rights while allowing feasibility to be demonstrated. An example is the Columbia River Basin Project area coordination between the Bureau of Reclamation and the Washington State Department of Ecology. However, such agreements are often difficult to form because of partisan jurisdictional disputes among agencies. Another disadvantage is the inability to restrain private non-party users from benefiting at the expense of the recharger.

8.4.4.5 Unilateral Institutional Action

Unilateral institutional action is also an interim solution. In this scenario, the recharger purchases water and stores it on the recharger's land without seepage into lands owned by others. Since, under Arizona law, the owner of the land retains ownership, there is no legal problem of recapturing your own water. Even if the water would eventually flow into another person's ground-water area, the length of time before seepage may be sufficient to allow periodic storage and removal without loss or a court fight. This would also be technically feasible where the flow of replenished water into common water areas can be arrested until removed. This method is utilized in the Potholes Reservoir area of Washington. The geological perching layers on the Gila River Indian Reservation could be a similar site.

8.4.4.6 Appoint a Water Master, Pursuant to Stipulated Adjudication Among Water Users

Two watermaster recharge plans exist in California. The watermaster concept is recognized in Arizona in similar water control situations.

8.4.4.6.1 The San Gabriel Plan

A nine member, court appointed Board of Administrators, six members nominated by ground-water pumpers, and three by the main water district. The watermaster's mandate is broad and includes

power to operate at a safe yield; to levy assessments; to purchase and recharge with supplemental water; and to maintain sole custody and control of ground-water storage rights subject only to review by the court.

8.4.4.6.2 The Chino Plan

This plan is similar to the previous plan (San Gabriel), except that the power of the watermaster is subject to review by committees representing agriculture, non-agriculture and appropriative rights holders, and by a general advisory committee consisting of all three.

8.4.5 Optimum Site Specific Information Needs

8.4.5.1 Maintenance of a Declaratory Judgment Action

8.4.5.1.1 Procedure:

Secure private counsel. Fixed amount rates. Cost unknown, hourly rate unknown.

8.4.5.1.2 Time Sequence:

After demonstration project exists, 1981.

8.4.5.2 Contract or Inter-Agency Agreements Formation

8.4.5.2.1 Procedure:

Secure counsel, hourly rate, time 20 to 30 hours, rate $50/hr.

8.4.5.2.2. Time Sequence:

Prior to implementation of demonstration project.

8.4.5.3 Survey of Complete Ownership of the Salt River and Verde River Water

8.4.5.3.1 Procedure:

1. Study court decrees;
2. Study records of the State Land Department water regulation program;
3. Study the records of the Salt River Project area; and
4. Study legal water law decisions.

8.4.5.3.2 Time:

100 person hours, 2-1/2 weeks, rate $6.00/hour. Hire a law clerk.

8.4.5.3.3 Time Sequence:

Prior to implementation of demonstration project.

8.4.5.4 Continuing Study of the California Legal Management Powers in General and Special Districts

8.4.5.4.1 Procedure:

1. Review the funding statutes for general and special California districts;
2. On site studies and interviews with California personnel; and
3. Comparison to demonstration project.

8.4.5.4.2 Time:

100 to 200 person hours, 4 to 5 weeks, cost $6.00/hour plus travel.

8.4.5.4.3 Time Sequence:

Prior to or during implementation of demonstration project.

8.4.5.5 Study of Legal Rights, Duties, and Safeguards of Indian Water Resources

8.4.5.5.1 Procedure:

1. Review statutes and treaties;
2. Review of judicial decisions;
3. Review institutional problems; and
4. Interviews of institutional and academic persons knowledgable in area.

8.4.5.5.2 Time:

300-400 person hours, 10-12 weeks, rate $6.00/hour. Hire second-year law student.

8.4.5.5.3 Time Sequence:

1. If the demonstration project is on Indian lands, prior to implementation.
2. If not, prior to full-scale project.

8.5 General Implications

The general implications of a full-scale project are the same as the site-specific implications of a demonstration project except

in two important respects: environmental law and use of Central Arizona Project (CAP) water.

Compliance with legal safeguards to protect the environment could constitute a barrier to a full-scale project. At the full-scale level, a sponsoring agency should be concerned about 1) degradation of ground-water quality, 2) disease control, 3) damage to archaeological sites, 4) alteration of native plant and animal habitat, 5) influx of unwanted species of plant and animal life, 7) land shifts and land subsidences, 8) water logging of cropped areas, 9) pesticide dispersion, 10) landfill disturbance causing exposure or leachate, 11) prohibitions to effluent disposal or use, and 12) sediment generation. Secondary concerns include 1) changes in air quality, 2) magnification of flood runoff and 3) drinking water safety.

Possible use of CAP water is a second area that should be investigated before implementation of a full-scale project. The Colorado River Basin Project Act provides for master contracts for irrigation, municipal, industrial water supply with organizations having power to levy assessments against all taxable property within their boundaries. The subsidiary contracts are under the same qualifications. Moreover, neither the contractors nor the Secretary of the Interior can pump or permit others to pump ground water from within the boundaries of the service area of a contractor for any use outside the area unless the Secretary and the contractor agree that a surplus exists and that drainage is or was required. The contract rights, as such, do not involve the Arizona appropriation doctrine. CAP water is not available directly or indirectly for new irrigation purposes except on Indian lands and in wildlife areas.

The provisions pose some degree of barrier and benefit to use of CAP waters if and when such water is available for recharge. Because the water is not limited by Arizona legal doctrines--unless it is abandoned on state lands--it would be a good source for recharge. Use of CAP water could avoid legal entanglements which exist in current Arizona law. However, the restriction on new

irrigation may limit the end use of the recharged waters, hampering profitable operation by the sponsoring agency. The transfer restriction would also be a substantial barrier to full-scale implementation where the source area has relatively small boundaries. Finally, CAP water is, in effect, totally allocated. Thus, any purchase or storage lease would of necessity be through a secondary contract.

8.6 Long-Term Information Needs

8.6.1 Survey of Environmental Law Compliance

8.6.1.1 Procedure:

1. Review regulations;
2. Review statutes; and
3. Review judicial interpretations of both.

8.6.1.2 Time:

200 to 250 person hours, 7 to 8 weeks, rate $6.00/hour. Hire a second-year law student.

8.6.1.3 Time Sequence:

Prior to full-scale implementation.

8.6.2 Expanded Study of Central Arizona Project Water (CAP) Availability and Use

8.6.2.1 Procedure:

1. Review of management mechanisms;
2. Review of federal supervision;
3. Review of extent of supply and demands for CAP water; and
4. Complete statutory analysis.

8.6.2.2. Time:

100 to 200 person hours, 6 weeks, rate $6.00/hour. Hire a second-year law student.

8.6.2.3 Time Sequence:

Prior to or during full-scale implementation.

TIME LINE - LEGAL CONSIDERATIONS

Task	First Year	Second Year	Third Year	Fourth Year	Fifth Year
Maintenance of a Declaratory Judgment Action		(After demonstration is implemented) →			
Formation of Inter-Agency Agreements or Contracts	→				
Survey of Complete Ownership of Salt and Verde River Water	→				
Continuing Study of California Legal Management Powers In General and Special Districts	→	→			
Study of Legal Rights, Duties and Safeguards of Indian Water Resources	→			→	
Survey of Compliance with Environmental Law				→	
Expanded Study of Availability and Use of CAP Water				→	→

9. ECONOMIC CONSIDERATIONS

9.1 Introduction

This section of the report will vary somewhat in scope from the other sections. In this section, the major emphasis will be on a potential, full-scale project rather than the proposed demonstration project. The rational for this approach is that the proposed demonstration project will be an experimental, applied research project, whose primary purposes are to obtain necessary data for further iterations and to generate practical knowledge regarding the feasibility of artificial recharge in the East Basin of the Phoenix metropolitan area in particular, and in the state of Arizona in general.

The intent of the Economics Section is to present methodologies by which costs and benefits for the full-scale project may be calculated. Because no information on data has yet been generated regarding a potential full-scale project, specific costs and benefits will not be quantified. Instead, potential costs and benefits will be listed and the economic formulas by which these costs and benefits may be quantified when the necessary data has been obtained will be presented.

The format of this section will be as follows: 1) development of basic economic techniques for calculating costs and benefits; 2) listing of specific categories of costs and benefits and presentation of methods for their quantification; 3) discussion of socioeconomic impacts of a full-scale project; and 4) discussion of the broader implications of such a project.

9.2 Basic Economic Techniques for Calculating Benefits and Costs

The proposed demonstration project is an applied research project whose specific purposes are to gather data and generate knowledge for determining the feasibility of artificial recharge. As such, the optimal combination of recharge site, water source,

and recharge technique will depend on the project's goals, not on the combination that will maximize net benefits. The demonstration project proposes to recharge approximately 3,500 acre-feet of water per year. Therefore, it is not expected to yield significant economic benefits. As an applied research project it is expected that funding will be the result of a federal grant, together with monies from interested state and local contributors. A project should be based on a cost-effectiveness analysis. Typically, such an analysis includes the following steps:

1. Define the objectives of a recharge project.
2. Develop alternative methods for meeting the objectives.
3. Establish measures for project evaluation.
4. Determine capabilities of all alternative methods in terms of the evaluation criterion.
5. Generate an array (table) that classifies alternative methods in terms of the decision criteria.
6. Analyze the merits of alternative methods.
7. Perform sensitivity analysis.

The preceding steps represent a standardized analysis for determining the "least cost" means of attaining the objectives of a demonstration recharge project. Engineering cost estimates for the alternative recharge methods are presented in Section 12 of this report. A hypothetical cost analysis for the alternative methods of recharge, discussed in Section 12 is presented as Example 9-1. It is possible that legal and institutional impacts will play a more significant role in the final choice of site, water source, and recharge technique than will cost-effectiveness analysis.

Example 9-1

HYPOTHETICAL EXAMPLE OF COST ANALYSIS

FOR DEMONSTRATION PROJECT

Summary of Engineering Cost Estimates ($)

	In Channel	Basins	Pits	Well
PRECONSTRUCTION	155,500	155,500	155,500	155,500
CONSTRUCTION	228,000	267,000	311,000	381,000
MONITORING	232,150	232,150	232,150	232,150
OPERATIONS	536,000	732,000	728,000	576,000
TOTAL (5 YRS.)	1,151,650	1,386,650	1,426,650	1,344,650

WATER COST (assumed)

Locally Contracted Delivery = $16/acre-foot

CAP Canalside Delivery = $76/acre-foot

DEMONSTRATION PROJECT WATER COST

$16 acre-foot x 3,500 acre-feet x 5 years = $280,000

$76 acre-foot x 3,500 acre-feet x 5 years = $1,330,000

Average Cost Per Year ($)

	In Channel	Basins	Pits	Well
LOCALLY CONTRACTED WATER	285,330	333,330	341,230	318,800
CENTRAL ARIZONA PROJECT WATER	496,330	543,330	551,230	528,800

The benefits and costs of a project will vary over time. Often costs are heavy during an initial construction period but will decrease to include operating costs only. This is then followed by a period of increasing maintenance costs (as illustrated in Figure 9-1). Benefits, on the other hand, may be small initially but will grow to some maximum over time.

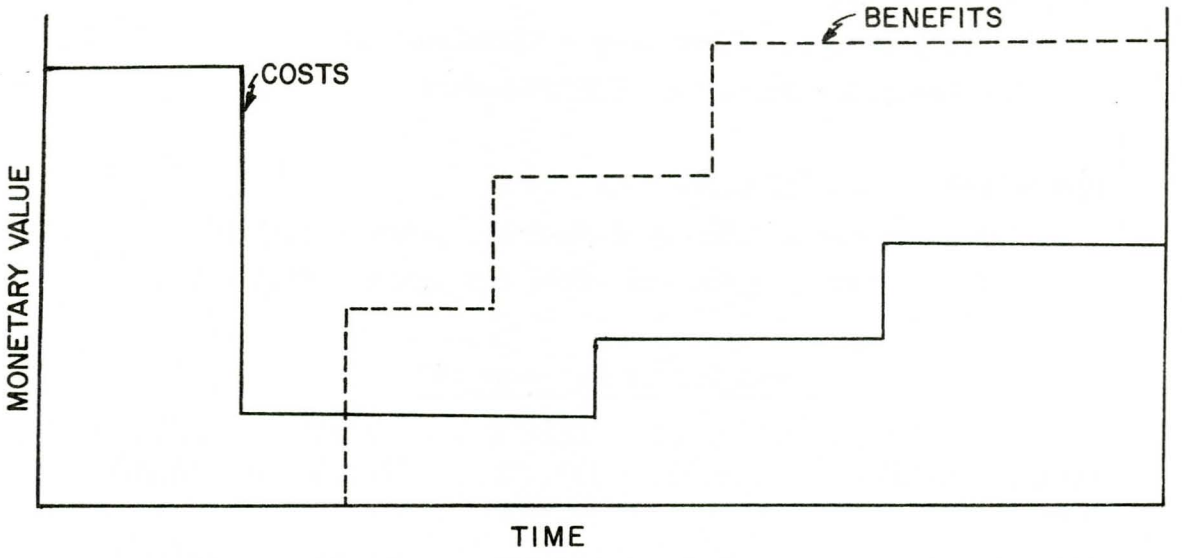


Figure 9-1
Typical Graph of the Variation in Time
of Project Benefits and Costs

To compare time streams of benefits and costs which vary over time, weights must be derived which will make values at different points in time comparable and additive. This weighting function is achieved by means of the discount rate (r) which is "based upon the estimated average cost of federal borrowing taking into consideration the average yield (over the preceding 12 months) of interest bearing marketable securities of the United States with remaining periods to maturity comparable to a fifty-year period of investment" (Principles and Standards, 1973). The discount rate (currently set at 6 7/8%) discounts the value of future benefits and costs such that their present values can be determined. The formulas which follow are the basic economic formulas for computing and comparing the benefits and costs of alternative project proposals.

1) Present value of costs (PVC) is defined as:

$$PVC = C_o + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_n}{(1+r)^n}$$

$$= \sum_{t=o}^{n} \frac{C_t}{(1+r)^t}$$

where C_o = initial costs

C_n = costs in the final year of the project (year n)

2) Present value of benefits (PVB) is defined as:

$$PVB = B_o + \frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} + \ldots + \frac{B_n}{(1+r)^n}$$

$$= \sum_{t=o}^{n} \frac{B_t}{(1+r)^t}$$

where B_o = initial benefits

B_n = benefits in the final year of the project

Once the present values of the costs and benefits of a project have been calculated, project worth can be analyzed and alternative proposals evaluated by several methods. The first method is the present value of net benefits (PVNB) which is defined as:

PVNB = PVB - PVC

In this method, an acceptable project will have a positive value for PVNB.

The second method is the benefit-cost ratio (B/C) which is defined as:

$$B/C = PVB \div PVC$$

In this method, an acceptable project will have a benefit-cost ratio greater than one.

The third method is the internal rate of return. This is the rate, designated by λ, that equates present value of benefits (PVB) with present value of costs (PVC). The internal rate of return is defined as:

$$\sum_{t=o}^{n} \frac{B_t}{(1-\lambda)^t} - \sum_{t=o}^{n} \frac{C_t}{(1-\lambda)^t} = o$$

In this method, an acceptable project is one for which the internal rate of return, λ, is greater than the appropriate discount rate (6 7/8% at present).

A final method of analysis is the difference between equivalent annual benefits (EAB) and equivalent annual costs (EAC). This method converts the present value of benefits and costs into two streams (benefits and costs), the values of which are equated for each annual time period. That is, PVB is converted into a single value which will be constant for each time period of the project. PVC are handled in the same manner. Equivalent annual benefits (EAB) are defined as:

$$EAB = PVB \frac{r(1+r)^n}{(1+r)^{n-1}}$$

Equivalent annual costs (EAC) are defined as:

$$EAC = PVC \frac{r(1+r)^n}{(1+r)^{n-1}}$$

Where n = number of years in the design horizon of the project. In this method, an acceptable project is one for which equivalent annual benefits are greater than equivalent annual costs.

These analytical methods will allow planners to determine the economic value of specific projects and aid in the comparison of alternative projects. The method of equivalent annual benefits and costs is particularly useful because it allows comparisons between projects with different design horizons. It is important

when determining the costs and benefits of a project to make certain that the analysis is done on a "with and without" basis rather than on a "before and after" basis. Significant errors will enter the calculations if this condition is not strictly observed.

A simplified example using the equations defined above is presented as Example 9-2. This example assumes a simple water resource project with a design horizon of five years (a realistic design horizon is much greater but a five-year period will suffice for the purposes of this example), a discount rate of 6 7/8%, and benefits and costs as defined in the example.

Example 9-2

HYPOTHETICAL EXAMPLE OF COMPUTING BENEFITS AND COSTS

	Initial	Year 1	Year 2	Year 3	Year 4	Year 5
COSTS ($)	500	100	100	100	200	200
BENEFITS ($)	0	200	200	300	400	400

$$PVC = 500 + \frac{100}{(1+0.069)} + \frac{100}{(1+.069)^2} + \frac{100}{(1+.069)^3} + \frac{200}{(1+.069)^4} + \frac{200}{(1+.069)^5}$$

PVC = $1,059.34

$$PVB = 0 + \frac{200}{(1+.069)} + \frac{200}{(1+.069)^2} + \frac{300}{(1+.069)^3} + \frac{400}{(1+.069)^4} + \frac{400}{(1+.069)^5}$$

PVB = $1,201.52

Present Value of Net Benefits PVNB = 1201.52-1059.34 = $142.18

Benefit Cost Ratio B/C = 1201.52 ÷ 1059.34 = 1.13

When faced with a long series of time periods for a project's design horizon, the internal rate of return, λ, is best found by a series of successive approximations, a process most easily accomplished by computer. For this example, $\lambda \cong 15.5\%$.

$$\text{Equivalent Annual Benefits (EAC)} = 1059.34 \frac{0.069(1+0.069)^5}{(1+0.069)^5-1}$$

EAC = 257.61

$$\text{Equivalent Annual Benefits (EAB)} = 1201.52 \frac{0.069(1+0.069)^5}{(1+0.069)^5-1}$$

EAB = 292.21

EAB-EAC = 292.21 - 257.61 = 34.60

Up to this point economic techniques have been discussed in terms of analyzing the worth of a project, and in comparing and evaluating alternative projects. Economic techniques can also play an important role in determining optimum project design. It should be recognized, however, that institutional and legal impacts may play a greater role in final project selection and size than may economic analysis. The economic rules for project optimization are presented in the following section (Section 9.3). These rules are presented, so that should optimum project design be based solely or in part on economic principles rather than legal or institutional factors, then the rules for economic optimization will, at least, be available in this report.

The first step in optimizing project design is recognition and identification of the full spectrum of alternatives which have the potential of satisfying planning objectives. If the most efficient course of action is not to be omitted at the outset, all reasonable possibilities must be considered. This includes both structural and nonstructural alternatives. The second step is to clearly define all alternatives which are physically capable of achieving design objectives. The physical consequences of each of these alternatives should be identified and evaluated in monetary terms. The differences among the alternatives will be the basis for comparison. All alternatives, however, should be compared on a uniform basis. This means that factors such as the discount rate, period of analysis, and unit costs should be the same. When comparing alternatives some weight should be given to differences in intangibles as well as to factors which can be clearly defined in monetary terms. After preliminary investigation has eliminated a number of the initial alternatives, detailed design studies will be required for evaluating the remaining alternatives. Economics plays an important role in comparing the remaining alternatives and in optimizing the final project design. The optimum design of a project is usually judged on the basis of maximizing the net benefits (PVNB) of the project. In economic

analysis, net benefits are maximized at the point where marginal benefits equal costs (see Figure 9-2).

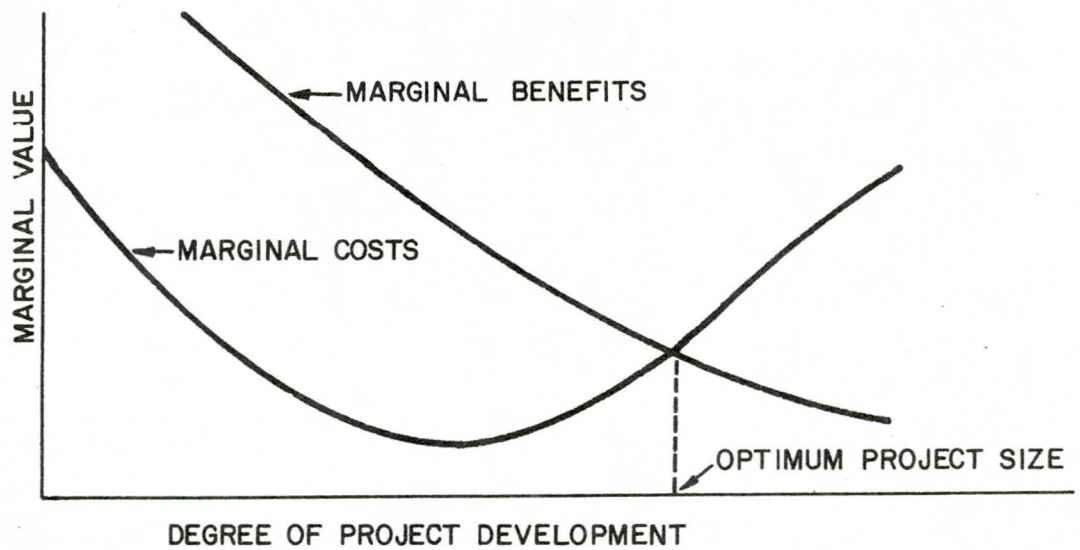


Figure 9-2 Marginal Value Curves

The use of marginality analysis in water resource type projects is illustrated in the following example. Suppose it is desired to landscape the facilities around the proposed artificial recharge project such that recreational day-use activities are allowed. Let dPVC(L) represent the marginal, or incremental present value of costs associated with the landscaping and let dPVB(L) represent the marginal (incremental) present value of benefits from the landscaping. The optimum scale of landscaping is determined at the point where any additional cost just equals the additional benefits:

$$dPVB(L) = dPVC(L)$$

The incremental present values of benefits and costs resulting from a given increase in the size of the project are found by:

$$dPVB = dV_o + \frac{dB_1}{(1+r)} + \frac{dB_2}{(1+r)^2} + \ldots + \frac{dB_n}{(1+r)^n}$$

$$dPVC = dC_o + \frac{dC_1}{(1+r)} + \frac{dC_2}{(1+r)^2} + \ldots + \frac{dC_n}{(1+r)^n}$$

Marginality analyses can be applied in the same manner to other potential additions to a project (i.e. water quality treatment, flood proofing, and increased capacity).

In general, the economic criteria for the optimum design of a project have been listed by Howe (1971) as follows:

1. $dPVB_i = dPVC_i$ for the "i"th separable purpose (a feature that can be either included or omitted). The scale of the project should be expanded until the marginal present value of benefits equals the marginal present value of costs.
2. $PVB_i > PVC_i$. A check should be made to ensure that the total present value of benefits from the "i"th purpose exceeds the present value of costs directly attributable to that purpose.
3. $PVB_i > PVC_i$. After the size of the project is optimized in terms of its separable features an analysis should be made to make certain that total present value of benefits is greater than total present value of costs.
4. Optimum timing of construction. Optimum timing can be derived from the present value formula. It is assumed that demand for project outputs is growing over time; therefore, the longer a project is deferred, the more quickly it is likely to be used to capacity and the greater the benefits generated per time period of project life will be. Offsetting this, however, is the tendency for the present value of benefits to diminish as the project is pushed further into the future. There is; therefore, an optimum point in time for project

construction. By specifying the growth in demand over time for project output and by assuming different times of construction it is possible to plot the present value of net benefits versus time of construction (see Figure 9-3).

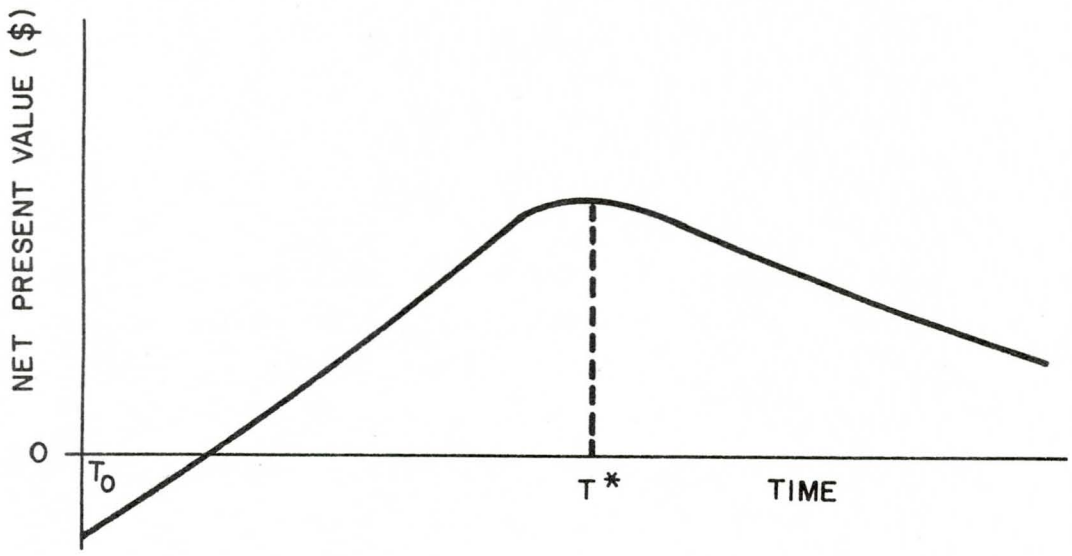


Figure 9-3 Net Present Value of a Project as a Function of Timing of Construction

T_0 represents today

T* represents the optimum time for construction

9.3 Specific Costs and Benefits

The Economics Section views the actual quantification of costs and benefits as an iterative process. The true monetary values for costs and benefits will be derived from data obtained from the proposed demonstration project, should this project be authorized and constructed. The purpose of the following section is to present the methods by which actual cost and benefit data, when available, can be evaluated for the presentation of the essential benefit-cost indices. Data generated from the demonstration project will enable planners to more accurately assess the benefits and costs expected from a full-scale recharge project. It will enable them to reach well informed decisions regarding the scope of a full-scale project and to compare a full-scale recharge project with alternative projects.

9.3.1 Opportunity Costs

The first cost to be discussed and possibly one of the most difficult to quantify is the opportunity cost of constructing the recharge project. All economic resources are scarce; therefore, the commitment of resources to a specific project necessarily results in their exclusion from other projects. This commitment of resources and the benefits foregone from the excluded projects are the opportunity costs of a project. The evaluation of the recharge project in terms of opportunity costs is a two-stage process. The first stage is to compare each of the alternative project proposals with the "no project" alternative in order to determine the value of the resources which would be committed under each. Alternatives to the artificial recharge project include surface storage, evaporation suppression, water harvesting, phreatophyte control, introduction of water conservation technologies (i.e. drip irrigation), and direct water transmission to users. Each alternative needs to be evaluated against the "no project" alternative to quantify the value of resources required for each. The second stage is to compare each alternative against the others in order to rank them in terms of net benefits. Once ranked the alternatives can be evaluated with respect to factors other than

net benefits (i.e. environmental impacts). If, at the end of the planning process, an alternative other than that with the greatest net benefits is selected, the opportunity cost will be the difference in net benefits between the selected alternative and that with the greatest net benefits.

Because the evaluation of each alternative with respect to benefits, costs, and value of resources committed is an extensive time consuming process, a first-cut investigation of the structural, institutional and environmental possibility of each alternative should be conducted to reduce the number of alternatives to a workable number.

9.3.2 Fixed Capital Costs

The fixed capital costs and the variable costs assigned to the project on an annual basis will be derived from the demonstration project. These costs are estimated in Section 12. A check list of items to be considered in the construction of an artificial recharge project was presented in a United Nations report (1975) on ground-water storage and artificial recharge. For construction costs the report listed the following:

1. Spreading facilities
    - a. grounds or basins
        1. levees or dikes
        2. inlet structure
        3. wasteway structure
    - b. recording equipment
    - c. diversion facilities
    - d. control facilities
    - e. access facilities
    - f. fences
    - g. shelterhouse
    - h. treatment equipment
2. Injection facilities
    - a. injection well construction
        1. casing material
        2. gravel packing
        3. grouting
        4. packers
        5. method of drilling
            - a. reverse rotary
            - b. standard rotary

c. cable tool
d. other
6. perforations

b. observation wells
1. casing material
2. gravel packing
3. grouting
4. method of drilling
a. reverse rotary
b. standard rotary
c. cable tool
d. other
5. method of completion
a. perforations
b. capped for geophysical well logging
6. monitoring facilities

3. Extraction Wells - same as for observation wells, plus:

a. pumping requirement
b. energy
1. electricity
2. internal combustion

4. Control facilities

a. pressure-regulation station
b. meters
c. valves
1. shut-off
2. control
3. pressure-relief
4. blow-off
5. vacuum

5. Treatment facilities

a. materials
1. concrete cylinder
2. steel: mortar-lined and coated
3. asbestos cement
4. plastic

6. Buildup

7. Monitoring equipment

a. recorders
b. sounders
c. samplers
1. submersible pump
2. thief sampler
3. air-lift pump
4. electrical conductivity

A more complete list of construction items requiring cost data is included in Section 12. Other fixed capital costs which are associated with the construction or preconstruction phases of a full-scale project (United Nations, 1975) are:

1. Land
   a. survey
   b. title search
   c. cost of easements and right-of-ways
   d. inverse condemnation proceedings
2. Water costs
3. Recapture costs

9.3.3 Legal Costs

Sand and gravel mining operations are common in the area proposed for the artificial recharge project. These operations may be inundated by the recharge operation. Inverse condemnation proceedings therefore represent a potential cost to the project in terms of legal fees and court costs. For a discussion of inverse condemnation see Section 8 of this report.

9.3.4 Variable Costs

The variable costs assigned to the demonstration project on an annual basis (operation and maintenance costs) are estimated in Section 12. The United Nations report (1975) referenced earlier, lists operation and maintenance costs, as well as construction costs, that should be included in this phase of the project. The report lists the following costs:

1. Spreading facilities
   a. grading
   b. storm protection
   c. structure repair and replacement
   d. equipment maintenance
   e. fuel for equipment
   f. equipment rental
   g. disking or silt removal
   h. insect control
   i. weed control
   j. aesthetic treatment (such as screen planting with adequate watering systems)
   k. rodent control
   l. patrolling
   m. treatment (flocculents)

n. slope maintenance
o. vandalism

2. Injection facilities

a. observation of monitoring devices
b. measuring water levels
c. sampling water
d. redevelopment of wells and disposal of wastes
e. treatment
    1. chlorine
    2. acid
    e. other
f. maintenance of equipment
g. structure repair
h. fuel
i. equipment rental
j. patrol
k. water analyses
l. vandalism

3. Office

a. supervision
b. administration
c. wages
d. office and (field) overhead
    1. rent and utilities
    2. telephone
    3. supplies
    4. maintenance of office equipment
e. salaries
f. liability
g. taxes
h. interest

When estimating construction, and operation and maintenance costs for the full-scale project, it should be possible to extrapolate from the demonstration project. Significant economies of scale can be expected for the full-scale project, consequently it will not be possible to project costs directly from the demonstration to the full-scale recharge systems. In the planning phase careful consideration should be given to the long-term economics of operation and maintenance costs, because the recharge method selected will have a substantial impact on these costs. A recharge facility using injection wells, for example, will have significantly higher operation and maintenance costs than will a recharge facility based on infiltration basins, (see Example 9-1).

9.3.5 Water Costs

The cost of the water that is recharged is one of the crucial elements affecting the economic feasibility of the project. The price for water that is potentially available to the recharge project ranges from no cost to $76.00/acre-foot for canal-side delivery of Colorado River water delivered through Central Arizona Project facilities (Barr and Pingry, 1977). In California, the lowest per unit costs of recharge are found in facilities which have a steady dependable supply of water. The most expensive per unit costs of recharge are found in facilities which depend on intermittent flood flows. The relevance of the California recharge experience to a full-scale recharge project in the East Basin region is that recharge efficiency is maximized when the project is assured of a definite dependable supply. At this time it is not possible to state whether costs will be lower with no cost for water and an undependable supply (flood waters) or whether they will be lower with a specific charge for water and a dependable supply that enables maximum efficiency of recharge facilities. This information will be generated from further iterations of the planning process.

9.3.6 Flood Control Costs

The flood control costs attributed to the project may or may not be significant. For the demonstration project, flood control costs would probably be only the costs involved in the floodproofing of those facilities which were deemed too expensive to replace should they be destroyed by a flood. In a full-scale project, floodproofing of facilities would be only one aspect of the flood control costs. From an economic perspective, floodproofing is an example of marginality analysis. That is, the aggregate costs of the project may be lower with floodproofing than without it. The optimal level of floodproofing would be the point at which the marginal cost of additional floodproofing just equaled the marginal benefit of additional flood losses prevented.

As a simple example, suppose it is desired to floodproof a flume used in the project. Normally the flume would be washed away in a ten-year flood and would have to be replaced. After floodproofing the flume will only be washed away by the 100 year flood. If the life of the project is twenty years and costs are:

flume - $500
floodproofing - $200

The present value of floodproof costs (PVC) is

$$700 + \sum_{t=1}^{20} \frac{(.01)(700)}{(1+.069)^t} = 779.89$$

The benefits would be the damages prevented. Damages prevented are found by multiplying the probability of the flood occurring each year (10%) by the damage that would have been caused (loss of the flume). Using the present value formula, present value of benefits are calculated to be:

$$500 + \sum_{t=1}^{20} \frac{(10)(500)}{(1+.069)^t} = 1070.67$$

PVNB = PVB-PVC = 1070.67-779.89 = 290.78

In this example the benefits of floodproofing exceed the costs. Therefore floodproofing of the flume passes the marginability criteria and would be included in the project.

A second cost associated with flood control will be the value of land committed exclusively to flood control structures and flood-water storage. This cost does not appear to be applicable to the demonstration project. It will only be applicable to a full-scale project if it is decided to impound flood flows behind a surface storage structure specifically to store for later recharge or if flood flows are diverted to some storage basin to hold for recharge. Should either of these alternatives be adopted then the cost of the land committed to flood control structures and flood storage, and the cost of the structures themselves would be added to the flood control cost account.

The full-scale project may have additional flood control costs assicated with it if the full-scale project is viewed as an

addition to an overall multipurpose flood control project. An interesting proposition that has been hypothesized in relation to an artificial recharge project, is that of lowering the water levels in one or more of the Salt River Project (SRP) storage facilities on the Salt and Verde Rivers to some predetermined level such that these facilities can be used for flood control. The water removed from these structures could then be recharged at the artificial recharge project (it may be possible for the Salt River Project to retain control of this water if the site chosen is one from which the hydraulic gradient would carry recharged water to the numerous Salt River Project wells in the area). Under such a situation, if the Salt River Project was the only source of recharge water, the recharge project would be viewed as an additional benefit to a multipurpose flood control project. Virtually the entire cost of the project could then be charged to the flood control cost account. Benefits would be calculated in terms of the flood control capacity of the Salt River Project structures and the additional benefits resulting from the recharge project.

9.3.7 Municipal-Industrial Water Supply Costs

Municipal and industrial water supply costs will involve the costs of source development, which include both the fixed capital costs of well contruction and pump installation, and the variable costs of operation and maintenance. These costs are only applicable if municipal and industrial users are recognized as beneficiaries of the project and the construction of new wells is as a direct result of the recharge project. The quantification of these costs will require an estimate of the number of new wells expected to be installed as a result of the full-scale project. Variable costs will be dependent on quantity of water pumped, energy cost per unit, pumping lift, and maintenance costs. A second element of cost associated with municipal and industrial supply is the cost of treatment over and above treatment costs for already existing supplies of water (if treatment costs should decrease then this would be an additional benefit of the project). If the City of Mesa, for example, has two sources of supply (surface water and

ground water from artificial recharge) and decides to utilize greater quantities of ground water as a result of the project, then any treatment costs attributable to the new source over and above normal treatment costs will be charged to the municipal and industrial supply cost account. A third element of cost will be the costs of distribution and storage for any new areas that as a result of the project are supplied with recharged ground water.

The quantification of costs attributable to the municipal and industrial supply account should be straight forward once data on the quantity of ground water to be recharged by a prospective full-scale project becomes available. When these data are known, municipal and industrial users can make decisions regarding capital expenditures and other expenditures associated with development of this source. A problem involved with this account is that of quantifying the approximate volumes of recharged water which will enter the local aquifers that are subject to municipal and industrial pumping and the volumes which will leave these local areas. This problem is one that should be answered by information derived from the proposed demonstration project.

9.3.8 Water Quality Costs

Recharging of poor quality water, such as treated sewage effluent, irrigation tail water, or turbid flood flows may result in treatment within the aquifer. However, long-term recharge of poor quality water may result in degradation of native ground water. The extent of the decline in quality is dependent on the characteristics of the aquifer, the characteristics of the poor quality recharge water, and the method of recharge.

The costs associated with the decline in aquifer quality are the decline of the value of the overlying land whose productivity is lost should it become necessary to protect against the effects of toxic or dangerous substances which have accumulated in the aquifer (i.e. heavy metals or pesticides). Costs will also be incurred in monitoring the quality of ground water in the area recharged with poor-quality water. Market value of overlying land

and the extent of monitoring will vary, consequently these costs must be analyzed on a site specific basis.

9.3.9 Agricultural Irrigation Costs

Agriculture is already practiced intensively in the East Basin area. Therefore, the impact of a potential recharge project would probably be quite small. However, this report would be remiss if it did not include some discussion of the possible impacts on agriculture of an artificial recharge project.

The first cost which would be included in this account is that of anticipated drainage requirements. If, as a result of the recharge project, irrigated agriculture is practiced more intensively or water is recharged above perching layers it is possible that drainage may eventually be required. Should this be the case, the present value of drainage costs must be added to the project. A second cost related to the more intensive practice of agriculture will be the cost of storing any increase in the output of farm products which can be attributed to the recharge project. The greater availability of water may encourage more intensive cultivation, which will cause greater output of agricultural products, which then requires greater storage capacity and, consequently, an increase in the costs for storage. Because the increase in storage requirements is a result of the recharge project the costs of the additional storage required must be charged to the agricultural cost account.

Any expansion in the agricultural sector that results from the presence of the recharge project will mean an increase in capital expenditures, and on-farm production costs. Construction of new wells (see following example) and ditches to capture and deliver the water, new farm machinery, additional labor, the application of greater quantities of fertilizer, and other items, represent example of costs that are derived from the services (water) provided by the project. These costs are an additional element which must be charged to the agricultural costs account.

Agricultural costs attributable to the project will probably be difficult to quantify because the agricultural sector is affected by many factors other than water. It will be difficult to specify exactly which costs are a result of a recharge project and which costs are a result of, for example, a new price support program from the government. Farm characteristics differ, therefore any quantification will probably require extrapolations from some "typical" (representative) farm or typical class of farms.

Identification of some costs with the project will be easily accomplished, construction of new wells and ditches is an example. The construction costs of a typical irrigation well in Maricopa County are illustrated in the following example.

Example 9-3

CONSTRUCTION COSTS OF TYPICAL IRRIGATION WELL

Assumptions:

1. Power source is electricity
2. Well is drilled and cased with 16-inch casing to a depth of 1200 feet.

Price quotations: (including 5 percent sales tax)

1.	Drilling cost and casing installation	$21,600
2.	Casing foundation and test pumping	22,826
3.	Pump assembly (8-inch column)	19,663
4.	Power unit - 250 HP motor	6,443
5.	Starter with compensator and secondary power station with safety switch	8,406
6.	Installation labor and site costs	1,449
		$ 84,487

Source: Hathorn
Arizona Pump Water Budgets, Maricopa County, 1978

Costs for well construction will vary with depth, radius, and power source.

9.3.10 Recreation Costs

Recreation costs may or may not be significant. In general, recreational use of artificial recharge sites is minimal. However,

because of the scarcity of water-based recreation in the region and the conception of the proposed project as a multipurpose project the costs of including additions to the project in order to allow recreational use will be discussed. Recreation costs should be computed first by the incremental project construction costs attributable to the recreation purpose. Examples of such costs would be the addition of trees and shrubbery, development of picnic sites, parking areas, restrooms, trash receptacles, and other items, depending on the scale of development desired. A second element will be the incremental operation and maintenance costs attributable to the recreation purpose. In general, operation and maintenance costs are a large element in the cost of developing a recreation area but they should be readily calculable because these costs will only apply to those areas used for recreation. A third element is the value of the land committed exclusively to recreation structures and purposes. These costs should not be difficult to calculate once the scale of the recreation development is known.

9.3.11 Joint Costs

The costs that have been mentioned in the preceding sections, excluding the initial fixed capital costs and variable operation and maintenance costs, are costs which are separable, and applicable to specific project purposes. For the most part, the inclusion of these separable elements of cost and their associated benefits will be subject to economic analysis to determine the point at which marginal benefits equal marginal costs. The decision to include the various elements represented by the separable costs, although subject to economic analysis, may be based more on political and institutional considerations than economic considerations. Those elements of cost not specifically separable but which link recharge to other purposes are considered joint costs. Joint costs are those which are attributable to some element of the project which is used for more than one purpose in a multipurpose facility. In the prospective full-scale recharge project, joint

costs arise for project construction costs associated with flood control, and with the value of land committed to flood control structures and storage, and recreational land and structures. These elements of the project will serve more than one purpose. For example, the construction of a levee around a recharge pond serves both flood control and artificial recharge purposes. The costs associated with the levee, not being separable, are considered joint costs. Joint costs need not be considered in justification of specific purposes of the project but must be included in the overall justification.

9.4 Potential Benefits

This section presents a listing of potential benefits that would be derived from a full-scale recharge project. It makes no attempt to identify specific beneficiaries, instead the object of this section is to identify classes of beneficiaries (agricultural, municipal-industrial and Indian) and derive the methodologies by which benefits can be calculated when the applicable data from further iterations become available.

In general, benefits stem from two basic sources. These are the value of increased output of goods and services from a project and the value of output resulting from external economics caused by the project. Most goods and services produced by water projects are intermediate goods-that is-they are not directly consumed but are intermediate products that serve as inputs to producers of final goods or other intermediate goods. The total value of the intermediate good (water) to the producer of final goods is measured as the increase in net income received by producers with the project as compared with the net income received in the absence of a project. This type of analysis is applicable in the agricultural sector, a discussion of which follows.

9.4.1 Agricultural Benefits

The benefits of an artificial recharge project to the agricultural sector will be derived from a decrease in water costs.

Water costs will decrease because of the reduction in pump lift requirements resulting from the rising water table and the improvement of water quality in those areas affected by poor quality ground water.

The benefits to the agricultural sector stemming from the decline in water costs can be calculated through the use of farm budgets. Standardized farm budgets are available for many areas of Arizona, including Maricopa County, from the Agriculture College at the University of Arizona. The increase in output resulting from reduction in water costs can be evaluated using these farm budgets. The net returns to the increased output will represent the overall benefits to the agricultural sector. Quantification will require an estimate of the area impacted by the recharge project, evaluation of farm budgets to predict the net returns expected in the impacted area and conversion into present value figures.

The actual effect of the recharge project on pump lift costs is dependent on whether the project raises the water-table elevation or merely retards its rate of decline. This, in turn, will depend on the quantity of water recharged versus the quantity extracted by pumpers in the affected area. The components of the lift costs reductions include: the energy savings, the reduction in the requirement for capital expenditures on existing wells (e.g., the cost of increasing the depth of the well, the cost of additional pump bowls), and the elimination of the need to construct new wells as old wells are abandoned.

The calculation of the decreased water costs derived from reduced pump lift requirements are demonstrated in Example 9-4. This example uses the same well as that discussed in the cost section (all costs are in 1978 prices).

Example 9-4

CALCULATION OF DECREASED WATER COSTS

Total cost of construction (including interest and depreciation)		$84,487
Annual fixed costs:		
Depreciation		$ 5,047
Interest		3,637
Taxes		833
Fire and Lightning Ins.		208
Total		$ 9,725
Feet of lift	=	400 feet
KWH to lift 1 acre-foot of water at 100 percent efficiency	=	1.024
Efficiency stated as a decimal	=	.540
Power cost per kilowatt (including sales tax)	=	$.03033
Cost of plant repairs, maintenance lubrication and attendance per foot of lift	=	$.007512
Quantity of water pumped per year	=	836 acre-feet

Water cost per foot:

1. Fixed cost = $9,725/836 acre-feet = $11.63
2. Energy Cost = (1.024x400)/.540 = 23.01
3. Repairs = .007512x400 = 3.05

37.65

Pumping Cost, per acre-foot, will vary with the power source:

Power Source	Cost/acre-foot
Natural gas	= $11.63
Diesel power	= $42.89
L P gas	= $62.74

Example 9-4
(Continued)

The decrease in pumping costs associated with a 10-foot rise in the water table for a pump using electric power is:

Fixed Cost	=	$11.63
Energy Cost (1.024x390/ .540x.03033)	=	$22.43
Repairs (.007512x390)	=	$ 2.93
TOTAL COST		$36.99

In Example 9-4, decrease in pump lift costs per acre-foot are $37.65-$36.99 = $0.66. For a well pumping 836 acre-feet annually this represents a savings of $551.43 per year. To quantify the decrease in costs from reduced pump lift requirements it will be necessary to determine the number of wells by each power source and the difference in the water-table elevation with and without the project for each year over the expected life of the project. Once these figures are known they can be treated in the same manner as those in the preceding example.

The reduced need for capital expenditures is a more difficult cost reduction to quantify. The value for this impact could probably best be determined by interviewing well owners to determine when they would have invested capital in their existing wells or in new wells as a result of the declining water table, in the absence of the project. From these interviews a "typical" (representative) well could be derived from which it would be possible to calculate the quantity of capital expenditures saved. This value could then be extrapolated over the entire project area. The Salt River Project, with 250 wells in the East Basin region, would probably be the most knowledgeable agency to interview.

In some areas of the basin, pumpers are extracting ground water of declining chemical quality. Declining quality can cause a decrease in crop yields, and increased operation and maintenance costs (leaching may be required at shorter intervals). Mixing of this poor quality ground water with good quality recharge water will improve overall water quality and can result in increased output, and decreased maintenance costs. In general, improved water quality also represents a net decrease in water costs because a smaller quantity of water can be applied for the same yield, or the same quantity of water can be applied resulting in a greater yield than with poor quality water. The adjusted direct and indirect gross output multipliers represent the proportion of gross output that is composed of value added, and the indirect value added that would be generated throughout the economy per dollar

of gross output in specific agricultural sectors (Kelso, Martin and Mack, 1973). As an example, a one dollar increase in gross output of food and feed grains would induce a total of $0.205 of increase in gross output of other sectors of the economy.

"Value added" measures the additional value added to a set of resources because of additional processing. The direct value added multiplier refers to the return to owners of capital and land, and to management and agricultural labor that will be generated in the specific agricultural sector because of the project. The indirect value added multiplier refers to the return to owners of nonagricultural capital and land, and to management and labor that will be generated in support of agriculture because agricultural output had increased. From the preceding example, of the one dollar of gross output of food and feed grains $0.568 was value added directly into the food and feed grain sector and $0.125 of value was induced in the other sector of the economy.

9.4.2 Flood Control Benefits

Flood control benefits of the project will be discussed in terms of applicability to the specific recharge project and in terms of the recharge project as part of a multipurpose flood control project.

The flood control benefits of the recharge project, when the project is viewed in its entirety, as solely a recharge project, will be the benefits resulting from floodproofing those facilities of the project which would be damaged by a flood. These benefits are not true benefits in the sense that when the project is analyzed on a "with and without" basis floodproofing of project facilities will not benefit the outlying areas. However, floodproofing will result in decreased costs in the long run. The example presented in the flood cost section demonstrates the type of analysis that should be made. Floodproofing should be provided up to the point at which the marginal benefits of floodproofing just equal the marginal costs. At that point operation costs in terms of flood damage will be minimized.

When the recharge project is viewed as part of a greater multi-purpose flood control project, benefits will be calculated in terms of damage prevented to flood plain property that would occur in the absence of the flood control project, and the enhanced productivity of the flood plain. Enhanced productivity results from the higher net incomes from activities that displace older activities or from new occupancy that finds the flood plain profitable only because of the new degree of protection.

The calculation of the flood damage prevented will require the derivation of a frequency, or probability curve of the flood damage to be expected. The expected benefit of any construction designed to prevent damage below a certain flood flow is the value of the damage prevented multiplied by the probability of its occurrence.

The calculation of benefits stemming from the enhanced productivity of the flood plain will be based on the change in net income accruing to users of land resources benefiting from the flood protection. Changes in net income will be due to productivity increases and changes in land use that would not have occurred in the absence of the project. The actual calculation of benefits will require a projection of development of the flood plain with and without the project. The value of this difference in terms of net income will then be the value of the benefits.

9.4.3 Municipal and Industrial Water Supply Benefits

The most direct benefit to municipal and industrial users will be the reduced energy costs and requirements for capital expenditures due to the decrease in pumping lift or the reduction in its rate of increase. The benefits resulting from reduced pump lift costs may be calculated in the same manner as those for the agricultural sector (see Section 9.4.1 for the calculation of benefits due to this source).

A second source of benefits for the municipal and industrial water supply account will be the value of the recharge water as an alternative source of supply. This condition is applicable

only if floodwaters, which previously were lost, are the source of the recharge water. Otherwise the water would probably be delivered by some other transport method, in which case recharge water would not represent a true alternative source of supply. Because alternative sources of supply already exist and are utilized by the cities with the project area, this class of benefit will accrue only if changes are made by users to take advantage of the augmented supply of ground water (recharged flood water). Benefits then, will be based on the "willingness-to-pay" criterion of customers when this can be deduced from market information. Presumably municipal and industrial customers will change their supply source to the augmented ground-water supply because this source represents a lower cost source than their previous supply (i.e. surface water).

Water supply represents a final good (as opposed to an intermediate good) to municipal and residential users. The benefits to these users will be the extent to which supply is changed to the augmented ground-water source multiplied by the decrease in cost represented by the new source versus the costs of the old source.

Should the recharge project represent a new source of supply to some community, then the benefits will be based on the customer's willingness-to-pay. If it is not possible to derive a demand curve upon which willingness-to-pay could be based, and the decision has been made to develop some source of supply, then the benefits will be the cost of the next best alternative source of supply.

For industrial users, water represents an intermediate good. It is used as an input in the production process. The benefits of the recharge project to an industrial user will be similar to those for the agricultural user. The benefits will be the extent to which production costs decrease and the value of additional output (if any) stemming from productivity increases which are a result of the project. There will also be a multiplier effect from the industrial benefits. At the present time the University of

California, under contract to the U.S. Energy Research and Development Agency (ERDA), is preparing industrial multipliers but they were not available for inclusion in this report.

9.4.4 Water Quality Management Benefits

Should poor quality water be recharged by the project (e.g. Mesa Treatment Plant effluent), its quality may be improved as it moves through the vadose zone and the aquifer. Flow through these zones will produce a tertiary treatment, possibly resulting in a higher quality of water at a lower cost than could be achieved by a tertiary treatment plant. The benefits resulting from the treatment characteristics of the vadose zone and the aquifer will be difficult to trace because the positive effects of improvements are difficult to locate and quantify. In addition, an improvement in quality of the source must be balanced against the degradation in quality of native ground water. For example, levels of nitrate and organics in ground water may increase as a result of recharging sewage effluent. The calculation of the benefits will require an estimate of the increase in productivity to users benefiting from increased water quality. Water quality benefits will probably be most significant in areas where mixing of good and poor quality water would occur and areas where pumpers are faced with declining ground-water quality conditions.

9.4.5 Recreational Benefits

Recreational use of recharge sites will probably not be a significant element of the recharge project. Nevertheless the methods for calculating the benefits stemming from such use are presented in the event that planners decide to include recreation as a purpose of the project. The benefits stemming from recreational use of the recharge facility will depend on the type of recreation service provided by the facility. Of the six major recreation activities found at reservoirs (camping, picnicking, boating, swimming, fishing and sightseeing), picknicking and swimming could conceivably be provided by the recharge facility. To quantify the benefits of these services, some measure of users willingness-to-pay is required. Willingness-to-pay can be estimated from the

expenditures incurred to enjoy the recreation services. These expenditures can be estimated by the analysis which follows to derive a demand curve which can be expressed in dollar terms. The dollar value resulting from summing the area beneath the derived demand curve will then represent the value of annual benefits from the recreation purpose.

The recreational use of the facility by the surrounding communities should increase with community population and decrease with the distance to the site. Regression analysis of annual visitation data collected for fully developed reservoir recreation sites has produced an equation of the form (James and Lee, 1971):

$$U = \frac{KP}{D^n} ;$$

where U is the annual visitation from an area having population P, located D miles from the site and K and n are constants determined from the regression. Statistical evidence indicates a value of about 2.4 for "n" for a typical recreation reservoir (James and Lee, 1971). This value should also be roughly applicable to recreational use of the recharge site. Values for K are affected by the characteristics of the population, characteristics of the routes to the site, the availability of competing recreation sites, and the characteristics of the site. These additional factors can be incorporated into the equation by including them in the multiple regression analysis to predict visitation (James and Lee, 1971).

To derive a demand curve based on travel distance an expression of the negative utility (disutility) of overcoming distance in money terms is required. Knetsch and Davis (1966) described this disutility as the sum of money cost (expense of making the trip), time cost (value of the time spent traveling) and the ability of the travel experience (the pleasure or discomfort, whichever it may be, one gets from traveling). These terms can be expressed in the following equation (James and Lee, ibid):

$$C = 2.42 \frac{(1+a)m + t/v}{bp} ;$$

where C is the cost per mile in dollars per visitor day spent at

the site; 2.42 is the product of 2.0, which accounts for round trips, and 1.21, an average ratio of road to air distance; a is the expense incurred for food and lodging above that spent at home, expressed as a fraction of vehicle operating cost; m is the variable vehicle operating cost in dollars per mile; t is the value of a vehicle hour of traveling time in dollars; v is the mean travel velocity in miles per hour; b is the number of days a visitor remains at the site; and p is the number of visitors per vehicle (James and Lee, 1971). Highway economy studies can provide a source of data for estimating values for these variables.

The first equation allows one to estimate the annual user days for a recreation site "D" miles away. By continually incrementing the number of miles from the site, the number of visitors placing a value on the recreation experience greater than the disutility (negative utility) of the travel time can be determined. Demand then can be estimated as a function of distance. The second equation can then be used for placing a monetary value on each incremental change in distance. James and Lee (1971) express this procedure for a reservoir recreation site in the following steps:

1. The site is viewed as being at the middle of a target with the surrounding area divided into population centers.
2. The population for each center is estimated.
3. A value of K must be selected for each center. The value found in deriving the first equation may be used for each one. Regression analysis may be used to vary K with specific independent population or route characteristics.
4. The first equation (taking D as the distance to/from the site to the center of population) gives an estimate of the number of potential visitors from each center. Total visitation is the sum of the center visitations.
5. By adding a series of arbitrarily selected distances to the value of D for each center, the number of visitors willing to travel the extra distance can be calculated and the results summed in a series of progressively smaller totals.
6. Data can be collected to evaluate the variables in the second equation and the unit cost per mile in dollars per visitor day can be calculated.
7. For each of the total distances in step 5, incremental distances can be calculated.

For recreational use of the recharge site it is assumed that

demand will be generated almost entirely from the surrounding communities and that total travel distance represents the distance the visitor goes out of his way to reach the site.

9.4.6 Other Benefits

As a result of the recharge project, aquifer compaction in the recharge area may be reduced. The surface effect of this will be to reduce the tendency for land subsidence. Land subsidence causes cracks in pipelines, canals, building and roads, and disturbs gradients in canals, ditches and other conveyance structures. Land subsidence can result in considerable damage. Therefore, the benefits due to the prevention of land subsidence will be the costs and damages avoided as a result of the project. To calculate these benefits an estimate of the projected damage that would occur due to subsidence in the absence of the recharge project will be required.

The subsurface impact of aquifer compaction is the deterioration of the transmission and storage capacities of the aquifer. Aquifer compaction in a ground-water system can be compared to the accumulation of silt in a surface storage system. Eventually the accumulation of silt will destroy the storage capacity of a surface reservoir. Compaction can have a similar effect on a ground-water reservoir. The prevention of compaction will prolong the life and maintain the quality of the ground-water system. The quantification of the benefits of preventing compaction will be difficult. It may be possible to compare compaction with siltation and somehow extrapolate the benefits of preventing one to the benefits of preventing the other.

The utilization of the transmission and storage capacities of the aquifer represent another benefit of the project. The value of these benefits may be determined by comparing the cost of transmission and storage of the aquifer (recharge and recapture) with the costs of similar surface storage and transmission structures. The benefits will be the decrease in cost attributed to the use of subsurface versus surface storage and transmission capacities. This type of analysis is only relevant where it has previously

been decided to meet the goals of some project and the alternative methods of meeting those goals are subsurface versus surface storage structures. If this condition is not present, quantification involves an estimate of the degree to which users change their mix of water sources to utilize the water supplies by the project. Once the quantity of the change in use to recharged ground water is known, benefits can be calculated by comparison with alternative methods for storing and delivering the same quantity of water.

Recharge of water is expected to prevent evaporation losses that would occur if the water would otherwise remain on the surface. However, during the transmission of water through the vadose zone and the aquifer, from recharge to the recapture point there will be water loss. The difference between evaporation losses saved and transmission losses lost represents an increase in the absolute supply of water available to the East Basin region. The benefits of this increase can be calculated by multiplying the number of units of water saved by some per unit value for the water. This per unit value could be the price charged to residential customers of a city's water system or some value based on the value of water as an input to agricultural or industrial users.

Downstream from the proposed recharge project in the general area of Buckeye, drainage costs have become a significant factor affecting agricultural production. Should the recharge project intercept and recharge some of the flood flows and releases that are contributing to the high water-table elevation in the Buckeye area, then the reduction or prevention of drainage costs attributable to the project becomes another source of benefits.

The final benefit will probably not be quantifiable in economic terms. This is the benefit that comes with the assurance to users of a stable water supply in the recharge area. It will be difficult to determine how investment decisions by users are affected by this assurance. Benefits can be quantified to the extent that investment decisions resulting in greater productivity or development in the recharge area are known to have been a result of the guarantee

of a stable water supply.

9.5 Economic versus Financial Feasibility

The economic feasibility of a project is determined through an analysis of its benefits and costs. The test of economic feasibility is passed if the total benefits of a project exceed those which would occur in the absence of the project by an amount in excess of project cost. It is important to ensure that the comparison be "with and without" the project rather than "before and after" because many of the project's after effects may occur without the project and thus cannot properly be used in project justification.

Financial feasibility, on the other hand, is the capacity to raise sufficient funds to pay for the installation and operation of a project. It is sometimes known as the "self liquidating" character of a project. A financially feasible project will generate revenues sufficient to cover all the costs of a project. A project may be economically feasible but financially infeasible because the benefits are insufficiently concrete for the beneficiaries to appreciate their true value or are so widespread that no institutional framework exists to set charges and collect funds for project repayment.

A major obstacle with respect to the feasibility of a full-scale recharge project is its financial feasibility. The lack of specific rights to ground water means that, after water is recharged to the aquifer below, all pumpers having access to that aquifer will be able to recapture recharged water with no requirement for compensating the agency responsible for recharge operations. Municipal, industrial and agricultural pumpers can, therefore, extract recharged water without devising a payment or charging scheme for repayment of benefits to the recharge project. The lack of an institutional framework for setting charges and collecting funds for project repayment is a serious obstacle affecting the financial feasibility of artificial recharge. A number of suggestions for alleviating the institutional shortcomings which affect repayment

and thus financial feasibility have been discussed in Section 8 of this report. It is imperative that a solution to this problem be found before artificial recharge can become a viable water management tool.

9.6 Socio-Economic Considerations

The socio-economic impacts of the proposed artificial recharge project will be briefly discussed. An in-depth analysis of the socio-economic factors affected by the recharge project is beyond the resources of this plan of study but should be undertaken in further iterations of the planning process. The first step in a socio-economic analysis is to describe the environmental setting of the project study area in terms of socio-economic factors. Canter (1977) has listed the factors which should be considered when describing the socio-economic setting of proposed projects. These factors are as follows:

1. General characteristics and trends in population for state, substate region, county and local communities.
2. Migrational trends in study area.
3. Population characteristics in study area, including distribution by age, sex, ethnic groups, educational level, and family size.
4. Distinct settlements of ethnic groups or deprived economic/minority groups.
5. Economic history for state, substate region, county and local communities.
6. Employment and unemployment patterns in study area, including occupational distribution and location and availability of work force.
7. Income levels and trends for study area.
8. Land-use patterns and controls for study area.
9. Land values in study area.
10. Tax levels and patterns in study area, including land taxes, sales taxes and income taxes.
11. Housing characteristics in study area, including types of housing and occupancy levels and age and condition of housing.
12. Health and social services in study area, including health, manpower, law enforcement, fire protection, water supply, waste water treatment facilities, solid waste collection and disposal, and utilities.
13. Public and private educational resources in study area, including junior college and universities.

14. Transportation systems in study area, including highways, rail and air.
15. Community attitudes and life styles, including history of area voting patterns.
16. Community cohesion, including organized community groups.
17. Tourism and recreational opportunities in study area.
18. Religious patterns and characteristics in study area.
19. Areas of unique significance such as cemeteries or religious camps.

The general setting of the study area can be described as an area which in the past has been predominantly agricultural. This agricultural base has and is steadily evolving into an urban and residential setting as the cities of Mesa, Tempe, and Scottsdale, the satellite cities of Phoenix, expand eastward. In terms of water use, medium density urban development uses approximately the same quantity of water as an equivalent area of agricultural development. The result then is that water requirements are not expected to decline as urban development replaces agriculture.

The Salt River-Pima-Maricopa Indian Reservation represents a distinct ethnic settlement in the study area. One of the sites proposed for the demonstration project is located directly on the reservation. The Indian community has encouraged the consideration of this site with the expectation that some form of recreation development could occur should this site be chosen. The shortage of water-based recreation in the study area and the high demand which exists in the Phoenix and satellite areas for such experience makes recreational development of the recharge sites an attractive proposal for developing the multi-purpose potential of artificial recharge. However, there is a tradeoff between recharge efficiency and potential for recreational development of recharge sites. When planning the project it will be necessary to determine which purpose will take precedence over the other.

After describing the socio-economic environment of the study area in terms of the factors presented in the preceding list, the second step is to identify the critical factors. Primary emphasis should be placed on those factors deemed marginal or substandard by social standards. In general, an artificial recharge project,

because of its small scale, will not have a large impact on socio-economic conditions. The major impact of the proposed project will be on the Indian community if the reservation recharge site is chosen. The Indian community as a whole has an average income below the national average. Recreational use of the recharge site may provide an additional income source for the community depending on the scale of recreational development. However, the disturbance of traditional family and community relationships may be a potential negative effect. The effects of an artificial recharge project on the Indian community will require further study before an in-depth analysis can be made.

A final step in analyzing the socio-economic impacts of a project is to discuss the implications of the changes relative to the critical or marginal terms identified in step 2 and to identify those factors which will be changed from satisfactory to marginal as a result of the project.

Sources of information for socio-economic factors are found in Bureau of Census Reports, statistical abstracts for various governmental levels, and in studies made by Chambers of Commerce, planning agencies and departments, educational institutions and recreational organizations.

9.7 Broader Consideration

9.7.1 Comparison of Subsurface versus Surface Storage

In the past, when a region has decided that it requires additional storage capacity its first inclination has been to develop surface storage capacities. At present many of the best surface storage sites are already developed, subsurface storage therefore becomes an atrractive alternative. There are several advantages to subsurface storage over surface storage. These include:

1. Ground-water reservoirs generally have a greater storage capacity.
2. Ground-water reservoirs are much less vulnerable to natural disasters such as earthquakes.
3. Ground water eliminates evaporation losses.

4. Water stored in the ground is not affected by plant growth which can impart objectionable taste to the water supply.
5. Pollution problems are minimized in ground-water storage.
6. Underground storage and transmissive capacities are not subject to disruption as compared with surface systems.
7. Artificial recharge acts as a water treatment mechanism and so can actually improve the quality of water as it moves through the aquifer formation.

An investigation of the relative economics of surface storage versus subsurface storage involves a comparison of the costs of construction, operation and maintenance of conventional surface reservoirs and surface water treatment plants versus the construction, operation and maintenance costs of recharge pretreatment facilities, recharge basins and recapture wells. In a study by Mawer and O'Kane (1970) it was found that the operation and costs of surface storage are dominated by the maximum volume of storage required. However, the costs of the aquifer storage system are dominated by the capacities of the pretreatment facilities, the recharge basins and the transmission facilities from water source to recharge site. They defined aquifer system cost and surface storage system cost as follows:

Aquifer System Cost = σP (unit capital cost of diversion and transmission + pretreatment + recharge basin or wells)
$+\sigma R$ (unit capital cost of recapture wells + post treatment)
+ R (annual unit operating cost of diversion and transmission + pretreatment + input + recapture + post treatment)
Where (R) is an annual fixed charge rate.

Surface storage system costs (on channel) =
σV (unit capital cost of reservoir)
$+\sigma R$ (unit capital cost of post treatment)
+R (annual unit operating cost of post treatment).

The unit capital costs of diversion and transmission will be strongly dependent on the distance from the diversion point to the

recharge site. The costs of pretreatment will be influenced by the quality of the raw water, its compatibility with the aquifer and the design of the recharge system. The costs of recharge basins will be strongly influenced by local hydrogeology and the design of the recharge system. The unit costs of recapture wells will be influenced by local hydrogeology, and the costs of post-treatment are expected to be negligible, generally involving only chlorination.

For surface storage, unit capital costs of impounding reservoirs depends on the scale of the reservoirs and local site conditions. Costs of post treatment consist of the cost of conventional surface water treatments. Mawer and O'Kane (1970) found that, in general, when the relative operating costs of the two systems were considered separately, the costs for a recharge system exceed those for surface storage. However, they also found that when diversion for recharge can be made downstream from a surface storage facility the recharge system is presented with a partially regulated streamflow regime. The surface storage facility captured the short-term peak flows which were then recharged at a constant rate. This system takes advantage of the high efficiency of surface storage in capturing peak flows for short retention periods and then exploits the high efficiency of aquifer storage for long-term storage.

The overall results of their investigation in terms of representative unit costs found artificial recharge to be favored over surface storage when the recharge system is faced with a high degree of streamflow regulation. Artificial recharge, under the same representative unit costs conditions was found to be unfavorable at lower degrees of regulation or for use on rivers which have highly variable (short term) flow conditions. The most efficient system found by Mawer and O'Kane (1970) was that provided by surface storage upstream from an artificial recharge site. They found that total system costs could be significantly lower than those associated with surface-only or aquifer-only storage systems.

The results of this investigation are favorable for the

proposed recharge project if the project is provided with a constant flow of water. The results are unfavorable if the recharge project is dependent on highly variable flood flows as the sole water source. The proposed location for the recharge project would place it downstream from storage and diversion dams of the Salt River Project on the Salt and Verde Rivers. This location would allow conjunctive management of surface and ground-water supplies and maximize the economic efficiency of the recharge project. If a conjunctive management arrangement could be established with the Salt River Project, in which the recharge project would be guaranteed a constant supply of water, it would be possible to draw down Salt River Project reservoirs to a prescribed level and then utilize the water storage capacity above this level to retain the short-term peak flows which have caused extensive damage ($60 million damage in 1978) in Maricopa County. The short-term peak flows captured in Salt River Project reservoirs could then be delivered to the recharge project and be recharged at a constant rate. The advantages of such an arrangement would be: reduction in flood damages, reduction in evaporation losses, minimum cost operation of the recharge project, and, should the recharge project be located up gradient from Salt River Project extraction wells, an absolute increase in quantity of water available to the Salt River Project because some of the water from flood flows which were previously lost, could now be captured, recharged and withdrawn from Salt River Project wells as needed. The potential for implementing such an arrangement will require resolution of legal and institutional constraints before it can become feasible.

A second proposal that has been discussed, is that the recharge project be considered as an alternative to the proposed Orme Dam. Recharge and storage of Central Arizona Project (CAP) water in the East Basin would enable the Central Arizona Project to pump "off peak" and thus maximize the benefits realized from sale of electricity. Such an arrangement would have many of the same advantages as those above except that the flood control capacity of Orme Dam would no longer exist.

9.8 Economic Tools for Final Analysis

Economic tools which can aid in the final analysis of the project and contribute to optimization of project design are briefly summarized in the following section.

9.8.1 Input-Output Modeling

The impact of the project to the agricultural sector will extend beyond the primary beneficiaries (producers) to other sectors of the regional economy. These secondary or "multiplier" effects represent changes in income within the local economy and sectoral shifts within the national economy. The method used in making estimates of the multiplier effects of income changes in the agricultural sector is Input-Output analysis. This method is based on the fact that expenditures by one spending unit are income to some other unit. The total of incomes and the total of expenditures in an economy at each point in time must balance. Input-Output analysis traces how the expenditures by a spending unit are distributed (as income) among other units with which the spending unit is economically related, as a buyer of the other units' products or services. Input-Output analysis then further traces how those incomes are in turn distributed. This chain continues on in an expanding manner, with the effects at each level becoming increasingly small.

Once having determined the expenditure sharing patterns and income consequences for all spending units in the economy, it is possible to determine by how much incomes throughout the economy are affected by each dollar of change in expenditure by any one unit. This then is the "multiplier", the amount by which incomes in the whole economy are changed by a change of one dollar of production in the initiating unit.

Input-Output linkages are generally constructed by grouping similar units into classes and then tracing the input-output linkages among classes of spenders and receivers. These classes represent sectors of the economy (for a detailed analysis of the multiplier principle, see Kelso, Martin, and Mack, 1973).

Considerable research has been done to investigate the multipliers associated with the agricultural sector of the Arizona economy. Multipliers have been developed by the Bureau of Reclamation, the Arizona Water Commission, the Water Resources Council, and Kelso, Martin and Mack in Water Supplies and Economic Growth in an Arid Environment, an Arizona Case Study (1973). The Arizona Water Commission is currently engaged in an update of their input-output model and it is expected that new multipliers from the model should be available later this year (1979). Dr. Martin of the University of Arizona Department of Agricultural Economics has stated (personal communication, 1978) that the multipliers derived in the 1973 study are still applicable to the Arizona economy which are presented in the following table:

Table 9-1

AGRICULTURAL MULTIPLIERS

Agricultural	Adjusted Direct & Indirect Gross Output Multipliers (1)	Direct Value Added Multiplier (2)	Adjusted Indirect Value Added Multiplier (3)
Food and Feed grains	1.205	0.568	0.125
Cotton	1.229	0.733	0.150
Forage	1.087	0.842	0.050
Misc. Agriculture	1.171	0.761	0.128
Livestock Products Processing	1.946	0.200	0.432
Misc. Agricultural Processing	1.444	0.515	0.246

Source: Kelso, Martin and Mack (1973) p. 135.

1) One dollar of direct output change for the sector listed plus induced changes for requirements for output from the rest of the economy.
2) Direct value added per dollar of output for the sector listed.
3) Change in value added in the rest of the economy induced by a one dollar change in output for the sector listed.

9.8.2 Graphical Optimization Techniques

The second technique is marginality analysis, which was

discussed earlier in this section. The optimum project design may be determined from this technique by combining the marginal benefit and cost curves for each project purpose into an aggregate marginal benefit and cost curve. The optimum design will be at the point of intersection of the aggregate benefit and cost curves.

9.8.3 Analytical Optimization Techniques

The analytical approach requires the decision problem to be converted to a mathematical model which describes the problem in terms of equations. The first task is to select physical variables for which an optimum quantity is desired (i.e., recharge project capacity, optimum rate of recharge, optimum water-table elevation). Equations are then derived which express the relationships among variables and limit the range of values that given variables may assume. Analytic techniques use specific sequences of mathematical operations to derive the most desirable values for physical variables according to an objective function.

Linear programming requires that all equations in the model be linear. It consists of three basic components: the objective function, the constraint equations, and an iterative procedure for finding the optimum solution. Linear programming can be used for locating recapture wells, optimizing the activity sequence in a construction project, and in determining what recharge rate will balance withdrawal rates. Most linear programming techniques are deterministic. They assume that the coefficients of the objective function and contraint variables are known and fixed.

Dynamic programming determines the optimum decision process for each of a sequence of periods of time, called stages. The model requires an objective function and a set of recurrence equations. A recurrence equation gives the value of a variable during a stage as a function of conditions resulting from earlier stages. The conditions within a stage are called the state and include all information required to describe the relevant condition of the particular stage. Dynamic programming is most useful when applied

to multi-stage decision process problems. Dynamic programming has been used to select the optimum design parameters and optimum operating policy for the conjunctive operation of a surface reservoir and an aquifer (Buras, 1963).

TIME LINE - ECONOMIC CONSIDERATIONS

Task	First Year	Second Year	Third Year	Fourth Year	Fifth Year
Cost-Effectiveness Analysis	→				
Cost Benefit Analysis				→	→
Input-Output Model		→	→	→	→
Linear Programming Model				→	→
Socio-Economic Analysis	→				→

10. ENGINEERING CONSIDERATIONS

For the purpose of this report, engineering requirements for a demonstration recharge project comprise the following elements: planning, design and construction, operation and management, monitoring, and administration. Engineering requirements for the area or areas selected for the demonstration project will of necessity be site specific. The purpose of this section is to review the general engineering requirements for a demonstration recharge project. Suggested investigations are also summarized.

At the outset it is important to stress that a demonstration recharge project should be located, if possible, on the site proposed for the full-scale project. Information gained on managing the demonstration facilities would thus be directly applicable to the same hydrogeological regimen of the larger project. In fact, the full scale unit would probably consist of modifying and enlarging the demonstration facilities. Accessary units such as the laboratory and shop buildings would be retained, together with water diversion and conveyance facilities. Similarly, land purchases, rights of way and other items required for a full-scale project would have been obtained during establishment of the demonstration unit.

10.1 Planning

Detailed information from legal-institutional, economic, environmental and technical surveys is paramount in planning a demonstration or full-scale recharge project. For example, legal and institutional constraints on purchasing land and water for the project need to be defined. Similarly, rights of way for conveyance structures or access roads must be determined. The cost of purchasing land, water and rights of way should be ascertained. Formal agreements will be required between land owners and the agency initiating the recharge project. The services of a lawyer would be required at this stage.

Information on the hydrogeology of a prospective recharge

site is of cardinal importance in selecting and planning for a specific recharge method. Hydrogeological conditions favoring or opposing each of the recharge methods such as water spreading, pits, or wells, are reviewed in Appendix A. Methods to obtain and assess the hydrogeology of potential sites for a demonstration recharge project are reviewed in Section 5 of this report.

A complete list of recommended planning items for a recharge project is presented in a United Nations Report on ground-water storage and artificial recharge (United Nations, 1975):

1. Source of water and pricing policy
2. Water rights
3. Potential liability (inverse condemnation problems-flood-out gravel-mining operations, building fresh-water mound too close to ground surface, thus jeopardizing surface improvements)
4. Effects on ground-water basin management
5. Effects on ground-water quality
6. Investigations (generally involving an exploration of the geological and hydrological conditions) to prove feasibility of scheme
7. Finances
   a) Capital improvements
   b) Water
   c) Operation and maintenance

Rights of Way	Engineering
1. Surveys	1. Surveys
2. Maps	2. Mapping
3. Title search	3. Design
4. Acquisition	4. Contract administration
5. Condemnation	a) Inspection
a) Legal fees	b) Testing
6. Rezoning	

10.2 Design and Construction

Facilities which generally are required for a recharge project include: 1) diversion works, 2) conveyance structures, 3) recharge facilities, and 4) appurtenances.

10.2.1 Diversion Facilities

Potential recharge sites for the demonstration project may require diverting water from natural or man-made channels. Diverting water from canals could involve 1) diversion gates, 2) siphoning or 3) pumping. A diversion gate would represent the simplest

technique for transferring water from a canal to the conveyance system. However, unless a gate is already located in the canal, near a suitable diversion point, it would be necessary to shut the system down to permit installing a structure. The water management agency (e.g., Salt River Project) operating the canal would understandably object to this approach because shutting down the system would interfere with normal water deliveries. Alternatively, a head gate could be installed during the annual period that the canal is drained and cleaned.

If sufficient head difference exists between the water surface in the canal and the conveyance channel, it may be possible to install siphons to obtain the necessary volume of water. Siphons could be fabricated from well casing. Great care must be exercised to ensure air-tight welds. The siphoning action would, of course, fail when the inlet lip is uncovered. Siphon discharge can be estimated using flow equations for orifices, provided that information is available to calculate the coefficient of discharge. The coefficient may be evaluated if the entrance coefficient, inside diameter of the tube, roughness coefficient and tube length are known (Robinson and Humphreys, 1967).

A pumping plant could be mounted on the canal to divert water to the conveyance system. The pumping capacity could be tailored to requirements for the project. Pumps are driven by gas engines or electric motors. Electric motors are desirable because they require less servicing.

Structures for diverting water from washes or stream channels could range from simple earth dams, constructed by crawler tractor, to inflatable rubber dams. Inflatable dams (commercially known as "Fabridams") have been successfully employed in spreading operations in California, e.g., the Walnut Wash spreading basin (Milne, 1975). Such dams are temporary structures, washing away during floods in the case of earth dams, or deflating in the case of rubber dams.

The diversion structure should be installed at a sufficient elevation to ensure gravity flow through the conveyance system,

into and through the recharge facility. Head losses during flow in the diversion structure, control structures, weirs and conveyance line must be determined in calculating the overall head loss required. Procedures for determining losses are presented in the Engineering Handbook on Hydraulics (Soil Conservation Service, no date).

10.2.2 Conveyance Structures

Water could be transported to the recharge area via an open channel or buried pipe line. The simplest technique would be to excavate an open channel via a crawler tractor and a suitable ditching plow. Other methods of construction consist of using the blade of a bulldozer or a backhoe. To reduce seepage losses, the channel could be lined with unreinforced concrete (Fullerform), plastic or butyl rubber membrane, or be compacted with heavy equipment (Lauritzen and Terrell, 1967). A suitable flow measuring device, e.g., a V-notch weir, could be installed in the ditch, near the diversion point, to meter discharge to the recharge area. A second weir could be located at the inlet to the project area.

The dimensions of an open ditch needed to conduct water to the recharge site can be estimated using Manning's equation and procedures described in the Engineering Handbook on Hydraulics (ibid. p. 5.4-27). Manning's equation is expressed as follows:

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}$$

where, Q = discharge rate (cfs)

n = roughness coefficient

A = cross-sectional area (ft^2)

R = hydraulic radius (ft)

S = slope

As discussed in subsection 10.2.3.2 of this report, the minimum discharge rate which the ditch should accommodate is 5.04 cubic feet per second (cfs). Assumptions include:

1) plastic lined channel, roughness coefficient, n = 0.010;
2) prevailing ground slope in the project area, s = 0.0017;
3) maximum discharge rate required, q = 5.04 cubic feet per second;

4) side slopes = 2:1; and

5) triangular cross-section.

The required depth of a triangular cross section to transmit 5.04 cfs is calculated to be 0.87 feet. However, to account for head losses because of in-line control structures or weirs, and to provide freeboard in case of flooding, a depth of at least three feet is recommended. In addition, the larger capacity would be required if the recharge facility is expanded.

Buried pipe lines are less subject to vandalism, flooding and disturbance from animals than open ditches, and do not interfere with traffic movement. However, the capital and installation costs are greater for a pipe line than for an open ditch. Pipelines could comprise concrete, asbestos cement or plastic pipes. Flows could be measured by a propeller flow meter, care being exercised to ensure that the meter is continuously submerged. Flow control could be effected using an in-line gate, or globe-type valve.

Manning's equation may be used to estimate the diameter of pipe to convey water to the recharge site. Assuming that concrete pipe will be used, the roughness coefficient, n = 0.010. Other conditions are the same as above: 1) slope, s = 0.0017, 2) discharge, q = 5.04 cfs. In addition it is assumed the pipe will flow full without back pressure. Using Table 60, in the Handbook of Hydraulics (King and Brater, 1954), the required pipe diameter would be about 1.5 ft. A precise pipe diameter should be determined for site-specific conditions.

10.2.3 Recharge Facilities

Possible recharge techniques for a demonstration recharge project along the Salt River include: 1) channel modification, 2) water spreading, 3) pits, and 4) wells. A detailed discussion of the salient features of these and other recharge techniques is presented in Appendix A. As pointed out above, the specific method and ultimate design selected for the demonstration project will depend upon the results of hydrogeological investigations, outlined in Section 5. The designs presented in this section are for illustrative purposes only. The main purpose of the following

discussions is to present alternatives for the appurtenances usually associated with a recharge facility.

10.2.3.1 Channel Modification

The results of hydrogeologic studies during Phase III of the project may indicate that the most effective recharge technique is natural stream infiltration. In this case a specific reach of the river could be selected to increase natural recharge. Diversion and conveyance structures may not be required in this instance. A general objective of recharge management is to enhance infiltration by increasing the time that a given area is flooded, coupled with an increase of the flooded surface area. To achieve this objective in the Salt River, small earthen dams such as shown on Figure 10-1a, could be constructed across the river, to create a series of basins. An alternative design is presented in Figure 10-1b. The inlet to the basin shown in the figure could comprise a flume (e.g. an HL Flume or triangular weir) to meter the inflow rate and total volume. A water stage recorder could be mounted on a stilling well, connected to the measuring device. A similar flume or weir and recording device would be mounted on the outlet from the basins. The flumes could be anchored to off-channel posts to enhance recovery should the facilities be washed away by a severe flood. The water stage recorders should be housed in locked, steel shelters to reduce the possibility of vandalism. The size of the flumes should be tailored to anticipate flood flows or releases from Granite Reef Diversion dam.

The size of individual basins would be based on the particular reach of the river selected for management. Checks could be constructed across the basins, such as shown on Figure 10-1b, to ensure that flow velocities are sufficient to transport fine sediment through the units, and to inhibit the growth of algae. The velocities should not be great enough, however, to cause scour.

A bypass channel could be constructed to divert large flows. Obviously, in-channel basins would be destroyed by floods of greater magnitude than the capacity of the bypass channel.

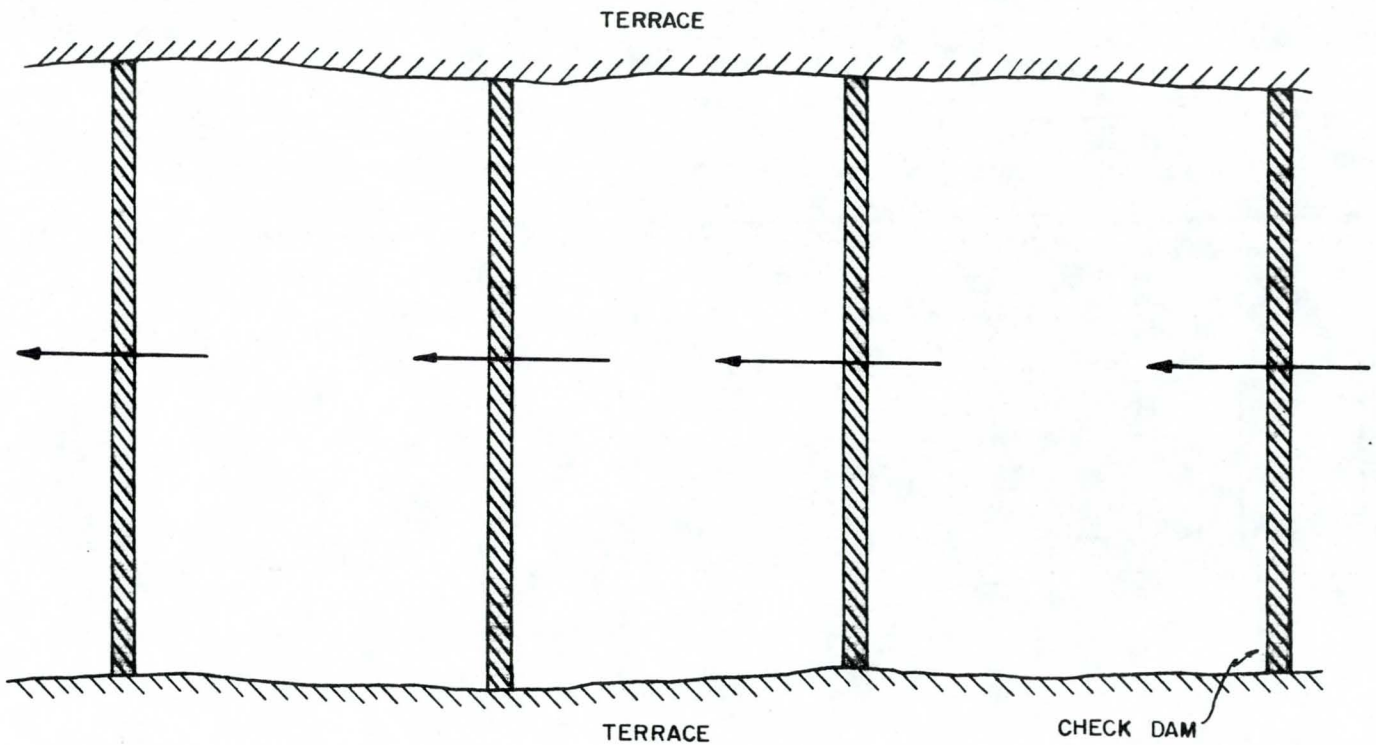


Figure 10-1a. In-channel Recharge Basins.

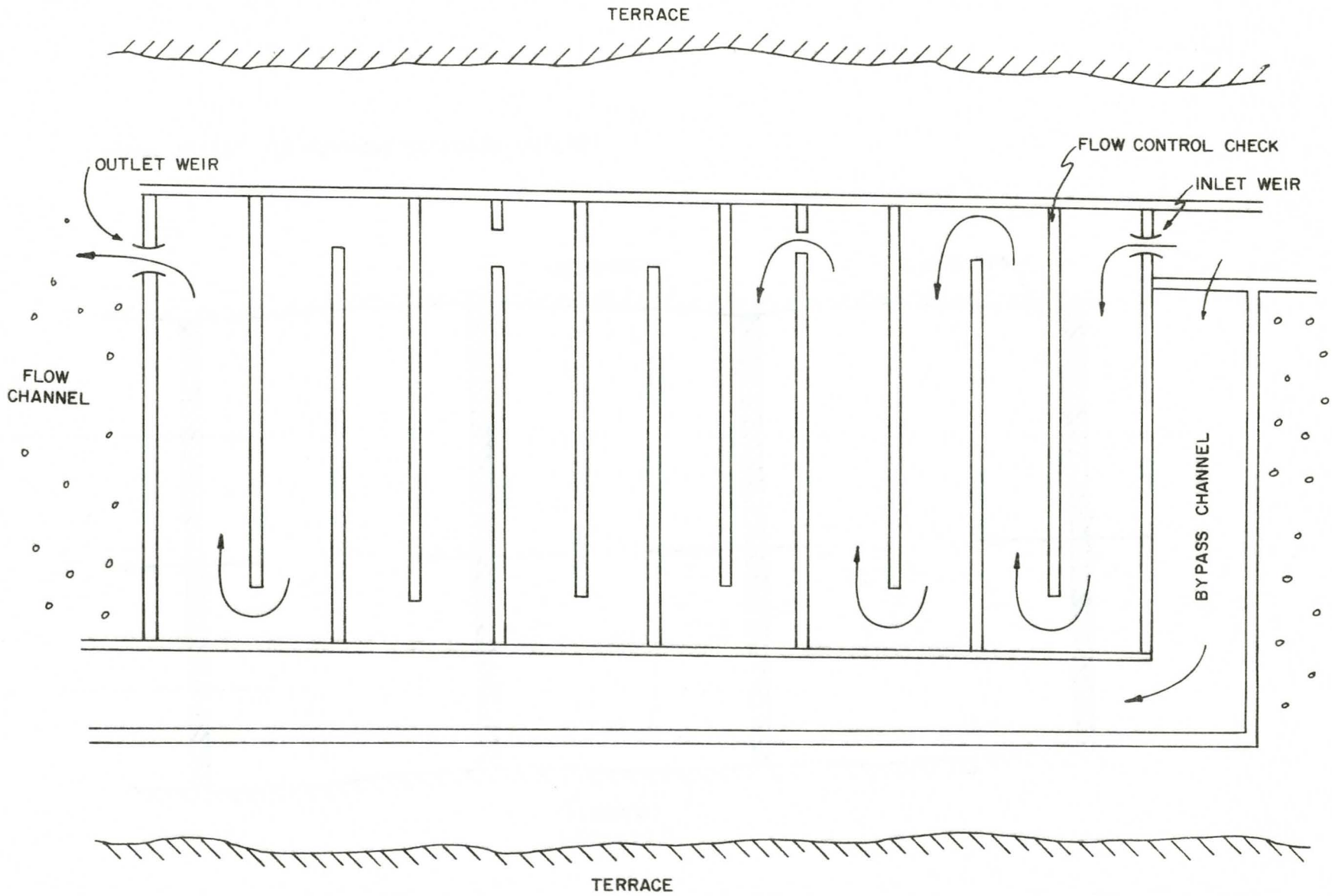


Figure 10-1b. In-channel Recharge Basins.

However, reconstruction would be relatively simple, involving the use of crawler tractors.

10.2.3.2 Spreading Basins

To ensure more prolonged testing than possible with in-channel methods, it may be desirable to construct recharge basins within river bed deposits but out of the low-flow channel. Two possible designs are shown on Figure 10-2 and Figure 10-3. Again, these designs are for illustrative purposes. Components of these systems include 1) settling basin, 2) delivery system, 3) bypass line, 4) recharge basins, and 5) control and flow measuring facilities. The facilities should be constructed as inexpensively as possible because of the danger of destruction from floods.

As a first estimate, individual basins could be about one acre in size. Based on field and model results, long and narrow basins are more efficient recharge units than basins with a lower length to width ratio. Long and narrow units promote lateral subsurface flow and because lateral permeability is generally greater than vertical permeability, greater intake rates would be expected than in more rectangular basins. The recharge basins depicted in Figure 10-2 and Figure 10-3 have the dimensions 50 feet by 870 feet.

The volume of water required for a demonstration project with four basins such as those in Figure 10-2 and 10-3, may be estimated as follows:

1) Assume a long term infiltration rate of 2.5 ft/day (this value was observed by Briggs and Werho (1966) in the Salt River from Granite Reef Dam to 48th Street during the 1965 flood).
2) Surface area of individual basins, one acre.
3) Use A = Q/I, where Q is the volume of water required, A is the surface area, and I is the long-term intake rate.
4) For each basin:

$$Q = 1 \text{ acre} \cdot \frac{2.5 \text{ ft}}{\text{day}} = \frac{2.5 \text{ acre ft}}{\text{day}}$$

$$= 0.815 \text{ million gallons/day (mgd)}$$

$$= 1.25 \text{ ft}^3\text{/sec (cfs)}$$

5) For two basins

Q = 5.0 acre ft/day

= 1.63 mgd

= 2.52 cfs

6) For four basins

A = 10 ac ft/day

= 3.26 mgd

= 5.04 cfs

10.2.3.2.1 Specific Details, Design No. 1

The design shown in Figure 10-2 is designated Design No. 1. As shown, two in-line basins constitute a set. In operation one set would be operated while the other set is dried. When intake rates decrease to a predetermined value, the operating set is shut down for drying and renovation; and the alternative set of basins is activated.

The arrangement of four basins could also be used to estimate the effect of shallow perched ground water on intake rates. Thus, operating an in-line set of two basins simulates a long-narrow recharge facility and the effect of lateral flow on intake rates may be estimated. When the four units are operated simultaneously, the effect is that of a recharge basin with a small length to width ratio. Vertical flow (and impedence from stratification) would become more important in this case. Consequently, comparing intake data from the two cases might indicate the effect of perching conditions on the operation of a larger, full-scale facility. Two separate ditches are provided as shown, to supply each set of basins. This design minimizes the distance between inner and outer units, thereby reducing the lateral flow of water between the units during operation of the four basins in unison.

Sedimentation-Holding Pond

A pond could be constructed, as shown on Figure 10-2, to permit settling of sediment if flood water is recharged, and to provide storage for flow control. The pond would be about one acre in area, with sides 210 feet by 210 feet. Levees could be

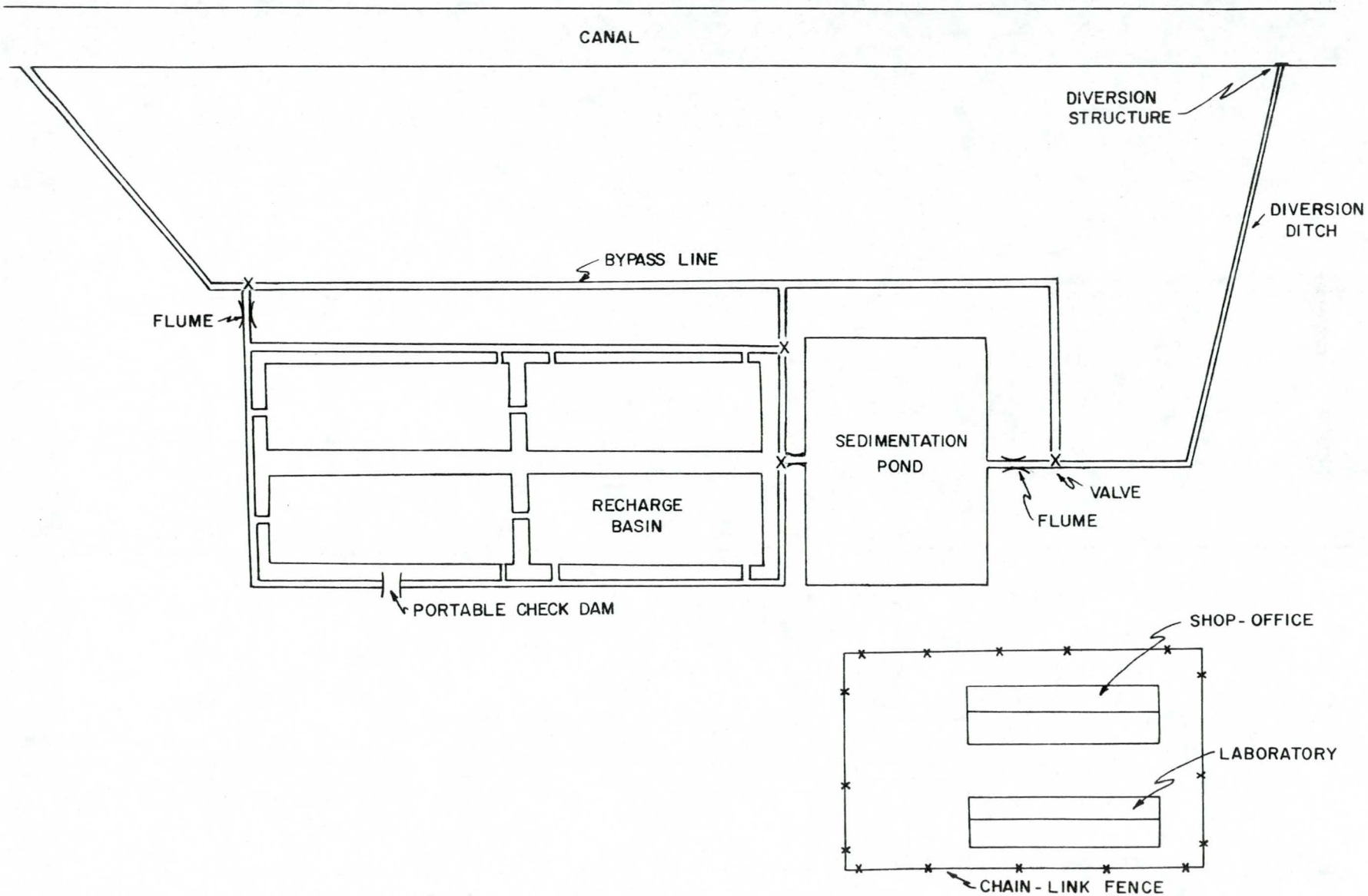


Figure 10-2. Schematic Representation, Recharge Basins Design No. 1.

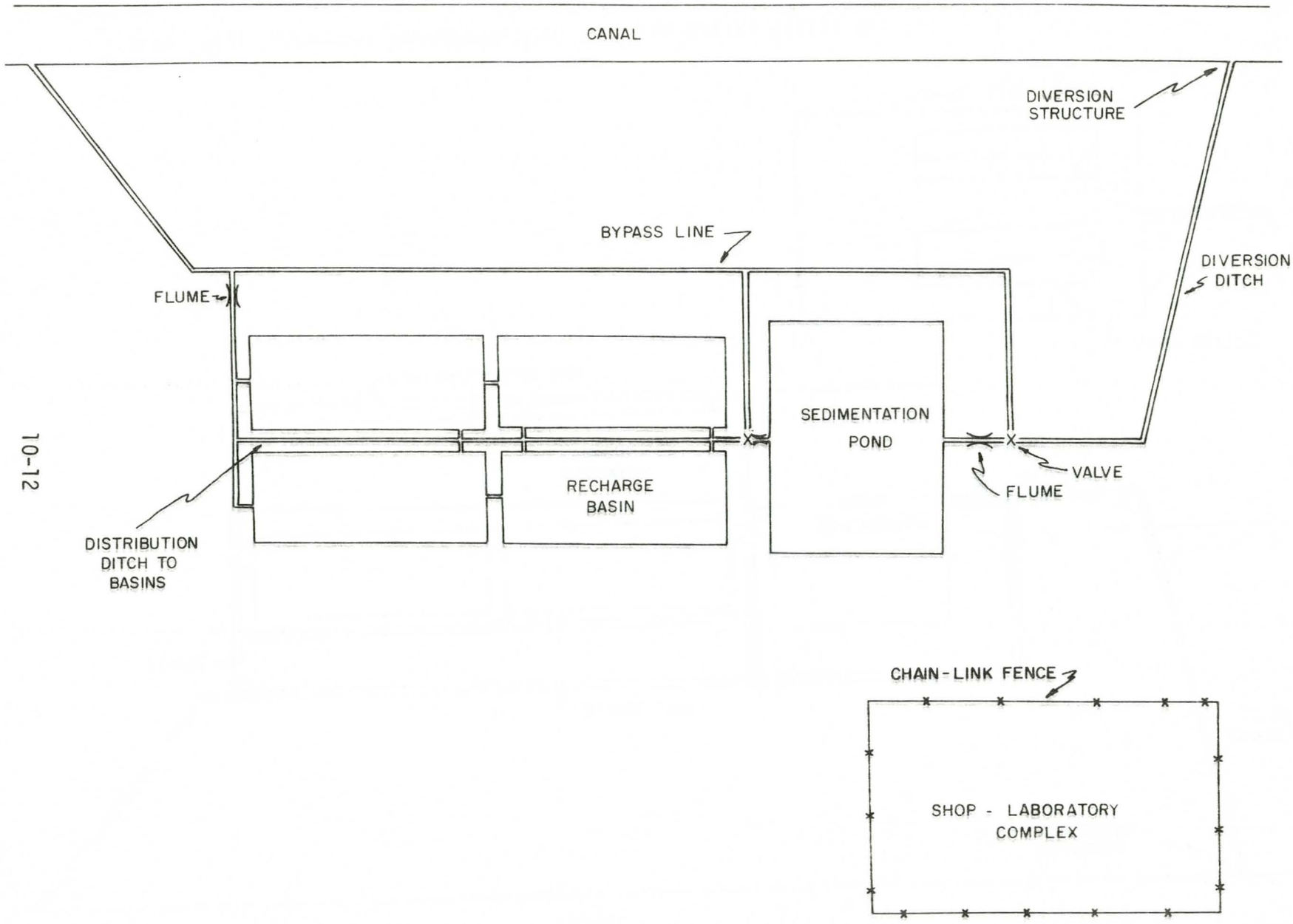


Figure 10-3. Schematic Representation, Recharge Basins Design No. 2.

constructed with 2:1 side slopes and a height of five feet. Note that this is a tentative design. A finalized design could be determined knowing the detention time necessary to effect sediment removal (see Brown, et al., 1978). A 10 foot wide roadway could be provided on the top of the levee. The levees should be constructed from fine materials obtained from nearby terrace deposits and compacted by heavy equipment. A ramp could be provided to provide access for equipment to remove sediment deposits. The bottom of the sedimentation pond should be compacted to minimize seepage inasmuch as seepage could interfere with recharge tests in the basins. Eventually, fine sediment in the incoming flood waters would probably seal the base of the pond. In order to estimate seepage losses it is advisable to periodically shut down the inlet and outlet gates and measure change in head within the pond. A staff gage could be installed for this purpose.

In lieu of a single sedimentation pond, two ponds could be constructed, separated by an internal levee. This design would permit shutting down one pond for renovation while operating the second unit for settling. Additional control structures would be required in this case, Brown, et al.,(1978) presented the design of a compartmentalized settling basin, with screen wire baffles.

Concrete headworks could be constructed at the inlet side to the pond with steel gates permitting diversion of the flow either into the pond on into a bypass line. A concrete structure with a single gate could be installed at the outlet from the pond to divert flow into the distribution system. A floating type outlet structure would minimize carrying sediment into the distribution line (ibid.).

Bypass Line

A bypass line could be installed to permit diverting the entire flow in the conveyance channel around the recharge works and draining the spreading grounds. Such diversion might be required if a break occurred somewhere in the distribution system to the basins; for other emergency purposes; and to facilitate

determining seepage losses in the sedimentation pond. The bypass line would drain into the main supply system.

The bypass channel could be simply constructed, using a crawler tractor and ditching plow. The channel could be lined with unreinforced concrete, plastic or butyl rubber membrane. A simple polyethylene-plastic cover would probably be adequate. However, the ditch would probably need to be continuously inundated or otherwise covered to prevent deterioration from sunlight. A flow measuring device (Parshall flume, V-notch flume) should be placed below the outfall from the spreading ground to permit determining the overall efficiency of the facility.

Dimensions of the bypass channel could be identical to the conveyance system, i.e., triangular cross-section; side slopes 2:1; depth of channel, 3 feet. Seepage losses in the channel should be periodically determined. A simple technique would be to locate check dams in the channel and determine head drop within the dammed-off section. A point gage could be used to measure head changes.

Basin Construction

Basins should be constructed with a minimum disturbance of the spreading surface. The natural slope of the area is about 0.17 feet per 100 feet, or 1 foot per 600 feet. Consequently the drop between inlet and outlet of each basin would be about 1.5 feet.

Levees should be constructed using fine sediments from nearby terrace, and compacted to minimize seepage. A suggested slope for the dikes is 2:1. Levees could be 5 feet in height. A 10 foot roadway should be provided to permit vehicular traffic. Overall width of the dikes would thus be 30 feet. The interior face of the dikes could be covered with coarse gravel or boulders, to minimize erosion from wave action. This cover could be held in place by a screen or grout. A ramp should be provided to permit access of equipment for sediment removal.

Water could be introduced from the supply ditch into each basin via a small diameter culvert, with a gated inlet (see Figure 10-4). The culvert could terminate in a length of steel pipe,

containing a propeller flow meter. An elbow should be welded onto the end of the pipe to ensure submergence of the flow meter. Alternatively, the culvert could terminate in U-shaped section containing a Palmer-Bowlus flow meter. The culvert should terminate about 1 foot off the bottom of each basin, to facilitate increasing the head at the upper end of the basins. A plastic sheet, concrete apron, or other protection should be provided beneath the inlet to retard scouring.

Interbasin transfer of water would require installation of a suitable drop-structure within the levee separating adjacent basins. Concrete pipe, culvert or steel pipe could be used. The inlet should contain a gate, such as a slide-type port valve. The pipe could discharge into a box structure with an overflow weir. The weirs should be equipped with flash boards to control the depth of water in the basin. Bianchi and Lang (1974) recommend installing a cutoff within the levee around the circular pipe to inhibit erosion and leakage. Discharge from the lowermost basins would be through a pipe containing a flow meter.

Distribution Ditches

As shown on Figure 10-2, each battery of two basins would be supplied with water from separate ditches. The ditches could be constructed by a crawler tractor and a ditching plow. A triangular cross section could be employed. The ditch could be lined with butyl rubber, plastic or cement. Polyethylene plastic would be adequate, although care must be exercised to avoid damage from equipment. Also the ditch should be protected somehow from sunlight. Seepage losses should be determined periodically.

Maximum dimensions of the individual ditches needed to transport 2.52 cfs may be calculated from Manning's equation, using a procedure outlined in the Engineering Handbook of Hydraulics (Soil Conservation Service, No date, p. 5.4-27). Assuming a roughness coefficient, n, of 0.010 (for plastic), a lengthwise slope, s, of 0.0017, side slopes 2:1, and a triangular cross section, the maximum depth required in the channel would be 0.67 feet.

However, in practice water would be diverted from the ditch into the basins by damming flow downstream of the inlet culverts. A two or three foot head might be developed in the ditch. Consequently, the ditch should have a depth of at least three feet to provide storage. The elevations of the ditch bottom and basin surface should be equal.

Short lengths of culvert should be laid lengthwise at several locations in the ditch system. The culvert sections would be covered with earth and ramps constructed to permit entry of vehicular traffic onto the levees.

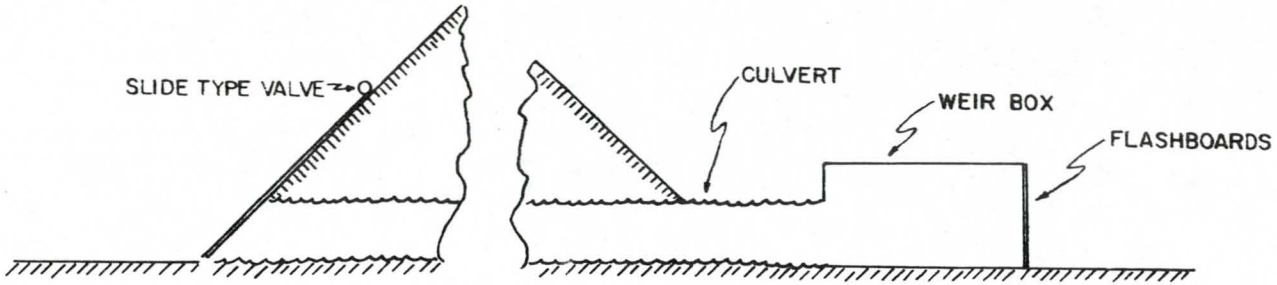
A weir or flume could be installed in the supply ditch at the outlet from the sedimentation pond, to meter flow into the recharge basins. A six-inch Parshall flume would probably be adequate. Alternatively V-notch critical-depth flumes, made from fiberglass, of the type employed on the Flushing Meadows Project could be installed.

In order to dam flow in the ditch, for diversion into the basins, portable, lightweight checks could be installed as required. Alternatively, a simple dam made from sheet plastic and a two by four board could be fabricated.

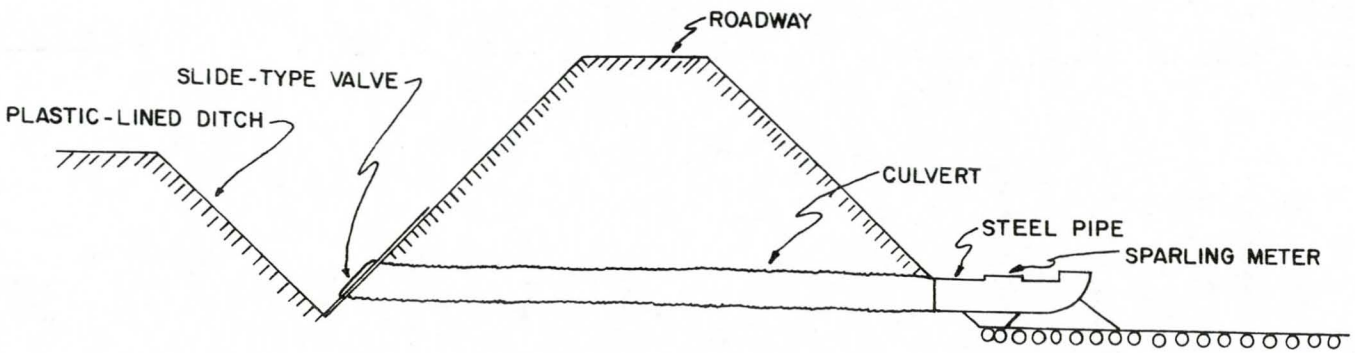
10.2.3.2.2 Design No. 2

The arrangement of basins and appurtenances for Design No. 2 is shown on Figure 10-3. In constrast to the first design, the supply ditch extends down the middle of the facility. Therefore, individual basins are supplied from the same ditches. This design would be less expensive than Design No. 1. However, the basins in the inner and outer units would be further apart for the second design because of the width of separate levees plus the width of the ditch. That is, for the first design, the basins would be 30 feet apart. For the second design, the basins would be about 80 feet apart. Because of the greater distance between sets of basins, it could be more difficult to detect perching conditions by operating the four basins in unison.

The elements comprising the design and construction of the



INTERBASIN TRANSFER



BASIN INLET

Figure 10-4. Basin Inlet Structures.

settling pond, bypass line, basins, supply ditch, and turnout structures would be similar to those for the first design.

10.2.3.3 Recharge Pits

A third alternative method for a demonstration recharge project is to employ pits. Pits could be constructed either within or next to the Salt River. In lieu of constructing pits, it is recommended that existing, abandoned gravel pits be employed. For example, the series of pits within the channel between Country Club Drive and Alma School Road could be modified for recharging flood water. The upstream pits could be used as sedimentation ponds and the larger downstream pit could be used primarily for artificial recharge.

The design and construction requirements for specially constructed pits are reviewed below. A possible arrangement for an experimental pit and accessories is shown on Figure 10-5. The basic components of this design are: 1) a diversion facility, 2) conveyance structure, 3) a settling-stabilization pond or ponds, 4) a bypass line, 5) a supply line, and 6) the recharge facility. Facilities for diverting, conveying, and bypassing water for the project would be similar to those previously discussed for basins. The settling basin could also be similar to the unit described for the recharge basins.

10.2.3.3.1 Supply Line

Water could be conveyed from the sedimentation pond(s) to the recharge pit either in an open ditch or buried pipe line. The latter is preferred. The pipe line could be constructed of concrete, asbestos cement, or steel casing. A valve should be located in the line near the sedimentation pond. Downstream from the valve a propeller flow meter could be installed. The length of pipe containing the meter should be at a lower elevation than other sections of the pipe to ensure submergence of the propeller. The pipe outlet should terminate at the base of the pit, to prevent side erosion. To further reduce scouring, the pipe should discharge onto a concrete apron or plastic sheet.

10.2.3.3.2 Recharge Pit

Specific design of a pit requires detailed information on the hydrogeology of the proposed site, e.g., location of shallow caliche or clay layers. Consequently, only a conceptual model of a pit will be described.

A possible design for a recharge pit is shown on Figure 10-5. The pit shown is 100 feet wide, 500 feet long, 20 feet deep with side slopes 2:1. A 20 foot roadway is provided at the base of the pit and a ramp could be provided at one end to permit access of equipment for removing sediment from the bottom.

The long narrow design (length to width ratio = 5:0) would promote greater lateral than vertical subsurface flow. The relatively steep slopes would comply with recommendations of California workers who found that intake rates increased during recharge studies as side slopes increased.

The pit shown on Figure 10-5 would probably require a drag-line for construction. Upon completion the interior dimensions of the pit should be surveyed. A relationship between depth of water in the pit and wetted surface area and volume should be calculated. To facilitate determining water level changes in the pit a platform could be constructed for mounting a stilling well and water stage recorder. The water stage recorder should be mounted in a locked, steel housing to prevent vandalism.

10.2.3.4 Recharge Wells

As pointed out in Appendix A recharge wells are normally installed where insufficient land is available for the other techniques, or where the water table is very deep and intervening sediments are highly stratified. The vadose zone is bypassed during well recharge and physical-chemical interactions between recharge water and sediments are thus excluded. An abundance of land is available for spreading methods along the Salt River. There are certain locations, however, where water spreading on land which has previously not been wetted could leach salts, creating salinity problems. A severe restriction on the use of recharge wells is

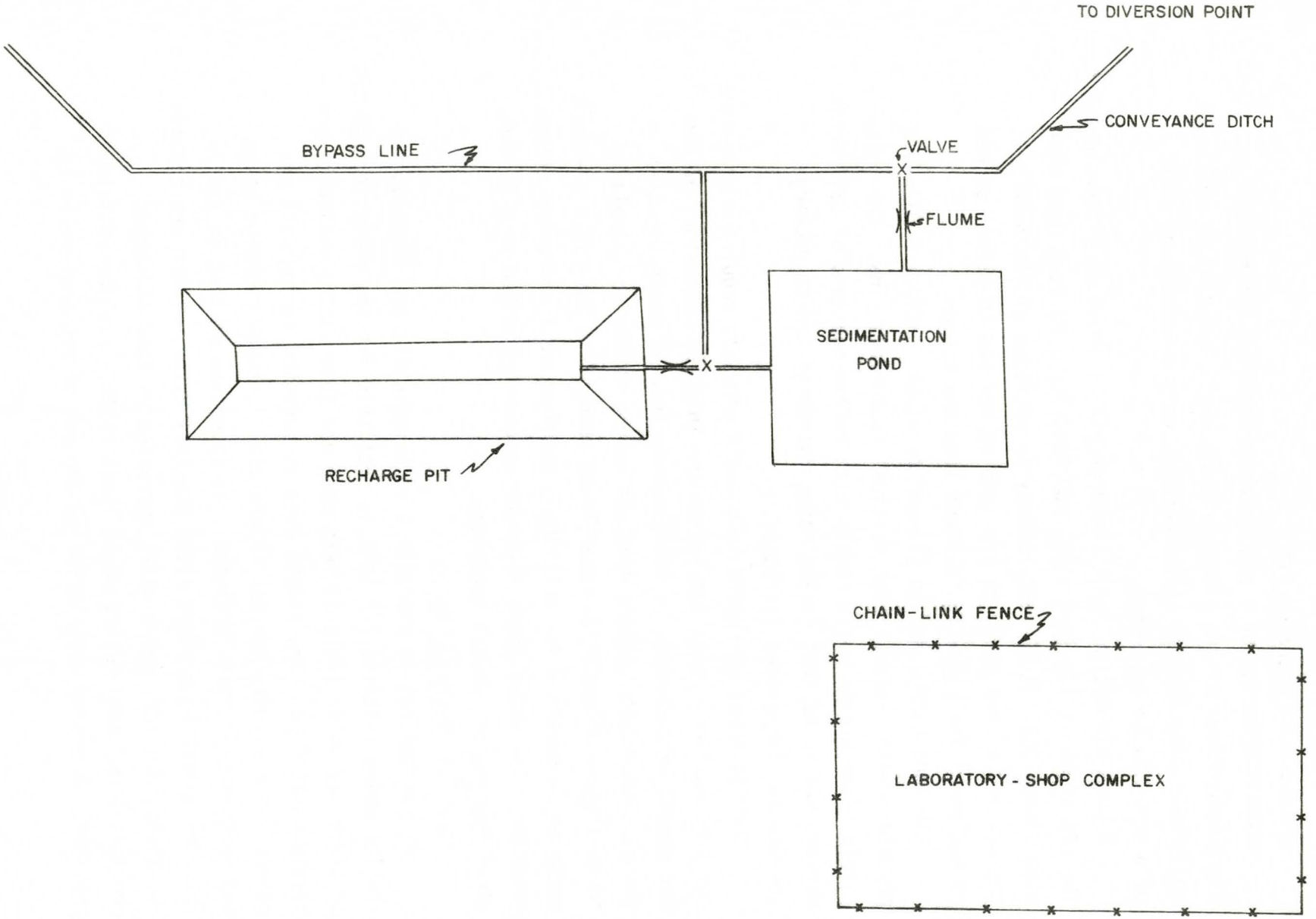


Figure 10-5. Recharge Pit and Accessories.

that only sediment-free water should be used. Extensive (and expensive) sedimentation works would be required.

Figure 10-6 shows a conceptualized arrangement for a recharge well and appurtenances. Water could be diverted and conveyed to the site using facilities such as those described for spreading works. A large sedimentation pond would be required for initial removal of sediment. A flocculating agent could be added near the diversion turn-out and floc formation would occur during flow in the conveyance ditch. A compartmentalized reservoir would be desirable, with settling occurring in the first compartment and clearer water spilling into the second unit. The settling basin could also serve as a storage reservoir, of sufficient capacity to ensure uniform water delivery to the recharge well.

Water could be diverted from the pond into a storage tank, leading to a final filtration unit (e.g., rapid sand filter), and chlorinator. Thereafter water would be pumped into a pipe line containing a propeller flow meter and control valve; ultimately discharging into the inlet to the well. The well should be enclosed by a chain-link fence.

A ditch should be provided to permit drainage of water pumped from the well during redevelopment or pumping cycles. The water should be discharged far enough away so that return flow will not interfere with pumping tests.

Figure 10-7 shows a cross-section of a possible recharge well design for the demonstration project, illustrating salient features generally common to all recharge wells. Specific details would naturally depend upon the local hydrogeology.

The well casing should be larger than the casing for an equivalent water supply well in order to permit installing conductor pipes. Casing material could be PVC, asbestos cement or steel. A well constructed for demonstration purposes along the Salt River would probably be constructed from steel casing, particularly if the cable-tool drilling technique is used. The well could be perforated in the water-bearing zone, or outfitted with a screen.

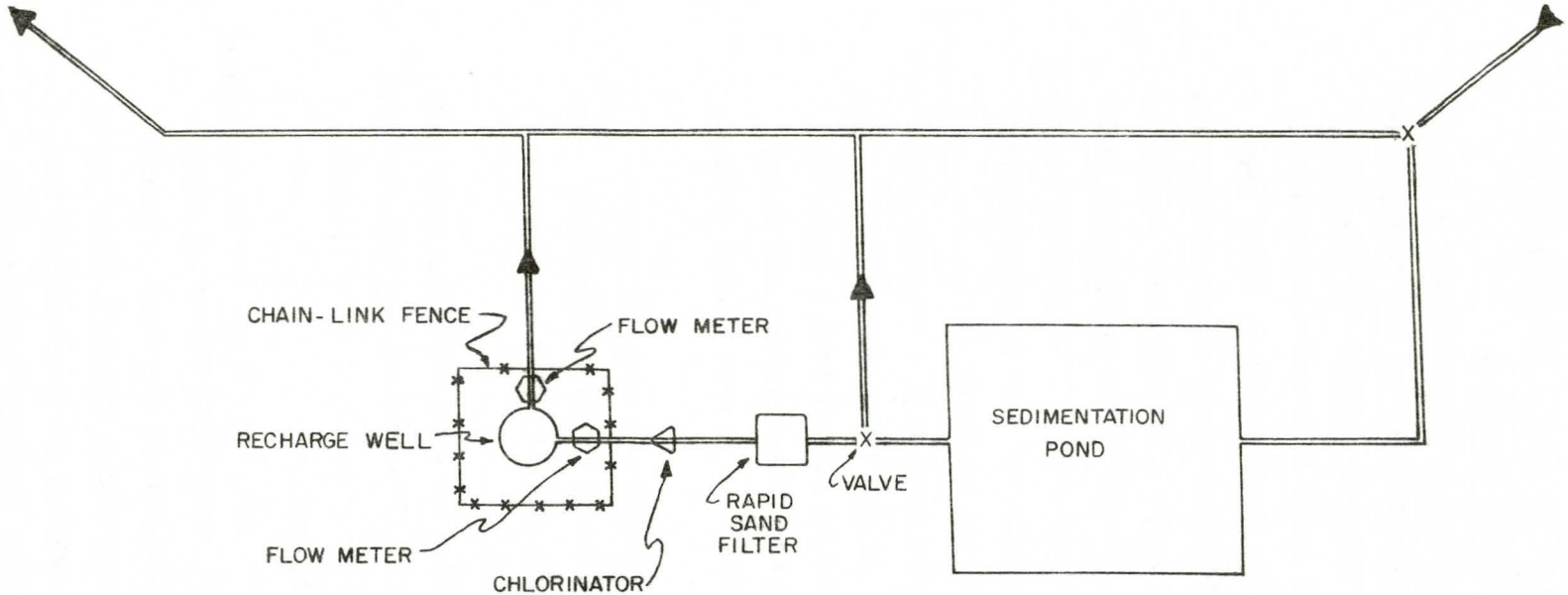


Figure 10-6. Schematic Representation, Recharge Well and Appurtenances.

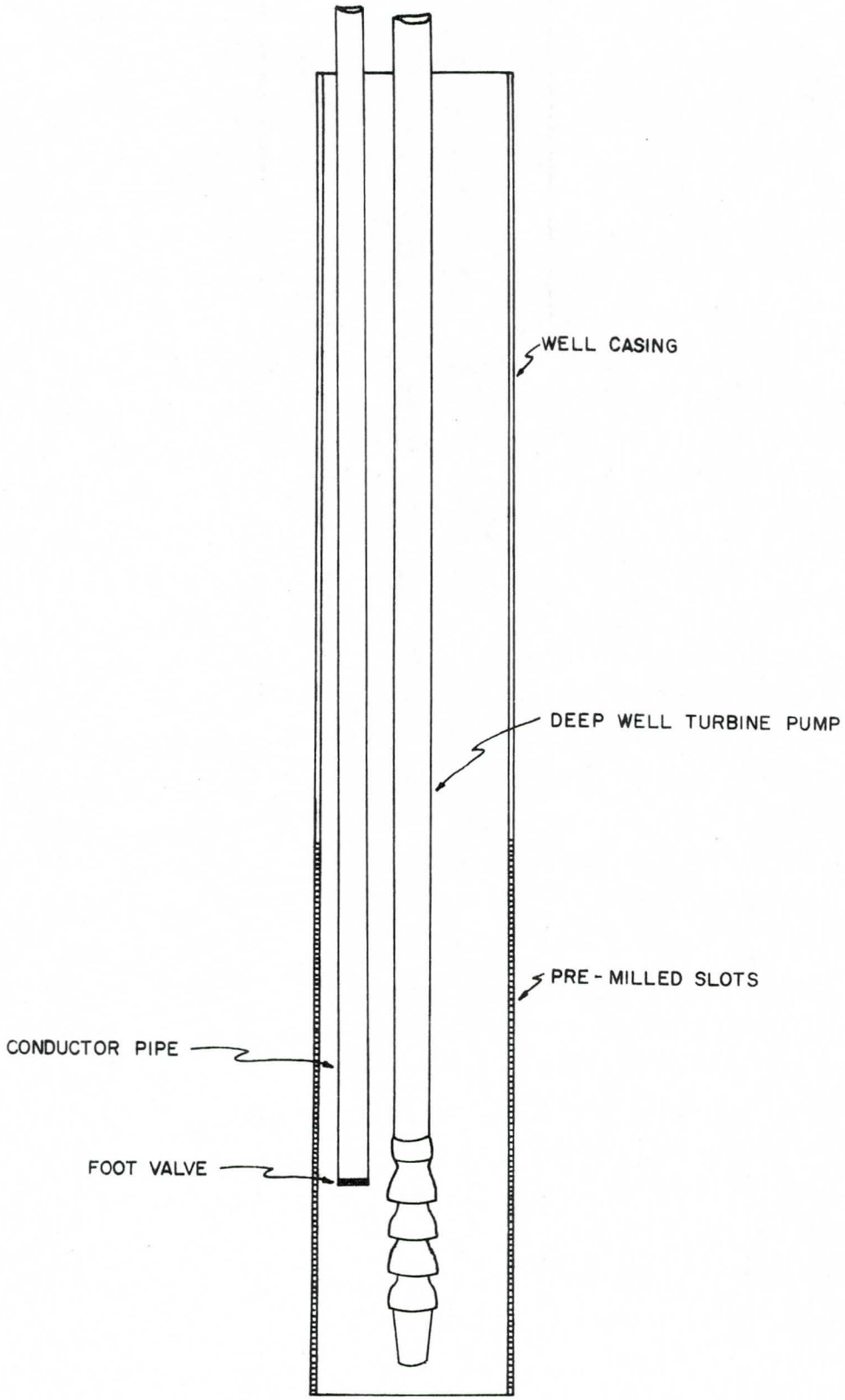


Figure 10-7. Cross-section Idealized Recharge Well.

Premilled slots would be preferred for recharge wells.

A deep-well turbine pump is shown installed in the well. The pump would be used for initial pump testing to determine aquifer characteristics; for step-drawdown tests to measure well and formation losses; and for redevelopment. Size of the pumping plant and number of bowls would be based on results of preliminary pumping tests. A length of small diameter pipe should be positioned within the casing extending for some distance below the water table, to permit sounding for water levels. Similarly, a length or lengths of PVC pipe could be installed in the annulus between pump column and casing to transmit recharge water to the water table. The pipe could be equipped with a foot-valve as a means of eliminating siphoning and maintaining positive pressure. Brown, et al. (1978) presented the design of a foot valve, developed by the U.S. Geological Survey for recharge wells.

Methods of well construction and completion for a recharge well should adhere strictly to the standards presented in "Manual of Water Well Construction Practices" (Environmental Protection Agency, no date). Specific items covered in the manual include: drilling methods, driller's logs and reports, geophysical logs, formation sampling, water sampling, casing selection, sanitary protection, grouting, well screens and perforations, well filter construction, well plumbness and alignment, well development, well testing for performance, well disinfection and water sampling and analyses. The manual also presents information on contractual agreements between a driller and contracting agency.

The reader should consult the "Manual of Water Well Construction Practices" for details on well construction procedures. Briefly, construction of a recharge well in the project area would probably entail using the cable tool method. In this method the sediments are pulverized by a drill bit and cuttings are removed by a bailer. Casing is generally driven in place as the hole advances in depth. The driller should be required to provide a

sample of drill cuttings either for every formation change or at specific incremental depths. The samples are removed to a laboratory for particle-size analyses. The rate of advance of the drilling operation should be recorded along with the weight of the percussion bit. The locations of perched ground-water bodies should be noted, and if possible samples of perched ground-water should be obtained for chemical analyses. Borehole geophysical methods could be employed to log the hole (see Section 5).

Upon termination of drilling the contractor should be required to complete the well. Completion would involve cleaning the casing, i.e., removing sediments, and developing a natural gravel pack around the perforations. Completion is particularly important for recharge wells because of the tendency for such wells to clog. Completion may involve the use of a surge block and bailing, and/or pumping (see "Manual of Well Construction Practices" for additional methods). Development should continue until the concentration of sand in collected water samples reaches a prescribed minimal value.

Following development, a well should be subjected to tests to determine the performance of the well for pumping. This procedure is essential in tailoring the appropriate pumping plant to the recharge well. Also data from the test indicate the potential recharge rates for the well. Step-drawdown pumping cycles are commonly used to determine well performance. Pumping rates up to 1-1/2 times the anticipated yield are commonly employed. Data from the head-discharge relationship are used to select a pumping plant.

After termination of the performance tests, the well should be sterilized by appropriate chemical treatment. Similarly a sanitary seal, constructed of cement, should be provided around the portion of the casing and land surface. Such a seal would prohibit surface drainage into and around the casing.

Prior to initiating recharge trials on a completed well, a series of pumping tests should be conducted. For example, a long-term (say one month) constant-discharge test could be performed to determine the aquifer properties, T and S. Similarly, a series of

step-drawdown tests could be conducted to evaluate well and aquifer, losses, and well efficiency (see Section 10.3.4). Water samples should be obtained for laboratory analyses at regular intervals during the constant-discharge tests.

10.2.3.4.1 Appurtenances

Ideally a demonstration recharge project should include a shop, laboratory, meteorological station, storage area and office. Location of a compound, containing these elements, near the recharge facility would minimize the travel necessary to effect repairs on damaged equipment or to pick up supplies; and would permit on-site analyses of water and solids samples. Such a facility would require electricity and be enclosed by a chain-link fence. If possible, the facility should be located out of the flood plain, to avoid flood damage.

To reduce costs, the shop could be of pole-type construction, i.e., an open-air building with protective roof. The shop should contain standard items to repair or build equipment; e.g., welding equipment (both electric and gas), drills, saws, hoists, and a complete set of hand tools. A small, locked structure should be provided for storage of tools. If more than one site is selected for the demonstration project, one shop facility could be constructed in a central location. A small crawler-type tractor with front-end loader and hitch should be purchased to assist in maintenance and other tasks.

A laboratory could be constructed as a separate building or comprise a modified mobile home. If several sites are used in the demonstration project, the latter unit could be transported from site to site, as needed. The laboratory should be equipped with an air conditioner and heater, to ensure uniform temperature for analyses. Basic laboratory items should include, pH meter; specific electrical conductance bridge; dissolved oxygen meter; a portable field analysis kit (e.g. Hach kit); a portable "Millipore Filter" incubator for fecal and total coliform analysis; turbidimeter; a shaker and nest of sieves for particle-size analyses of solids; refrigerator, drying oven, hood, balances, glassware and

miscellaneous supplies. A more complete (and more expensive) laboratory could include chemical supplies for complete chemical analyses, steam distillation equipment for nitrogen analyses, BOD incubator, TOC analyses, atomic adsorption spectrophotometer, gas chromatograph, and microscope.

A simple weather station could be located at the site, containing rain gages (recording and non-recording), wind direction and velocity anemometer, temperature recorders, evaporation pans, a wet-dry bulb psychrometer, and solar radiometer. The station should be constructed according to specifications regarding proximity to structures. If necessary, a separate fenced area should be provided.

Sufficient storage should be provided to house auxiliary or back-up equipment for the project; e.g., wood, metal, flumes, pipe and PVC tubing. It may be necessary to provide a separate building for protection of easily moveable items. If a neutron logger is used it will be necessary to store the source in a manner approved by nuclear control agencies.

A separate office space could be provided to permit recording, transcribing and analyzing data, and for report preparation. Standard items would include desk, chairs, filing cabinet, calculators, and communications equipment. If a mobile home is used to house a laboratory, one of the rooms could be used as an office.

10.3 Operation and Management of Recharge Facilities

In this report operation of a recharge facility includes 1) controlling water movement into and through the facility, and 2) determining intake rates. Management includes those measures necessary to sustain optimal intake rates.

The overall goal of operating and management procedures is to promote maximum utilization of the recharge area; i.e., ensuring the maximum number of acre-days of operation. In the Leaky Acres Project at Fresno, Bianchi, et al. (1978) related the number of days the project was shut down to specific causes. Included among the causes were, inflow water quality, pond rotation and

environmental control, fluctuations in water deliveries, and construction of accessory facilities in the basins.

10.3.1 Channel-Modification

In the Salt River, facilities for in-channel recharge would be best suited for controlled releases of water, such as from Granite Reef Diversion Dam or from the Arizona Canal and South Canal. It is unlikely that the simple control structures envisioned for this method could withstand substantial floods.

For the recharge design envisioned in Figure 10-1b, water would be directed in a maze-like fashion through each basin at a velocity to maintain fine sediments in suspension. Intake rates and cumulative intake volumes could be determined from flume data; for example, hydrographs could be prepared by analyzing charts on water stage recorders.

The area would probably require repairs after a spreading operation, to rebuild control checks and interbasin dikes. Management to ensure favorable intake rates would entail mechanically removing fine sediments deposited when flows recede, and scarification of the surface via rippers.

10.3.2 Spreading Basins

For the two designs shown on Figures 10-2 and 10-3, the basins could be flooded individually, in pairs, or all at the same time. As discussed earlier, operation of two in-line basins would simulate recharge from a long narrow facility. Operation of all four units would simulate recharge in a facility with a lower length to width ratio. Flow could be controlled into the individual basins from the supply ditch by simple, portable check dams. Flow from an upper to a lower basin would be through a drop structure containing a valve. Water could be metered into each basin, via a propeller flow meter or critical depth flume. A meter or flume installed in the outfall line from the lowermost basin would measure excess flow returned to the disposal ditch.

The overall operation of the spreading area should be determined by determining the differences between the amount of water

introduced to and discharging from the area. Meters or weirs at the inlet and discharge end of the system would be used for this purpose.

Intake rates in the sedimentation pond should be determined by the instantaneous intake method, described below for the recharge basins. Staff gauges would be installed in the pond to facilitate using this method.

Operational characteristics of the individual basins should be determined periodically by the instantaneous intake method. In this method, the inlet and outlet gates to a basin are shut and the drop in water surface within the basin measured on staff gages. Staff gages installed at the upper and lower ends of the basin facilitate determining an average change in water level. The period of observation should be between 12 hours and 24 hours. Bianchi, et al. (1978) used this technique in operating the Leaky Acres recharge facility in Fresno. They observed that periodically determining instantaneous intake rates, "...allowed separate evaluation of each pond for the yearly rate changes caused by soil sealing, vegetative growth, and water-table rise. This evaluation was independent of pond-storage fluctuation, and gave the best measurement of the accumulated seasonal effects of surface management, aquatic environment, shifts, and rise of the general water table in the project area. The individual pond rates also were used in the annual project-performance evaluations where the end-of-season ponded recharge rate was established as a calibration, or reference recharge rate on which to base potential project performance."

The intake rate values, obtained as discussed above, should be corrected for evaporation losses, and/or rainfall. Values of these factors would be available from the on-site weather station.

As pointed out in Appendix A, intake rates in a spreading area decrease because of energy losses in overcoming viscous resistance during advance of the wetting front, and possibly because of shallow impeding layers. Other factors which reduce

infiltration rates include, sediment, microorganisms, air, temperature and salinity. The reader is referred to Appendix A for a detailed review of these problems and ameliorative procedures.

Concentrations of coarse-sized sediment entrained in the incoming water supply would be reduced in the settling pond because of the decrease in velocity. The clay-sized fraction would require either prolonged settling times or the use of polyelectrolytes to promote flocculation. A recommended technique would be to introduce the flocculating agent near the diversion headworks so that flocs would form during transit in the conveyance ditch. The resultant flocs would settle out in the sedimentation pond. The effectiveness of various anionic, cationic and neutral polyelectrolytes could be tested during the demonstration project. Laboratory studies by Brown, et al. (1978) showed that the most rapid flocculation of sediment in recharge water occurred when water was treated with a combination of organic and inorganic flocculants. Additional settlement of sediments would occur behind check dams in the supply ditch, and in the uppermost recharge basin.

Sediment generation in the basins by wave erosion of the dikes could be markedly curtailed by lining the sides of the dikes with coarse gravel and boulders, as described in the section on basin construction.

The equation of Berend (1967) could be used to estimate the maximum time, t_r, to reach a minimum acceptable infiltration rate reduction due to sediment. Berend's equation is:

$$t_r = \frac{1}{aM} \ln (V_o/V_{min})$$

Where V_o = initial infiltration rate

a = empirical coefficient describing the clogging process

M = concentration of suspended matter in water that will be retained in the bottom

V_{min} = minimum acceptable infiltration rate

Details on the use of this equation are presented in Appendix A. The equation could be tested during the demonstration project. An alternative approach is to plot instantaneous intake rates for each

basin. When it is apparent that rates have reached some minimum, asyptotic value, the basin could be shut down. Renovation includes drying, physical removal of fine sediments and scarification of the surface. During a period of renovation in one set of basins, recharge would be conducted in the alternative set. The project should determine the optimal duration of wet-dry cycles.

The intense sunlight in the project area during the summer months, coupled with high temperatures, would enhance the growth of microorganisms in the flooded basin. Eutrophication would be particularly favorable if sewage effluent were used as a recharge source. A goal of the demonstration project should be to study the effect of algae on intake rates and develop appropriate control procedures. As pointed out in Appendix A, clumps of algae growing on the soil surface in a flooded basin may periodically float to the surface. Intake rates may be improved by this mechanism because 1) fresh surface areas are exposed, and 2) when floating algae clumps cover a sufficient area of water surface, sunlight penetration is decreased and algae growth is inhibited. Tests should also be conducted to determine the effects of suitable algacides (e.g. chlorination) on algal activity. Wet-dry cycles should be imposed when it is evident that microbial clogging has reduced intake rates to a prescribed minimum value. During drying cycles, mats of algae should be physically removed from the surface.

As a consequence of studies on the 23rd Avenue land treatment facility in Phoenix, Bouwer (Personal communication, 1978) noted an indirect effect of algae activity on intake rates. In particular, algae respiration raised the pH of water in ponds on the project, causing a precipitation of calcium carbonate. Subsequently, the precipated calcium carbonate clogged the soil surface; reducing the long-term infiltration rates.

If basins are used to recharge sewage effluent a trade-off must be arrived at between the effect of microorganisms and organic matter deposits on intake rates and the concomitant effects on denitrification. Thus, an algal bloom in the basin would increase

the pH as discussed above. At the same time that calcium carbonate precipitates, the increased pH promotes ammonia volatilization. In addition, an organic layer could promote anaerobiosis and consequently dentrification (provided that sufficient organic matter is present as a substrata for the microorganisms). Problems with chlorinated hydrocarbons could also develop if effluent is chlorinated.

Air may moderate intake rates as a result of occlusion of bubbles in the porous matrix during infiltration, or because of air pressure build-up ahead of the wetting front. The first effect is normal during the infiltration process - it is virtually impossible to completely saturate an undisturbed soil mass. The latter effect, air confinement, occurs when an impeding layer (clay or caliche lens, or water table) restricts the movement of air. Confined air is generally manifested by escaping air bubbles at the surface of the spreading area. Relief of air pressure may require the installation of wells in the vicinity of the confining layer.

Bianchi, et al. (1978) observed that air temperature is the predominant ambient parameter affecting intake rates. An increase of water temperature reduces the viscosity and correspondingly increases the hydraulic conductivity. In other words, cumulative recharge during the summer exceeds that during the winter. An objective of the demonstration project should be to quantify the effect of ambient temperature on cumulative intake in the basins. Unfortunately, the growth and clogging potential of algae and microorganisms are also enhanced by increased temperatures and incoming radiation. Microbial growth and clogging may mask the effect of temperature on intake rates.

Application of water to a spreading basin may have two effects relating to salinity: 1) leaching of salts and 2) modification of permeability. Leaching of salts could be a problem if the demonstration project were located on land not previously flooded; for example, on the Salt River Indian Reservation, north of the Arizona

Canal. The dissolution and movement of indigenous nitrate might be a particular problem. The effect of salinity on the hydraulic conductivity of a soil is discussed in detail in Appendix A. Briefly, for soils with clay, a relationship exists between the exchangeable sodium percentage (ESP), total salt concentration of the soil solution, and K, the hydraulic conductivity. In general, as the salt concentration decreases for a given ESP the value of K also decreases. In addition to sodium, carbonates and bicarbonates may affect permeability through reactions with calcium and magnesium (e.g., solution or precipitation of $Ca\text{-}MgCO_3$). To account for such reactions, the concept of adjusted sodium adsorption ratio (adj SAR) was developed by soil scientists. Adjusted SAR is defined:

$$\text{adj SAR} = 1+(8.4-pH_c)$$

Methods for calculating pH_c and SAR are detailed in Appendix A. In general, adj SAR values greater than 9.0 indicate potential permeability problems in clay soils. To determine the potential impacts of soil salinity, both on leaching and on the hydraulic conductivity it is highly recommended that laboratory column studies be initiated prior to constructing recharge facilities. Soils from the potential site should be packed into columns to approximate field bulk density. Water intended for the recharge project should be used during the laboratory studies.

In addition to the above factors, certain environmental effects may influence the operation and management of a recharge facility. For example, burrowing animals may cause leaks in the dikes. In addition, growths of insects may require addition of pesticides or imposition of wet-dry cycles.

10.3.3 Recharge Pits

Operation of abandoned gravel pits in the Salt River to recharge flood water would obviously require the arrival of flood water at the site. Measurement of the volume of surface water entering and discharging from the pits could be difficult if flood flows are excessive. Nearby control-structures, such as culverts,

could be used to measure inflow and outflow rates. The intake rates in sedimentation units and main pit could be estimated via staff gage readings and a relationship between depth of water and volume in storage. The accuracy of determining intake rates would be greater once surface flows have ceased and losses from the pit are entirely due to infiltration and evaporation. Evaporation losses could be estimated using values from a nearby weather station.

A similar approach could be used to operate specially constructed pits. The volume of water introduced into the settling pond-recharge pit system would be adjusted so that surface overflow would not occur. Inflow rates to the system would be measured by flow meter or weir. Head changes in the pit would be recorded automatically on a water stage recorder mounted on a stilling well. Intake rates would be determined from data on inflow and the relationship between head, wetted volume and wetted surface area.

The factors affecting the operation of recharge pits are identical to those for recharge basins, including: sediment, microbial activity, air, temperature and salinity. As pointed out in the section on construction of pits, the sides of pits excavated during a demonstration project (and full-scale project) should be steep enough to preclude deposition of sediment on the walls. Thus, intake would primarily occur in a lateral direction. Other management techniques are similar to those suggested for recharge basins.

10.3.4 Recharge Wells

During operation of a recharge well such as shown on Figure 10-7 water would be pumped from the sedimentation-stabilization sump through final filtration facilities, chlorinator and flow meter, into the inlet to the well. The inflow rate could be controlled via an in-line valve. Water would be delivered to the water table through a suitable conductor pipe, or by free-falling. The instantaneous inflow rate and cumulative volume would be determined from the propeller flow meter. The change in water level within the casing should be determined routinely using a chalked, steel tape or electric sounder. The specific intake of the well

is calculated by dividing the inflow rate (gallons per minute) by the head of water in the casing (feet) above the pre-recharge water level. The specific intake is time dependent. The change in specific intake during individual recharge operations could be plotted versus time, or determined at prescribed times after initiation of recharge (e.g. 200 min, 400 min, etc.).

Periodically, the well should be subjected to step-drawdown test to determinte the effect of recharge on the well and aquifer-loss coefficients in the Rorabaugh equation:

$$s_w = BQ + CQ^n$$

where s_w = drawdown
B = aquifer-loss coefficient
Q = discharge rate
C = well-loss coefficient
n = an empirical constant

Methods for determining the coefficients in this equation via step-drawdown tests are described by Hantush (1964). Rorabaugh (1953) presented a straight forward and simple graphical technique for determining the coefficients. The values of B, C and n determined after recharge cycles have been imposed on the well should be compared with associated values for the new well.

The factors influencing intake rates in wells include: 1) sediment, 2) microbial slimes, 3) air, 4) chemical reactions, and 5) physical reactions. A detailed discussion of these factors and ameliorative measures is presented in Appendix A. Briefly, sediment should be removed as completely as possible from a water source prior to recharging in a well. The sedimentation pond and rapid sand filter should therefore be designed and operated to effect complete removal of sediment. A demonstration recharge well project should test the effectiveness of various polyelectrolytes for flocculating colloidal-sized sediment. Once a day the recharge operation should be stopped to permit pumping the well for about an hour. The water extracted would probably be turbid and should be discharged to a disposal ditch. Once each week the well

should be pumped for several hours and possibly subjected to surging to enhance redevelopment. If the specific capacity of the well diminishes appreciably, it would be necessary to redevelop the well by pumping and bailing. A deflocculating agent (e.g. sodium metahexaphosphate) could be introduced to disperse colloidal-sized sediments.

The formation of microbial slimes could be inhibited by chlorinating the recharge water. Potential problems from chlorinated hydrocarbons should be kept in mind, however. Periodically pumping the well, as described above, could help to remove slimes and microbial particles.

Air binding could be reduced by ensuring that the water column within the well is continuous. Thus, the conductor pipe shown on Figure 10-7 would prevent free fall of water to the water table. A foot valve should be installed on conductor pipes. An objective of the demonstration project could be to study the effect of air on intake rates. Consequently, controlled tests could be conducted by allowing the water to free fall within the casing. Recharging through the pump column might cause formation of a siphon and cavitation near elbows. In general it is also recommended that the temperatures of the recharge water and ground water should be about the same to prevent bubble formation. It could be difficult to comply with this recommendation in the project area in the winter months. If air binding occurs it might be necessary to redevelop the well by pumping for a prolonged period of time.

Apparently the most important chemical reaction affecting intake rates in wells is the equilibrium between calcium and carbonates and bicarbonate ions, i.e. calcite solubility. In particular when the solubility of calcium carbonate in the recharge water is exceeded, calcite may precipitate causing a diminution of intake rates (Sniegocki, 1963).

As indicated by Sniegocki (ibid), "An equilibrium pH value (pHeq) can be calculated from water analysis data and compared with the measured pH value of the water sample. If the calculated value

(pHeq) exceeds the measured pH, the water is capable of dissolving more calcium carbonate. If the measured pH of the water exceeds the calculated value, the water is supersaturated with respect to calcite, and calcium carbonate will precipitate". Sniegocki reviewed a technique for calculating the theoretical pH and presented an example for a water used during a recharge project in the Grand Prairie area in Arkansas. To preclude the effects of carbonate precipitation on intake rates it could be necessary to adjust the pH of the recharge water. Sniegocki (ibid) also discussed ferrous-ferric interactions potentially affecting intake rates in wells. Periodic redevelopment of the well and possibly acidizing might be required to remove chemical incrustations.

10.4 Monitoring

A monitoring program for a demonstration recharge project is conducted to determine the following items: 1) the subsurface disposition of recharge water, and 2) changes in ground-water quality. The subsurface disposition of water relates to the storage and recovery functions of the recharge project. Determination of the disposition of water entails examining the hydraulic response of the subsurface flow system, i.e., the movement of water and associated changes in water storage. Water quality changes occur as a result of the mixing of recharge water and native ground water. Monitoring of water quality changes is mandatory when municipal wastewater is used as the recharge source.

10.4.1 Monitoring the Disposition of Recharge Water

In this section typical facilities for monitoring the hydraulic response of the vadose zone and underlying aquifers to recharge are reviewed. A conceptualized network is included in Section 10.4.1.3.

10.4.1.1 Monitoring in the Vadose Zone

Facilities for monitoring water movement and storage in the vadose zone could include: tensiometers, moisture blocks, psychrometers and shallow observation wells (see Figure 10-8). Briefly,

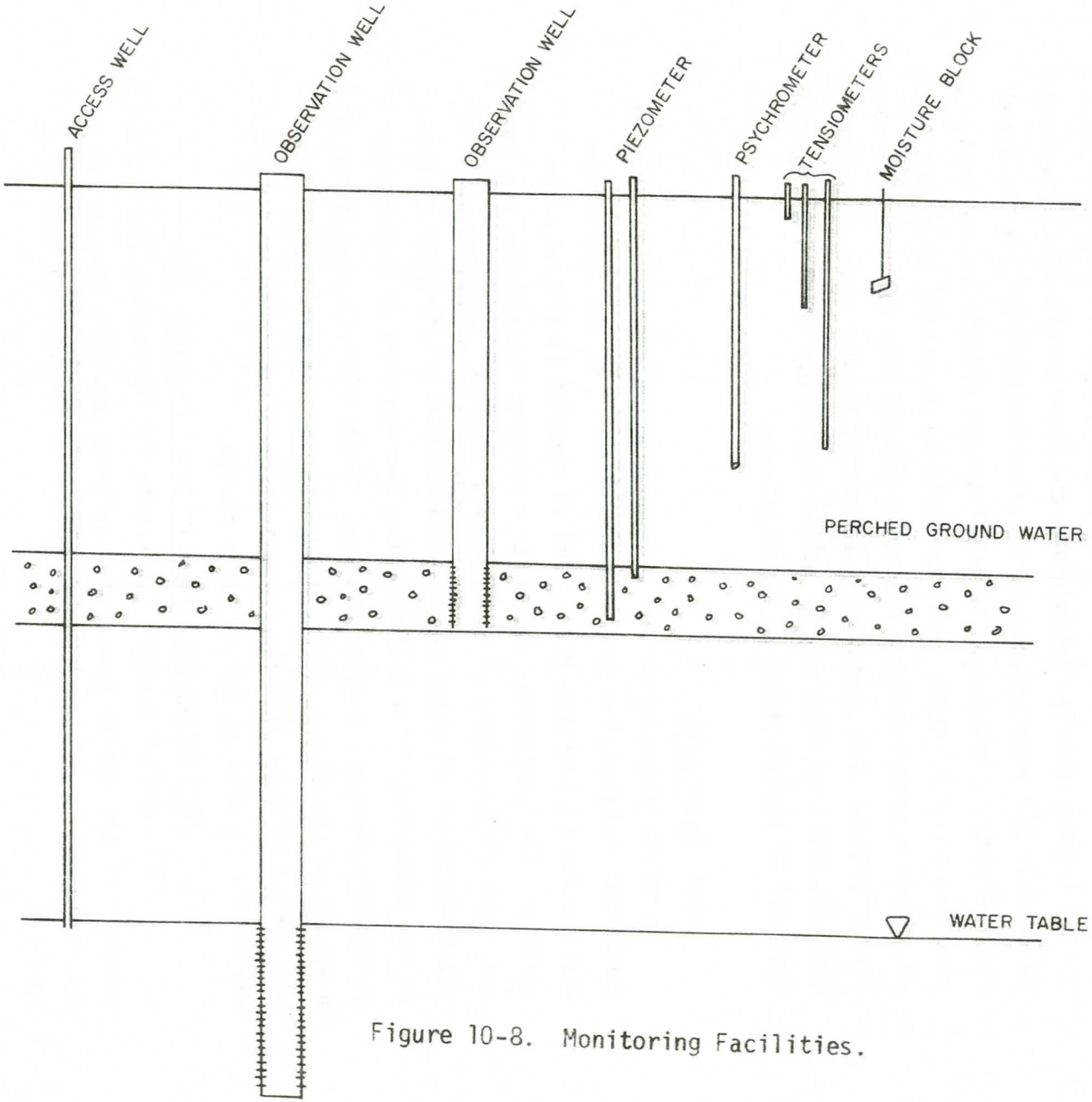


Figure 10-8. Monitoring Facilities.

a tensiometer consists of a porous ceramic cup sealed into a hollow PVC tube and connected to a mercury manometer or gauge. The system is filled completely with water. The principle of operation is that the pressure of water in the ceramic cup and in the outside soil solution come into equilibrium. The associated pressure (negative) is read on the manometer or gauge. A network of tensiometers at incremental depths provide data on hydraulic gradients and head losses within the flow system. Water pressure values may be related to water content values via laboratory characteristic curves. Problems with tensiometers are 1) an intimate contact between cup and soil is essential, and 2) the air entry value of cups is about -1.0 atmospheres. The installation of cups to ensure contact could be a severe restriction on their use in the Salt River during a demonstration project, because of the coarse size of river bed deposits.

Tensiometers are generally installed at shallow depths. However, techniques are available for installing units at greater depths. For example, a cluster of units could be installed in a common bore hole. Again, conditions might not be suitable for this approach on the Salt River, because of construction difficulties and contact problems.

Thermocouple psychrometers relate soil water pressures to vapor pressures in a ceramic bulb. Psychrometer bulbs have been installed to great depth. Psychrometers operate in the dry range, i.e., at pressures less than -1.0 atmosphere and are commonly used with tensiometers to provide a wider range of pressure values.

The principals of neutron moisture logging are reviewed in Section 5.4.3.1. Briefly, a source of hypothermal neutrons is lowered within an access well. The hydrogen atoms in water stored in the sediments around the casing slow down or thermalize the fast neutrons. The thermalized neutrons are captured via a suitable detector (e.g. lithium enriched BF_3). The detector converts the incoming pulses into electrical pulses, which are transmitted to a measuring device on the surface. Pulses may be translated using

a decade counter, ratemeter or recorder. The resultant information is converted into water content values via a suitable calibration relationship. Water content is reported on a volumetric basis. The source of high energy neutrons in original units was Ra-Be. Later units employ Am-Be. Am-Be is a "cleaner" source than Ra-Be so that a more intense source can be installed in the down-hole probe.

Access wells for moisture logging generally consist of small diameter steel casing installed throughout the depth being monitored. Ralston (1967) found that the size of the casing has a bearing on the accuracy of neutron logging with sources in the millicurie range. In particular, he observed that the larger the inside diameter of the casing relative to the probe diameter the greater will be the interference. Consequently, the inside diameter of the casing should be only slightly greater than the outside diameter of the probe.

For shallow depths, a hand auger could be used to install casing. For greater depths it would be necessary to use a power driven auger, percussion rotary equipment, or other standard drilling equipment. For shallow depths in soils a good contact between soil and tubing is generally possible. For deeper holes it may be necessary to first drive in a larger casing; install the access well casing; and pull back the larger casing. Unfortunately, good contact is not always possible with this approach. Side leakage of water along the outside of the casing could cause erroneous results during moisture logging. In addition, because of the small clearance between the downhole probe and the walls of the casing, even a slight bend in the casing could prohibit free vertical travel of the probe. Such bends are likely to occur in small diameter, deep access wells, constructed in coarse sediments such as those along the Salt River. Alternatively, it may be necessary to construct large diameter access wells and use a neutron logger with a multicurie source. Access wells should not be constructed of PVC because the chloride in PVC interferes with

neutron thermalization.

Inasmuch as a neutron logger manifests only water content values, translation of water content data into equivalent water pressure data requires the preparation of a water characteristic curve for each sequential change in lithology. A sequence of moisture logs reflects changes in water content storage within the profile. Thus the growth and dissipation of perched ground water may be observed. However, it is important to keep in mind that water could be transmitted through regions of the vadose zone without a corresponding change in storage. Detection of such movement would require the use of a battery of tensiometers, or psychrometers.

During drilling of observation wells or production wells in the vicinity of the recharge facilties, perched ground water might be detected. Alternatively perched ground-water regions might be observed during neutron moisture logging. Water pressures in perched ground water are commonly measured using piezometers. Piezometers consist of pipes open only at the ends, driven or otherwise installed to a prescribed depth. The head of water (measured relative to a datum) in the tube reflects the pressure head of water at the basal end of the unit. Piezometers could be installed at sequential depths in perched ground water to detect vertical hydraulic gradients and the direction (up or down) of flow. Similar units installed laterally away from the recharge facility provide data on horizontal hydraulic gradients in an extensive perched ground-water mass.

Piezometers should be installed so that a tight fit is maintained between the casing and bore hole. Shallow units could be installed by augering within and ahead of the tube, and pounding in the tubing as the hole progresses in depth. Deeper units could be installed using standard drilling techniques. However, maintaining a tight fit could be a problem unless large-sized casing were employed. Unfortunately, larger casing creates a substantial response lag. Alternatively, a larger casing could be installed

to depth and a tube installed within the larger casing. When the larger casing is pulled back out of the hole grout could be poured around the outside of the small tube in an effort to prevent side leakage. Another construction technique entails construction of a large bore hole and installing a cluster of piezometers within the hole. Individual units would be installed at prescribed depths. The cavity around the ends of the units would be back-filled with sand. The region between units would be backfilled with bentonite plugs. This technique is suitable when holes are drilled by rotary techniques. Piezometers must be developed by pumping and/or bailing after installation to remove fines around the opening.

Piezometer tubing could be provided with screened well-points to facilitate water sampling. Units equipped with well points could be used to measure the in-situ hydraulic conductivity, K, using a modified piezometer method. Piezometers could be constructed from steel or plastic tubing. For water sampling purposes PVC is preferable because of minimal interference in sampling for trace metals.

Observation wells could be installed within perched groundwater regions to provide an estimation of water level changes. Approved practices for installing and completing wells would be identical to those discussed above for the recharge well. Perforations would be installed in observation well casing throughout the depth of the perched ground water mass. Water levels could be measured via chalked tape or electric sounder. Alternatively, automatic water stage recorders could be mounted to record water level fluctuations. Observation wells could be used to sample perched ground water.

10.4.1.2 Monitoring the Aquifer Underlying the Recharge Site

Monitoring the hydraulic response of the aquifer underlying a recharge site will entail 1) establishing a network of existing wells, and 2) installing special wells on site.

Existing wells in the environs of a project should be incorporated into a regional network. These wells should be tabulated and located on a base map. For each well, data should be

obtained on ownership, date of construction, method of construction, drillers log, depth, diameter, location of perforations, pumping capacity, pumping test data if available, water quality data, and water level measurements. Static water levels should be obtained in the network as soon as possible after selecting the location of wells. Large capacity irrigation wells should be sounded during down time. Maps showing the potentiometric surface of ground water should be prepared. Assuming that aquifer materials are isotropic, flow nets could be prepared from the potentiometric data (see Section 5.4.4). The orientation of streamlines, derived from a flow-net analysis will indicate the possible direction of flow of recharged water. If transmissivity values are also available, estimated flow velocities could be calculated by methods discussed by Bouwer (1978, pp. 229-230). Alternatively, digital models of the flow system could be constructed using finite element or finite difference techniques.

A network of on-site observation wells could include units installed during hydrogeological studies. Basically, observation wells should be constructed and completed using procedures outlined above for the recharge well. In particular, specifications in the "Manual of Water Well Construction Practices" should be strictly applied. Wells should be of sufficient diameter (at least 8 inches) to permit installation of a portable submersible pump. Such a pump would be used to conduct pumping test and to obtain water samples for analyses. Perforations should begin about 10 feet below the water table. If possible casing should extend throughout the entire thickness of the aquifer. The upper end of the casing should be grout encased and furnished with a sanitary seal. Water levels in observation wells could be measured via chalked tape, electric sounder, or measured continuously via a water stage recorder.

Piezometer clusters could be installed throughout a prescribed region of the aquifer in order to determine vertical and lateral hydraulic gradients. It should be noted that errors in measurement

of true water levels may occur when vertical flow occurs in the aquifer (see Bouwer, 1978, pp. 52 & 53). Piezometer units could also be used to obtain water samples, as described below. Ideally the uppermost unit should terminate slightly below the existing water table. Techniques for constructing and operating these units would be similar to those for units installed in the vadose zone.

10.4.1.3 Conceptualized Monitoring Network

Until a specific site for a demonstration project has been selected, and detailed hydrogeological studies have been completed, it is not possible to present a finalized design for a monitoring network. Thus, the conceptualized design presented in this section is mainly for illustrative purposes.

At the outset, it should be stressed that the available monitoring techniques, described above, may not be sufficiently sensitive to account for the entire mass of recharged water. In fact, in some cases, definition of the recoverable water may be an impossible task. For recharge wells the task is simpler than for spreading basins or pits because the entire vadose zone is bypassed. When a recharge well is also used as a recovery well, the mass of recharge water recovered during pumping could be accurately determined if the recharge water is tagged with a suitable tracer (Percious, 1969). Similarly, when down-gradient wells are used for recovery, the fraction of tagged recharge water arriving at individual wells could be determined from a mass balance. For surface spreading facilities and recharge pits, water traverses the vadose zone prior to merging with native ground water. As discussed in Section 5.3.3, flow in the vadose zone is influenced by changes in stratification (promoting perched ground water), water content storage deficits, and variations in hydraulic properties because of lithological heterogeneity and anisotropy.

Devices described above for measuring hydraulic pressure changes in the vadose zone and aquifers (e.g., tensiometers, psychrometers, piezometers, and observation wells) are useful in estimating the direction and velocity of ground-water movement.

Accounting for the mass transport of water in the vadose zone requires preparation of a water budget. Inflow to the system is obtained from intake rates. Outflow from the vadose zone could be estimated from data on the amount of water stored above and below the prerecharge water table (assuming that ET losses are minimal). The amount of water stored in the mound above the prerecharge water table could be estimated from data on water level changes and values of the specific yield of aquifer materials. Determination of the amount of recharged water stored beneath the water table will be more difficult because of mixing. Some type of tracer (e.g. bromide) could be used to tag the recharge water. Determination of tracer levels in water samples obtained at different depths below the water table would be required to estimate the thickness of the mixed zone.

To complete the water balance in the vadose zone changes in storage must be determined. Changes in such storage would be determined most directly by neutron logging. Other devices such as tensiometers, psychrometers, and moisture blocks, require empirical relationships between water pressure and water content. Thus a monitoring design for obtaining water budget data would include a system of access wells for neutron moisture logging, observation wells for monitoring changes in water levels, and nests of piezometers for depth-wise water sampling below the water table.

Obviously, the installation of a network of wells of the required density to account for bulk water movement from a recharge facility would be prohibitively expensive. The results of hydrogeological studies may suggest that lateral flows in the vadose zone and aquifer are preferentially oriented in a particular direction. The orientation of the network and required numbers of units could be further defined as a result of recharge trials during a demonstration project.

A conceptualized network of monitoring facilities is shown on Figure 10-9, again for illustrative purposes only. The network

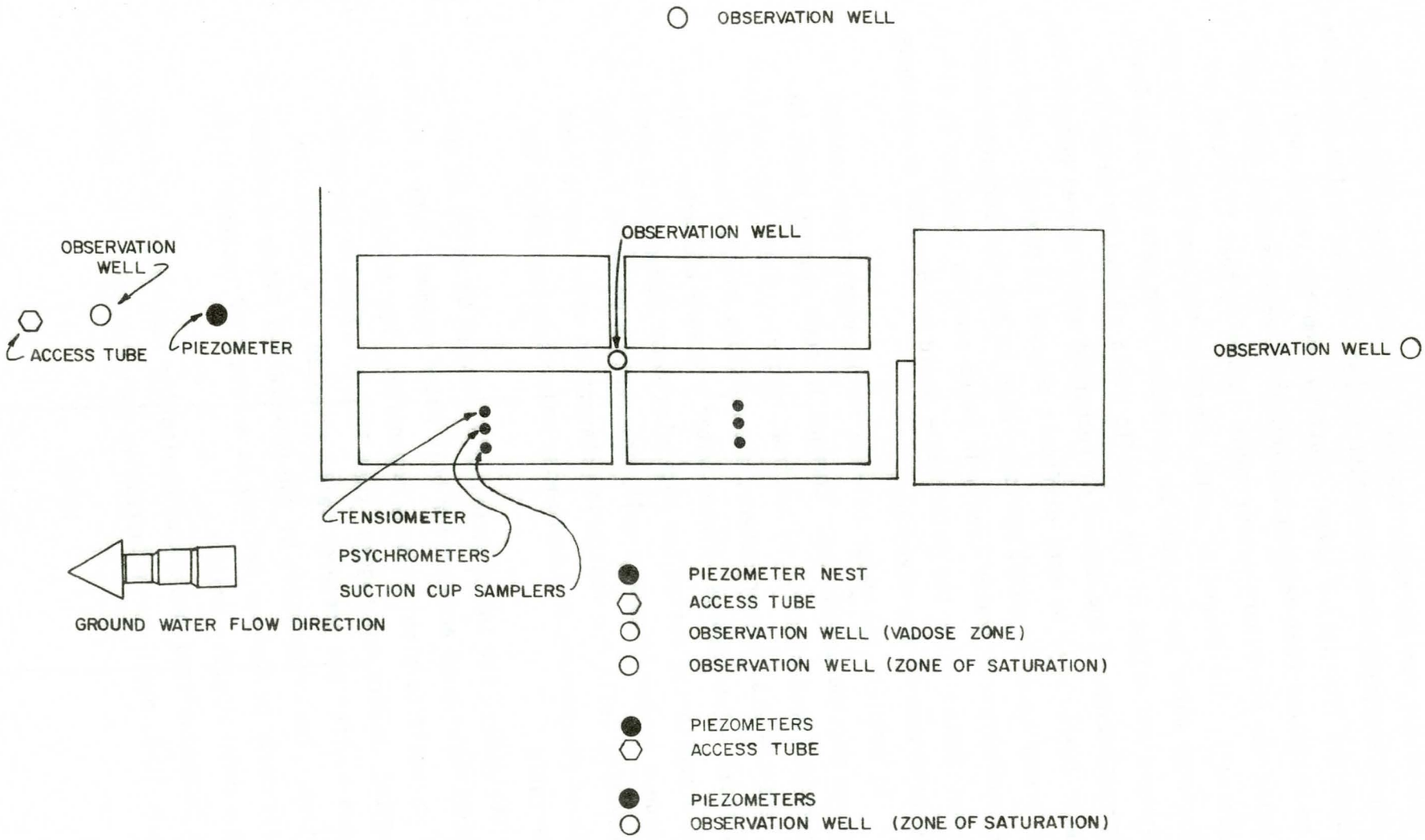


Figure 10-9. Conceptualized Network of Monitoring Facilities Near Recharge Basins.

shown is for one of the recharge basin designs presented above. A similar network would apply to recharge pits, and a modified version could be adapted for a recharge well.

A transect of monitoring units is shown extending laterally outward from the in-line basins, ostensibly in line with the principal direction of flow in the vadose zone and aquifer.

Elements in each monitoring unit could contain shallow tensiometers and psychrometers, piezometers and observation wells terminating within perched ground water, access tubing for neutron moisture logging throughout the vadose zone, and observation wells the piezometers within the zone of saturation. As indicated earlier it may be difficult to ensure that tensiometers or psychrometers function properly in the coarse sediments of the Salt River. It may also be difficult to install small diameter casing in these sediments without bends which restrict the travel of the neutron probe. Consequently, it would be necessary to install larger diameter wells and use a probe with a multicurie source. Such wells could also be used as observation wells within the zone of saturation.

On Figure 10-9 a set of five observation wells is shown in the vicinity of the recharge facility. According to Mooji and Rovers (1976), a minimum of three wells in a set is required to define the orientation of the ground-water surface near such a surface recharge source. One well is shown upgradient of the recharge area and two wells are down-gradient. The remaining wells are located on the diagram, in-line with the long axis of the basins. As indicated earlier observation wells should be a minimum of eight inches in diameter and be installed throughout the saturated thickness of the aquifer, probably between 500 and 700 ft. One or more of these wells could be installed during preconstruction hydrogeological studies. The remaining wells would be used to obtain additional hydrogeological data, as described in Section 5.4.4. In addition, as discussed in Section 10.4.1.2 the network of observation wells should be tied in with

a larger network of existing wells.

Nests of piezometers are included to determine flow direction beneath the water table, and for depth-wise water sampling.

Measurement frequency for monitoring facilities should be determined on a trial and error basis. Continuous recording equipment, such as water storage recorders should be used when possible.

10.4.2 Water Quality Monitoring

In the context of this report, "quality" refers to physical, chemical, biological and organic characteristics of water samples. Physical properties which could be examined include turbidity, sediment composition, temperature, and dissolved oxygen. A complete chemical analyses could include the major constituents: calcium magnesium, potassium, sodium, chloride, sulfate, carbonate, bicarbonate, phosphate, SiO_2, the nitrogen series: NH_4-N, NO_2-N, NO_3-N, organic-N, and Kjeldahl-N, pH, and specific electrical conductance (EC). Analysis for trace constituents could include: boron, selenium, arsenic, iron, fluorine, mercury, aluminum, zinc, copper, chromium, lead, cadmium, and nickel. Examination of microorganisms could concentrate primarily on coliform organisms, with periodic characterization of algae species, insects and aquatic vegetation. If sewage effluent is used as a water source, samples should be examined for virus. The presence of organics could be inferred by determining the biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC) or dissolved organic carbon (DOC). In addition, examination of samples for pesticide and herbicide residues may be essential for certain water sources such as irrigation tail waters. New developments in dissolved organic carbon fractionation techniques may be applicable for determining pesticides and other organics.

For the demonstration project many of the quality parameters could be determined in the on-site laboratory. However, it is recommended that the services of a commercial laboratory be obtained to periodically conduct complete analyses of samples from the sampling points as a quality control measure.

The laboratory selected for analyses should use approved analytical procedures such as those in "Standard Methods for the Examination of Water and Wastewater" (American Water Works Assocation, 1975), Methods for Chemical Analyses of Water and Wastes (U.S. Environmental Protection Agency, 1974), and Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases (Brown, Skougstad and Fishman, 1970).

Selection of a laboratory for analyses of water samples should be based on performance capabilities as well as cost. As a result of a study by the U.S. Geological Survey on the analytical capabilities of 28 laboratories, Erman (1976) concluded:

> Overall the performances of the 28 laboratories was disappointing because only 5 were able to perform at an acceptable level on the second set of test samples. The selection of a capable laboratory for the determination of chemical constituents in water obviously requires great care. A satisfactory performance on test samples should be mandatory and an integral part of the selection process. Furthermore, the periodic use of test samples should be continued to ensure high quality results after the laboratory is chosen.

Methods for quality control which should be routine in the selected laboratory are reported in "Handbook for Analytical Quality Control in Water and Wastewater Laboratories" (Analytical Quality Control Laboratory, 1972). Checking for the correctness of analyses should also be routine, particularly before samples are discarded. A primary method for checking correctness of analyses, reported in "Standard Methods," involves and anion-cation balance. Theoretically, the sum of the cations in milliequivalents per liter (meq/l) should equal the sum of the anions, also expressed in milliequivalents per liter. According to Brown, Skougstad and Fishman (1970, it is expected that, with careful analyses, the difference between equivalents per million (i.e. meq/l) of the sums of cations and anions should not exceed one or two percent of the total concentration for analyses of waters with more than 150 mg/l dissolved solids.

As an approximate check on the completeness of analyses, it is recommended that samples be periodically evaporated to dryness

at 180°C and the weight compared to the total solids determined by analyses. This check is approximate because losses may occur during drying by volatilization; and other factors may cause interference (see Brown, Skougstad and Fishman, ibid). Another recommended check on analyses involves multiplying specific conductance (micromhos per cm) by a factor ranging from 0.55 to 0.75. The product should approximately equal total dissolved solids in milligrams per liter, for water samples with TDS below 2000-3000 mg/l (ibid). Also, within limits the specific conductance divided by 100 approximately equals the meq/l of anions or cations. This relationship is useful in deciding on which sum, cations or anions, is in error (ibid). A more refined method for check TDS by the EC relationship is the diluted-conductance method, as given in Standard Methods, and by Brown, Skougstad and Fishman,(1970).

Analytical results should be expressed both as mg/l and meq/l. The latter values are particularly useful in constructing water analyses diagrams, such as trilinear diagrams.

If water (or solids) samples are to be analyzed immediately in the on-site laboratory, preservation may not be essential. Normally, however, it is necessary to preserve and store samples for analyses at a more convenient time. Tables 10-1, reproduced from an Environmental Protection Agency (1974) publication "Methods for Chemical Analysis of Water and Wastes", should be consulted for approved preservation methods.

Water samples could be obtained at any or all of the following locations: 1) diversion point, 2) inlet and outlet to the sedimentation pond, 3) within the spreading basins or pit (or at the inlet to a recharge well), 4) within the vadose zone, and 5) within the zone of saturation. Possible sampling techniques are discussed below.

In sampling for sediment at the diversion point care must be exercised to ensure that a well-mixed (not settled), representative sample is obtained. Water samples could be extracted at the diversion point by grab sampling or by a mechanical sampler. Grab

Table 10-1

From: "Methods for Chemical Analysis of Water and Wastes", U.S. EPA (1974)

Preservative	Action	Applicable to:
$HgCl_2$	Bacterial Inhibitor	Nitrogen forms, Phosphorus forms
Acid (HNO_3)	Metals solvent, prevents precipitation	Metals
Acid (H_2SO_4)	Bacterial Inhibitor	Organic samples (COD, oil & grease organic carbon), Nitrogen-phosphorus forms
	Salt formation with organic bases	Ammonia, Amines
Alkali (NaOH)	Salt formation with volatile compounds	Cyanides, organic acids
Refrigeration	Bacterial Inhibitor, retards chemical reaction rates	Acidity-alkalinity, organic materials, BOD, color, odor, organic P, organic N, carbon, etc., biological organism (coliform, etc.)

In summary, refrigeration at temperatures near freezing or below is the best preservation technique available, but it is not applicable to all types of samples.

sampling is the simplest technique. However, a mechanical unit permits collecting samples at predetermined intervals and results indicate fluctuations in loading. The recommendations of Harris and Keffer (1974) should be consulted prior to the selection of a commercial sampler. Separate samples should be collected, preserved and stored for each of the sampling catagories (physical, chemical, biological, and organic). On-site measurements should include pH, EC, DO, temperature and possibly turbidity.

Similar procedures would be initiated to collect samples near the sedimentation pond and within recharge basins. Note that samples should be collected within the basins and not at the inlet, in order to account for the concentration of constituents by evaporation.

Sampling within the vadose zone may include obtaining water samples via suction cups, piezometers, or shallow wells; and solids samples using coring techniques. Suction cups are similar to tensiometer cups in that both units are generally made from ceramic, both operate under negative pressure, and both require an intimate contact with the soil. Suction cups are installed to obtain samples when the media is unsaturated, when piezometers or wells fail. Details of suction cup samplers (also call suction lysimeters) are discussed by Everett, et al. (1976). Basically, the operating principal of these units is that when placed in the soil the pores in the ceramic cups become an extension of the pore space in the soil. By applying a vacuum to the interior of the cups via tubing, such that pressure is slightly less inside the cup than in the soil solution, flow occurs into the cup. The sample is then pumped to the surface through collection tubing. Figure 10-10 is an illustration of a commercially available suction cup sampler. Another type of sampler includes a check valve, permitting sampling to depths of 100 feet (Signor, Personal communication, 1979).

Certain problems associated with suction cup operation should be kept in mind. One problem is that samples cannot be obtained

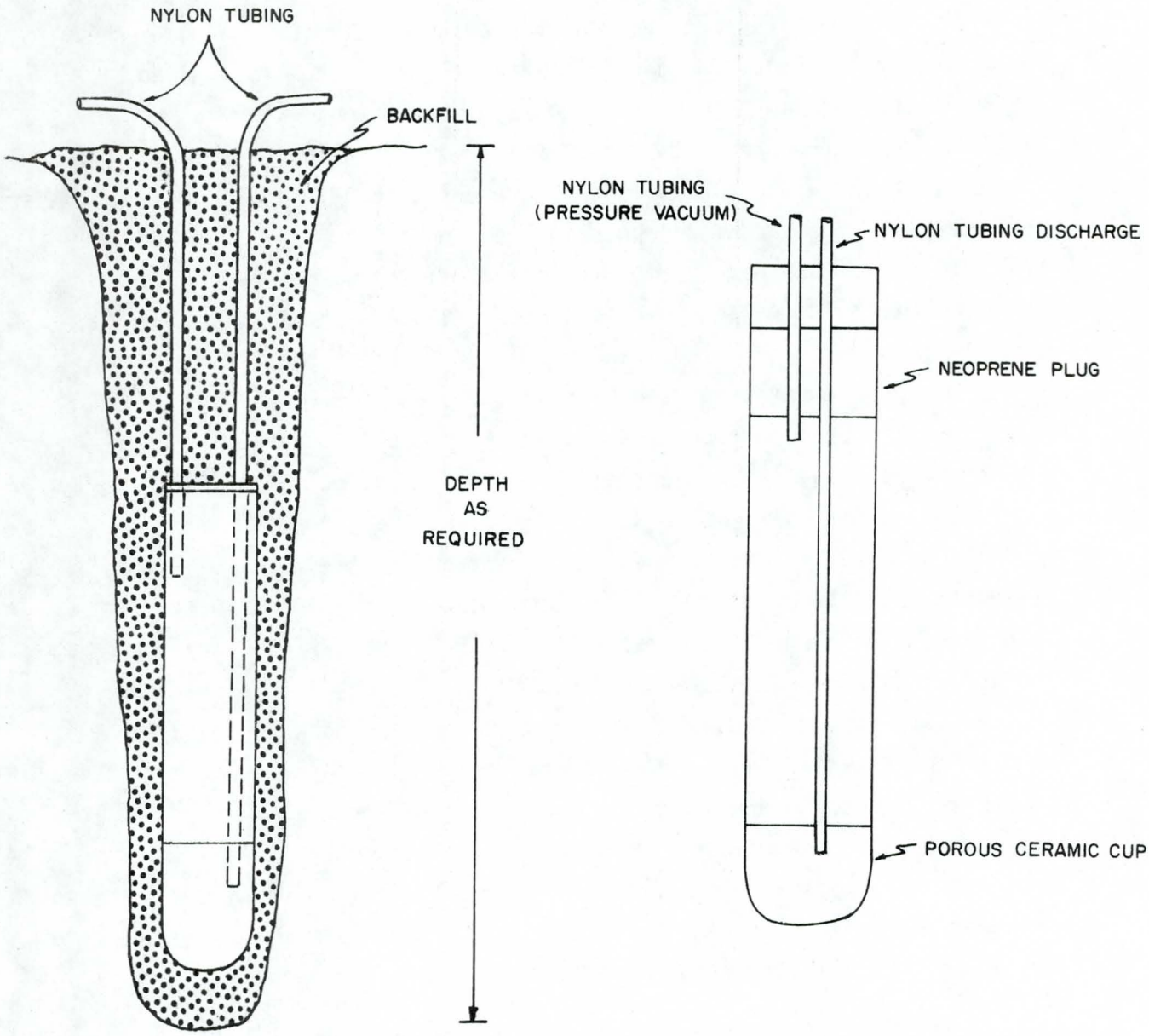


Figure 10-10. Suction Cup Sampler.

over the entire range of soil-water pressures; suction cups are capable of sampling only at pressures greater than about -1.0 atm.

In operating suction cup samplers care must be exercised to match the negative pressure applied within the cup to the pressure in the adjoining porous media. If a much greater vacuum is applied, the additional suction could influence the movement of water in the vicinity of the cups. It is generally advisable to install suction cups immediately next to tensiometers to obtain an accurate measurement of the vacuum to apply to the cups.

Piezometers and observation wells terminating within perched ground water could be used to obtain water samples. Small diameter piezometers could be sampled via a bailer or air lift pump. A positive displacement pump such as those manufactured by Clayton-Marks could be used. However, these pumps are more suitable for permanent installations because of the effort required to install and remove accessories. Observation wells could be pumped using portable submersible pumps. During extraction of water samples from piezometers or observation wells it is essential to pump at least five times the volume of the casing (Mooji & Rovers, 1976). This precaution is necessary to ensure that fresh ground water is obtained.

An alternative method for sampling perched ground water entails collecting cascading water in wells near the project area. Cascading water occurs when perched ground water enters breaks in casing, or when perforations are uncovered as the water table recedes. One possible procedure in the project area is to sample cascading water when pumps are removed from casing for repairs. Cascading water samples could be obtained by lowering a bucket into the casing.

Samples of solids could be obtained from the surface of recharge basins for determination of microorganisms using a procedure recommended by Dunlap, et al. (1977). This method requires augering, via a hollow-stem auger, to a short distance above a desired depth, and forcing a "dry-tube" core sampler through the region to be sampled. The core is then extracted at the surface. Smaller cores

are obtained from the parent core for determination of organics and microorganisms. Procedures for preserving and preparing the samples for analysis are described by Dunlap, et al. (ibid). The method is applicable to depths to 25 feet. Sampling for organics and microorganisms using the above technique would be particularly important when sewage effluent is spread upon recharge basins.

Water samples could be extracted from the zone of saturation using the on-site monitoring wells. Techniques for sampling would be similar to those discussed previously for observation wells in perched ground water. In addition, samples could be obtained in the deeper wells in increments to determine vertical changes in quality, reflecting displacement of indigenous ground water. Prior to obtaining depth-wise samples it is necessary to obtain a temperature profile within the saturated region of the casing to ensure that mixing is not occurring in the casing. Sampling could be effected using a thief type sampler or by installing a submersible pump and packer assembly.

Pumped ground water should be obtained from the network of existing wells used to monitor local water levels. Background quality data for these wells should be obtained where possible to detect trends in constituents. If possible, samples should be obtained at intervals for a period of at least a year prior to initiating recharge.

During collection of ground-water samples in the field it is imperative that unstable constituents be determined on site. Included among such constituents are: pH, EC, temperature, DO, HCO_3, and oxidation-reduction potential.

10.5 Data Processing and Reports

Detailed records should be maintained during each phase of the demonstration project, i.e., during preconstruction, construction, testing, recharge, and monitoring activities. For example, during operation of the recharge facility, a diary of daily activities should be maintained. Particular attention should be

paid to noting the factors affecting the operation of the facility, including conditions requiring cessation of recharge. The total operating time and down-time could thus be related to factors such as reduced intake rates, excess sediment, burrowing animals, and insects. Writing data onto scraps of paper or matchbook covers should be strictly forbidden. Data or operating information should be entered immediately into a hard-bound data book. Later, field data should be transcribed onto permanent data forms. The forms should be formatted to facilitate keypunching the information for batch computer input. Alternatively, the data could be directly entered into an interactive computer.

Standard forms could be prepared for hydraulic data, including flow rates at the diversion structure, in the conveyance line, into and out of the sedimentation pond, into the recharge facility, and into the bypass-drainage line. The following data could be entered onto a form for the recharge facility, e.g., a basin: 1) date, 2) time of day, 3) total number of days of operation, 4) inflow rate, 5) outflow rate, 6) head of water at upper end of basin, 7) head of water at lower end of basin, and 8) comments. A separate form could be prepared for data from instantaneous recharge tests, including: 1) time test was initiated, 2) time of reading, 3) head at upper end of basin, 4) head at lower end of basin, 5) average head over basin, 6) change in average head, and 7) intake rate (feet per day).

Special forms should be prepared for collecting data during investigations such as pump tests, laboratory column studies and flocculation tests.

Information collected during the monitoring effort should also be carefully documented in data books. Standard forms should be prepared for entering data from monitoring units such as tensiometers, psychrometers, piezometers, observation wells, and from a network of existing wells. As an example, the form for water level data from monitoring wells could include, 1) name of well, 2) legal description, 3) date, 4) time, 5) depth to water

below a standard datum, 6) water level elevation, and 7) comments.

Information on water samples should be entered into a separate field note book. Values of unstable constituents measured in the field should be entered into this book. Results of laboratory analyses should be written into data books and suitable bench sheets. A water-quality work sheet should be compiled for each analyses to permit: 1) determining anion/cation balances, and 2) preparing data for interpretative analyses such as by trilinear diagram. A copy of a work sheet is included in Figure 10-11. A final version of the data should be entered onto a sheet in a format suitable for key punching.

Reports should be prepared on project activities on a monthly and yearly basis. The monthly reports could be brief, with salient information on project administration and principal activities. The yearly report would be a comprehensive document including data on recharge studies, results of experiments, significant observations, discussion and conclusions, and recommendations for future activities.

10.6 Administrative Requirements

Consultants from the following disciplines could be involved during the planning phase of a recharge facility: 1) hydrogeologist, 2) soils scientist, 3) hydraulics (civil) engineer, 4) irrigation engineer, and 5) water quality chemist. Permanent personnel should be hired to assist during the construction, operation, management, and monitoring activities. A permanent staff could include: 1) project manager (responsible to and guided by the project coordinator and technical committee), 2) two field-shop assistants, 3) two laboratory technicians, and 4) a data analyst. The project manager should be a full-time staff member, with an M.S. in hydrogeology or soil science. He or she would be responsible for day by day activities, data collection and reports.

One laboratory technician should be employed on a full time basis, while the other technician could be part-time. The principal laboratory technician should have a B.S. in chemistry with a strong

Figure 10-11

WATER QUALITY WORK SHEET

WELL IDENTIFICATION: _____

CATIONS					ANIONS				
ION	PPM	EPM	%	% TOTAL	ION	PPM	EPM	%	% TOTAL
MG (12.2)					HCO_3 (61.0)				
CA (20.0)					CO_3 (30.0)				
OTHER					OTHER				
NA (23.0)					SO_4 (48.0)				
K (39.1)					CL (35.5)				
NH_3-N (14.0)					NO_3-N (14.0)				
OTHER					OTHER				
TOTAL					TOTAL				

COMMENTS:

pH =

ECw=
(micromhos/cm.)

TKj-N =

Org-N =

cations/anions =

$\frac{ECw}{100}$ =

TDS (ppm_c + ppm_a) =

background in analytical chemistry and analytical instrumentation. The chemist should be willing to assist in collection of samples. The second technician could be a university student. The shop and field personnel should be adept at using shop equipment; operating field machinery, such as crawler tractors and backhoes; and in operating and maintaining equipment, such as water stage recorders. The field technicians would assist in routine management of recharge facilities and possibly in data collection. The data analyst could be a part-time student knowledgeable in data reduction, and computer programming.

Graduate students from the University of Arizona and Arizona State University could be invited to assist in research activities. Student assitants would gain valuable field experience and possibly collect data for theses.

10.7 Recommended Investigations

During a demonstration recharge project a large, almost unlimited number of engineering/technical investigations could be conducted. Particular research project, objectives and methods would be tailored to site-specific conditions. However, the investigations would probably be related to three general catagories: 1) determining the potential intake rate features for the site, prior to construction, 2) determining best management practices to sustain favorable intake rates during operation of the facility, and 3) determining the disposition of infiltrated (or well-recharged) water during monitoring programs. A few possible studies or investigations in each of these catagories are outlined below, together with objectives, and possible methods.

These investigations have a predominantly engineering/technical slant. Nevertheless results could have a direct impact on legal, institutional, economic, and environmental elements of a demonstration project. Consequently, the final plans for the investigations should be reviewed by a full, technical-advisory committee.

10.7.1 Preconstruction Investigations

Preconstruction investigations would be coordinated with the technical data needs, discussed in Section 5, to assess potential recharge sites. Aside from site assessments, goals of preconstruction tests would be to facilitate the design, operation and management of alternative recharge modes; to quantify potential problems, and to obtain technical base line information for future comparisons. In general these tests would involve small-scale, field or laboratory experiments. A wide variety of conditions could be tested, so that a substantial mass of data could be obtained at a low cost. Specific tests could include the following:

10.7.1.1 Intake Rate Tests (Basins or Pits)

A. Objectives

I. To estimate long-term infiltration rates to assist in designing the capacity of recharge units.

II. To estimate spatial variability in properties governing infiltration, throughout the site.

III. To examine alternative management techniques, e.g., wet-dry cycles.

B. Methods

I. Small (20 ft. by 20 ft.) dikes, test plots; using water intended for recharge.

10.7.1.2 Potential Intake Rates in Recharge Well

A. Objectives

I. To characterize potential intake rates in a recharge well.

B. Methods

I. Collect information on the hydraulics of existing wells in the environs of the proposed site.

II. Conduct pumping tests on existing, nearby wells; particularly to determine the specific capacity.

10.7.1.3 Leaching Studies (on areas not previously flooded, irrigated or otherwise wetted)

A. Objectives

I. To examine leaching of salts, including indigenous nitrates.

II. To estimate the effect of interactions between recharge water and native salts on permeability.

B. Methods

I. Laboratory column leaching studies, using soil and water from the site.

II. On-site field plots, instrumented with suction cup samplers.

III. Collect soil and water samples for laboratory determination of adjusted SAR.

10.7.1.4 Flocculation Effectiveness of Polyelectrolytes

A. Objectives

I. To determine the effectiveness of various commercial polyelectrolytes (anion, cationic and neutral) for flocculating colloidal-sized sediments in surface water at the site.

B. Methods

I. Laboratory bench studies, using wrist action shakers.

II. Field plot studies.

10.7.2 Operation and Management Techniques

The general purpose of studies on the operation and management of facilities would be to examine techniques for determining long-term intake rates, and management techniques to sustain infiltration rates. Results would be applicable to the design and operation of a full-scale facility.

10.7.2.1 Basin and Pit Intake Rates

A. Objectives

I. To estimate long-term intake rates.

B. Methods

I. Impose long-term cycles on basin.

II. Use data from inflow and outflow flumes.

III. Use instantaneous rate method.

10.7.2.2 Wet-Dry Cycles

A. Objectives

I. To determine the effect of various wet-dry cycles on intake rates and on insect activity.

B. Methods

I. Impose a variety of wet-dry cycles, e.g., 1 day wet - 1 day dry; 1 day wet - 1 week dry; 1 week wet - 1 week dry, etc.

II. Determine intake rates using inflow and outflow rates and the instantaneous rate method.

III. Characterize insect population.

10.7.2.3 Chemical Ammendments

A. Objectives

I. To determine the effect of chemical amendments on intake rates, via inhibiting microbial activity.

II. To determine the effect of chemical amendments on water quality.

B. Methods

I. Column, test plot, or full-scale basins, including control areas.

II. Introduce metered concentrations of amendments, such as chlorine or copper sulfate, to recharge source.

III. Determine long-term intake rates in test and control areas.

IV. Obtain soil solution samples at depths via suction cup samplers, and determine presence of copper and chlorinated-hydrocarbons.

10.7.2.4 Effect of Perching Layers on Intake Rates

A. Objective

I. To examine the effect of perching layers (if present) on long-term intake rates in basins or pits.

B. Methods

I. Determine the long-term intake rates in a set of in-line recharge basins (see Figure 10-2).

II. Determine the corresponding long-term intake rates in the complete set of basins.

10.7.2.5 Intake and Management of Recharge Wells

A. Objective

I. To determine the long-term intake rate in the recharge well.

II. To examine management techniques.

III. To determine the effect of well recharge on well and aquifer properties.

B. Methods

I. Recharge the well for a prolonged period, determining the specific intake rate of the facility.

II. Pump the well for various periods during the day, when conducting a long-term recharge test.

III. Introduce various chlorine doses in the well (pump downstream observation wells and analyze samples for chlorinated hydrocarbons).

IV. Conduct step-drawdown tests on the well in intervals between recharge tests and calculate well and aquifer loss coefficients.

10.7.3 Disposition of Recharge Water

A purpose of installing monitoring facilities, such as those recommended above for the demonstration project, is to elucidate, albeit approximately, the disposition of water in the vadose zone and zone of saturation. For example, the transect of access wells could be logged to ascertain the volume of water in-transit within the vadose zone at any time.

Possible tests which could be conducted using the monitoring facilities to estimate the movement and potential recovery of recharged water include:

10.7.3.1 Movement in the Vadose Zone

A. Objectives

I. To observe changes in storage within the vadose zone.

II. To monitor flow paths of water in the vadose zone.

B. Methods

I. Log access well transects at established intervals during recharge tests; prepare sequences of water-content profiles; determine the change in volume of water stored within the vadose zone; and relate the change in volume to cumulative recharge volume.

II. Delineate perched ground-water regions.

III. Monitor water level response in piezometers.

IV. Mix tracers (e.g. fluorocarbons, fluorescent dyes) with recharge water and obtain tracer breakthrough curves in piezometers and/or observation wells.

10.7.3.2 Mixing in the Zone of Saturation

A. Objectives

I. To estimate dispersion of recharge water in native ground water.

II. To determine values of the dispersion coefficient for the ground-water system.

B. Methods

I. Introduce tracer into recharge source (alternatively if there is a relatively great difference in quality between ground water and recharge source a natural tracer, e.g., chloride could be used).

II. Obtain depth-wise ground water samples in observation wells using packers or thief sampler; obtain tracer breakthrough curves; and estimate the extent of mixing below the water table.

III. Obtain samples from observation well network and determine tracer concentration versus time relationships, and the lateral extent of the plume of displaced ground water.

TIME LINE-ENGINEERING CONSIDERATIONS

Task	First Year	Second Year	Third Year	Fourth Year	Fifth Year
Preconstruction (Planning)	→				
Construction		→			
Operation and Management		→	→	→	→
Monitoring		→	→	→	→
Investigations	→	→	→	→	→

11. ALTERNATIVE SITES FOR A DEMONSTRATION RECHARGE PROJECT

11.1 Introduction

Five sites were selected in the project area as being potentially suitable for a demonstration project or projects, and deserving of further in-depth study in each constraint area during the initial stages of Phase III. Each site was selected by reviewing the known hydrogeology of the Salt River; by determining the proximity to available water sources; and by conducting an on-site inspection. The five sites offer a variety of possible recharge techniques and water sources from which to make a final selection. While it may be feasible to use only one site for the demonstration project, flexibility and comparability could be enhanced by using more than one site, thus providing project sponsors with more information for Phase IV planning.

The sites selected are shown on Plate 1. The location, legal description, possible water sources, and land ownership of each site are summarized in Table 11-1. Note that the first four sites are within the original study area boundaries delineated on Plate 1. The fifth site (Site E) is outside the project boundaries, within the Salt River Indian Reservation.

The principal physical characteristics of each site are described below.

11.2 Physical Site Characteristics

11.2.1 Site A

The first potential site was selected about a mile downstream of Granite Reef Diversion Dam. On the day the site was visited, ponded water was observed in the stream. The source of the water appeared to be overflow from the dam and/or underflow. A growth of algae was noted on the surface of the channel in the inundated reach, indicating that control measures for algae would be required for a recharge project.

This site is near Granite Reef Diversion Dam and the Arizona and South Canals, which could be used to supply water when there is no flood water. Because there is overflow and seepage from the dam, moisture content of the soil profile should be at field capacity. The soil in the streambed is very coarse and would allow for high infiltration if silt and algae cover were controlled. There may be a problem because of bedrock in the area. Outcrops are seen along the sides and in the channel. At this point in the river, recharged water would be expected to flow south towards several Salt River Project wells. No significant water level change in the area would be experienced because of the coarseness of the aquifer material which would encourage rapid spreading of recharged water.

Tentatively, it appears that the most suitable recharge method at this site would be in-channel spreading.

11.2.2 Site B

A second potential site is about 7.4 miles downstream of the dam, at the confluence of the Evergreen Drain and the Salt River. On the inspection trip it was noted that the natural wash comprising Evergreen Drain empties into the low-flow channel of the river. The low-flow channel appeared to be one or two feet lower in elevation than the remainder of the channel. In addition, deposits in the low-flow channel were somewhat finer than the boulder-sized deposits elsewhere in the channel. The site is located directly below power lines of the Salt River Project.

The Evergreen Drain is a diversion channel for excess water in the Arizona Canal, and for flood water emanating from the Salt River Indian Reservation. The site, at the confluence of the drain and the river, is somewhat upstream from a channel used to dispose of irrigation tailwater. Both floodwater and tailwater could be used as water sources for the project. Tailwater would have the advantage over floodwater in being available on a more dependable basis. However, tailwater could contain undesirable levels of pesticides, herbicides, and/or nutrients promoting the growth of

algae. Floodwaters resulting from upstream releases could also be used as a source. Finally, water could be diverted into the Evergreen Drain for use on the site. The latter source could possibly be obtained on a continuous basis and has the advantage over irrigation tailwater in being relatively free of undesirable agricultural chemicals.

The stream channel comprises coarse material, with a potentially high infiltration rate. No known geological problems exist at the site. The locations of the ancient river channel and formation changes or caliche layers should be investigated. According to the regional flow pattern, recharge water would flow southeasterly towards Mesa. If there are any large production wells nearby the flow path could be altered locally.

Recharge methods appropriate to the site include in-channel spreading or basins.

11.2.3 Site C

A third potential site, located approximately 10.9 miles downstream of the Granite Reef Diversion Dam, comprises abandoned gravel pits in the river between Country Club Drive and Alma School Road. The pits are located within the low-flow channel, receiving floodwaters which have flowed this far downstream. It was noted that a relatively large pit was excavated near Alma School Road, with smaller pits upstream. The surface of the larger pit comprised a thin layer of silt, overlying coarser deposits. There appeared to be little colloidal-sized material because the characteristic clay crust was absent. It was tentatively concluded from this observation that the upstream pits probably serve to settle fines from floodwater.

Floodwaters enter into the series of pits via culverts installed beneath Country Club Drive. These culverts could be used to meter flow into the pits.

During the inspection trip, an abandoned landfill was observed immediately downstream from Country Club Drive. It appeared that

the landfill was encroached upon and eroded during the floods in the winter of 1978.

Other than floodwaters there are no additional water supplies available near the site at a reasonable cost. The soils and hydrogeology at this site are similar to those at the Evergreen Drain site (Site B).

The site is best suited to pit recharge. Inasmuch as the pits have already been excavated, construction costs would be minimal. Some preliminary earth moving and shaping would probably be required.

11.2.4 Site D

The fourth potential site is within the river channel next to the Mesa wastewater treatment plant. At this site, water which has received secondary treatment could be used in a recharge project. During an inspection tour it was observed that two relatively large basins are used as oxidation ponds for evaporation and/or percolation of effluent. With a small amount of modification and installation of weirs and staff gages these pits could be used to obtain preliminary intake and management data.

The soils in the channel are very coarse. Out of the channel there is some coarse material with a loam matrix. In this area a perched water table exists at 100 feet. Recharged water would not follow the regional gradient in the main aquifer but would flow in a direction toward large production wells in Tempe which pump from both formations. The coarse size of river bed sediments could militate against effective filtration of particulate matter in wastewater. Additional information should be obtained on the nature and extent of the perching layer and water quality in the vicinity of the treatment plant.

11.2.5 Site E

A site located on the Salt River-Pima-Maricopa Indian Reservation outside of the project area was suggested by Roger Evans, planning director for the Indian community, when he was contacted concerning the use of the Salt River Indians' land for the recharge

project. The site to be considered would be in the northeastern portion of the reservation. For the full-scale project, runoff from a nearby wash and possibly Colorado River water delivered through the Central Arizona Project (CAP) would be the water sources. For the demonstration project ground water would have to be used to show the feasibility of the operation. Advantages of this site are: the Indians' desires to store CAP water, to create recreation sites, and to overcome the flow of ground water from under the reservation south to Mesa and westerly to Scottsdale. At the proposed site the recharged water would move southwesterly under the reservation toward a line of wells in Scottsdale at the boundary of the reservation. The transmissivity will be lower in this area and the distance long enough that the Indians should be able to recapture the water with irrigation wells before it flows out into Scottsdale. Problems would arise because the suggested area has never been farmed. As a result, a large amount of water would be lost as dead storage to fill the soil pores to field capacity. There would also be a large amount of unleached salts in the soil which would deteriorate the water quality in the aquifer which presently contains about 500 ppm of TDS. One salt of concern would be the native nitrates in the soil. Possible caliche layers under the soil might also retard the flow of water unless recharge wells were used. Source water is also a problem as the Colorado River water to be delivered through CAP project facilities has a high sulfate content. This mixed with the calcium present in the soil and ground water would create an undesirable gypsum precipitate.

The use of spreading methods or pit recharge may be precluded by the presence of caliche and other impeding layers and large moisture deficits in vadose zone sediments. Recharge wells appear to be the best alternative at this time unless results of hydrogeological studies prove otherwise. One approach could be to recharge overflow from recreational lakes into a series of wells. The lakes would act as settling basins.

11.3 Site Assessment

To assist decision makers in assessing each of the five sites described above, a review of possible associated advantages and disadvantages in each constraint area--economic, institutional, legal, environmental, technical--is presented in the following table. These assessments are preliminary and necessarily incomplete. Ranking and final selection of sites must await results of activities under Phase III of the project.

The table of site assessments (see Table 11-1) is suggestive of the interdependency of factors project planners are likely to encounter. Institutional problems may be created by environmental or economic concerns. Refinement of technical plans may require more environmental or legal information. Additional environmental problems may be revealed as those technical plans are refined. Further study of the relationships among constraint areas and integration of the findings into an overall assessment of the advantages and disadvantages of each site should be a prime concern of Phase III activities.

One additional point is that decision makers should keep open the option of selecting more than one site for the project. For example, one site, such as Site B, could be operated continuously by purchasing water, while a second site, such as Site C, could be operated only during controlled releases. If this approach is adopted, the comparative advantages and disadvantages of possible combinations of sites could be evaluated and more thorough recommendations made concerning potential Phase IV activities.

TABLE 11-1: SITE ASSESSMENTS

SITE A

Location:	Approximately one-mile downstream of Granite Reef Diversion Dam, in the Salt River Channel.
Legal Description:	NW 1/4 NE 1/4 Section 23, T2N, R6E
Water Sources:	1. Flood water 2. Free water (SRP spillage) 3. CAP water
Land Ownership:	Salt River-Pima-Maricopa Indian Reservation

Economic Considerations

Advantages

1. Minimal water conveyance costs due to proximity of water sources.

2. Water recharged at this site will flow towards SRP wells. It may be possible to establish an arrangement in which the recharge project can receive a dependable supply of water from the SRP at reduced cost.

Disadvantages

1. If variable flood flows are the source of recharge water, their variability will result in high operation and maintenance costs.

Institutional Considerations

1. Because the site is on Indian land, planners are dealing with an institution (the Indian community) which has expressed a great deal of interest in an artificial recharge project; thus, potential political support is high.

2. The remoteness of this site may minimize the impact of the recharge project on metropolitan areas. Potential political controversy which could surround a project located near a population center may be lessened by this remote site.

1. This site could generate institutional opposition or public controversy in these areas: beneficiaries of the project, environmental disturbances in the area, technical considerations associated with the geography of the area.

2. Indian support may be questionable if no direct benefits to the Indian community can be demonstrated.

SITE A (Cont.)

Legal Considerations

Advantages

1. Unilateral surface water ownership sufficiently extensive to avoid water rights disputes.
2. Minimal possibility of inverse condemnation and tort claims.
3. Possibility of appropriating "abandoned" flood and spillage waters.

Disadvantages

1. Potential Indian reservation border dispute with BLM.
2. Uncertainty of ownership of "abandoned" flood and spillage waters.

Environmental Considerations

1. Remoteness of site will minimize aesthetic disturbances (visual and audial) to local populous.
2. Remoteness of site will minimize rodent and insect vector problems.
3. No known landfills.
4. No known archaeological sites.

1. Riparian vegetation may utilize much of water supply intended for recharge (high evapotranspiration losses possible).
2. Riparian vegetation and wildlife may be adversely impacted during construction if additional roads are necessary to provide access to project site.
3. Algae control methods would be required.

Technical Considerations

1. High infiltration capacity.
2. Response to recharge should be immediate with minimal loss to storage, since soil is at field capacity.
3. Water recharged will spread out rapidly and flow south recharging SRP project wells and wells of the Roosevelt Water Conservation District.
4. Seepage and overflow could be constant depending upon operation of Granite Reef Diversion Dam by SRP.

1. Potential problems with geological outcrops.
2. Potential flooding of site even at low-flow stage.
3. No significant changes in water level anticipated due to high transmissivity.
4. Difficult to monitor.
5. Great distance to extraction wells.

TABLE 11-1 (cont.)

SITE B

Location:	Near confluence of Evergreen Bypass Channel (Drain) and the Salt River.
Legal Description:	NW 1/4 SE 1/4 Section 26,T2N, R5E.
Water Sources:	1. Flood water from reservation. 2. Flood water in Salt River. 3. Irrigation tail water.
Land Ownership:	Salt River-Pima-Maricopa Indian Reservation

Economic Considerations

Advantages	Disadvantages
1. Irrigation tail water discharged near this site could provide a dependable supply at no purchase cost.	1. Irrigation tail water is of poor quality; therefore, treatment costs, and operation and maintenance costs will be high.
2. Minimal conveyance costs because of proximity to tail water discharge outlet.	
3. Recharge of irrigation tail water will cause a net increase in the supply of ground water. This water which was previously lost can now be reused.	

Institutional Considerations

1. With the site on Indian land, planners are dealing with an institution (the Indian community) which has expressed a great deal of interest in an artificial recharge project; thus, potential political support is high.	1. This site could generate institutional opposition or public controversy in these areas: water quality problems due to the use of irrigation tailwater (pesticides and chemicals), determination of the beneficiaries of the project, disturbance of archaeological sites, and rights-of-way problems.
2. Capturing flood and irrigation tail water may help achieve a water management goal of the Indian community.	
3. The remoteness of this site may minimize the impact of a recharge project on metropolitan areas. Potential political controversy which could surround a project located near a population center may be lessened by this remote site.	

SITE B (cont.)

Legal Considerations

Advantages

1. Unilateral surface water ownership sufficiently extensive to avoid water rights disputes.
2. Minimal possibility of private suits for inverse condemnation or tort claims.
3. Possibility of appropriating "abandoned" flood and spillage waters.

Disadvantages

1. Location of site directly under power lines could create legal problems if there is a potential for damage to the transmission towers, and if construction and operation would interfere with access to these lines.
2. Uncertainty of ownership of "abandoned" flood and spillage waters.

Environmental Considerations

1. No known landfills upstream from site.
2. Relatively remote site may minimize potential adverse air quality and noise impacts.
3. Little vegetation in immediate area.
4. Spreading basins could increase available wildlife habitat.

1. Adjacent archaeological sites which could be impacted by road construction to provide access to project site.
2. If used for recharge, irrigation tailwater may contain pesticide and herbicide residues contributing to the growth of algae and to ground-water contamination.
3. Landfill located immediately downstream on Salt River-Pima-Maricopa Indian Reservation lands.

Technical Considerations

1. High infiltration capacity
2. No known geological problems.
3. Water recharged will spread out rapidly and flow south toward Mesa.
4. Several available water sources with irrigation tail water being the most dependable.

1. Potential flooding of site.
2. Irrigation tail water will likely be of poor quality due to fertilizer and pesticides.
3. Flood waters would be high in total dissolved solids (TDS).
4. Difficult to monitor.
5. Possibly great depth to ground-water table.

TABLE 11-1 (cont.)

SITE C

Location:	Gravel pits between Alma School Road and Country Club Drive.
Legal Description:	N 1/2 SW 1/4 and S 1/2 NE 1/4 Section 4, T1N, R5E.
Water Source:	Flood water
Land Ownership:	Salt River-Pima-Maricopa Indian Reservation

Economic Considerations

Advantages	Disadvantages
1. Capital costs for construction will be small because conversion of existing gravel pits into recharge facilities would involve minimal expense.	1. If flood flows are the source of recharge water, then operation and maintenance costs will be higher.
2. Operation and maintenance costs may be low because upstream pits help to settle out fine material.	2. Other sources of recharge water would involve high conveyance costs.
	3. Sanitary landfills near the site may affect water quality and result in higher water treatment cost.

Institutional Considerations

1. Site is on Indian land. Planners are dealing with an institution (the Indian community) which has expressed a great deal of interest in an artificial recharge project; thus, potential political support is high.	1. This site could generate institutional opposition or public controversy in these areas: water quality problems due to nearby landfills, proximity to population center, disturbance of archaeological site, determination of the beneficiaries of the project, and ownership of recharged water.
2. Minimal construction required for spreading basins may minimize opposition to structural alternatives.	2. Although this site is located on Indian land, it appears that the primary beneficiaries will be Mesa well owners. Of the four sites located on Indian land, this site is likely to be the least institutionally acceptable to the Indians.
3. Minimal construction required may alleviate some of the concerns over the environmental damage that construction could cause.	

SITE C (cont.)

Legal Considerations

Advantages

1. Possibility of appropriating "abandoned" flood and spillage waters.

Disadvantages

1. Potential Indian reservation border dispute with state or political subdivisions.
2. No legally recognized ownership of artifically generated ground water.
3. Gravel pits could result in potential inverse condemnation or tort claims.

Environmental Considerations

1. Little vegetation in area.
2. If used, existing basins would require minimal construction disturbance in the area.

1. Aesthetic and insect vector problems may be present because of the site's close proximity to a populated area (Mesa).
2. Three active and inactive landfills immediately upstream from site may create a potential leachate problem.
3. There is one archaeological site close to site which could be impacted by road construction to provide access to project site.

Technical Considerations

1. High infiltration capacity.
2. No known geological problems.
3. Useful site to monitor infiltration rates during and after flood events.
4. Construction costs would be minimal.
5. Located near potential extraction wells.

1. Flood water is only available water source.
2. Monitoring for leachate required due to presence of landfills.
3. Possibly great depth to a ground-water table.

TABLE 11-1 (cont.)

SITE D

Location:	Salt River Channel due north of Mesa Wastewater Treatment Plant.
Legal Description:	SE 1/4 SE 1/4 Section 7 and NE 1/4 NE 1/4 Section 18, T1N, R5E.
Water Source:	Secondary treated wastewater
Land Ownership:	Private

Economic Considerations

Advantages

1. Proximity to Mesa Treatment Plant will allow recharge of treated effluent at minimum conveyance costs.

2. Treated effluent will assure the project of a stable dependable supply of water for recharge.

Disadvantages

1. Recharge of treated effluent may increase operation and maintenance costs.

2. Lease or purchase of private lands for the recharge site may increase costs.

Institutional Considerations

1. General public support may be generated for the management alternative of recycling wastewater.

1. This site could generate institutional opposition or public controversy with respect to: water quality problems due to use of treated wastewater, closeness to population center, and determination of beneficiaries of recharge.

2. Inasmuch as the land is privately owned, there is considerable uncertainty over whether the land owner would be supportive of a recharge project.

3. There is the question of who would be the local sponsor for a project at this site.

SITE D (cont.)

Institutional Considerations

Advantages	Disadvantages
	4. The City of Mesa may lack the institutional capability to manage and operate a recharge project.
	5. Legal and political changes may be necessary in order to distribute the associated costs to the beneficiaries. Potential sponsors may be hesitant to become involved until such questions are resolved.
	6. Administrative or legal changes may be necessary to obtain this water.

Legal Considerations

	1. No legally recognized ownership of artificially generated ground water.
	2. Gravel pits could result in potential inverse condemnation or tort claims.

Environmental Considerations

1. No known archaeological sites.	1. Aesthetic and insect vector problems may be present because of the site's close proximity to a populated area (Mesa).
2. Little vegetation in area.	2. Wastewater from Mesa treatment plant could contaminate ground water.

Technical Considerations

1. High infiltration rates.	1. Perching layer at 100 feet.
2. Flooding limited to high flood flows.	2. Coarse-textured material may not provide adequate filtering of secondary treated wastewater.
	3. Possible introduction of microorganisms and organic pollutants into ground water.

TABLE 11-1: SITE ASSESSMENTS

SITE E

Location:	Salt River-Pima-Maricopa Indian Reservation, North of Arizona Canal
Legal Description:	NW 1/4 NW 1/4 Section 24, T2N, R5E
Water Sources:	1. Flood water from reservation 2. CAP water
Land Ownership:	Salt River-Pima-Maricopa Indian Reservation

Economic Considerations

Advantages

1. If irrigation tail water derived from agricultural activities on the reservation is the source of recharge water then conveyance and source costs will be minimal.

3. The distance of the site from the Salt River channel means the potential for flood damages is minimal.

Disadvantages

1. Water sources other than irrigation tail water will involve high purchase and transportation costs.

2. May be a danger of subordinating the recharge purpose to the recreation purpose.

Institutional Considerations

1. Project planners will be dealing with primarily one institution which may simplify management problems.

2. The site is not only located on Indian land, but the Indians would also be the primary beneficiary of the recharge project.

3. This site was the site most preferred by the Indian Community.

4. The possibility of combining several water management functions--i.e., recreation, creation of wildlife habitat, and recharge--into project design and operation is high at this site.

5. The remoteness of this site may minimize the impact of the recharge project on metropolitan areas. Potential political controversy which could surround a project located near a population center may be lessened by this remote site.

1. This site could generate institutional opposition or public controversy in these areas: environmental disturbances in the area, water quality problems created by unleached salts, uncertainty regarding the surrounding geology.

2. Financing may be a problem if the Indian community as principal beneficiary lacks the institutional capabilities to finance the recharge project.

SITE E (cont.)

Legal Considerations

Advantages

1. Unilateral surface water ownership sufficiently extensive to avoid water rights disputes.

2. Minimal possibility of private suits for inverse condemnation or tort claims.

3. Possibility of appropriating "abandoned" flood and spillage waters.

Disadvantages

1. Uncertainty of ownership of "abandoned" flood and spillage waters.

Environmental Considerations

1. Flooding hazard is minimized by off channel location.

2. Relatively remote area will minimize aesthetic disturbances (visual and audial) to local populous.

3. Remoteness of site will minimize rodent and insect vector problems.

4. No known landfills.

5. No known archaeological sites.

1. Since this is a heavily vegetated area, there could be considerable disturbance during construction.

2. Possible adverse effects on wildlife dependent upon the site's vegetative cover.

3. Potential water contamination by pesticide and herbicide residues.

4. Soil properties may make it more difficult to construct recharge facility here than in river channel.

Technical Considerations

1. Groundwater flow would be under Indian reservation southwesterly toward Scottsdale wells near western reservation boundary providing more control of water movement and opportunity for recapture by Indian interests through irrigation on the reservation.

1. Since area has never been irrigated, there will be an initial loss of water to dead storage in filling soil profile to field capacity and a large amount of unleached salts causing water quality problems (TDS and native nitrates).

2. Possible caliche layers retarding infiltration and flow of water.

3. If eventually used as a source water, CAP water, which has a high sulfate content, may mix with calcium in the soil to form a gypsum precipitate.

12. ESTIMATED BUDGET

12.1 Technical Subphase[1]

12.1.1 Capital

Well construction, estimate three 10 inch wells, at $80/ft, total depth 700 ft	$168,000
Infiltrometers	200
Subtotal	$168,200

12.1.2 Operations

Construction of test ponds	$ 10,000
Surface geophysical logging	25,000
Subsurface geophysical logging	25,000
Drill cutting analysis	10,000
Chemical analysis	5,000
Pump testing	10,000
Travel	5,000
Miscellaneous	5,000
Subtotal	$ 95,000

12.1.3 Wages

Project Manager and Assistants (See Engineering budget)	
Consultants:	
Hydrogeologist, 10 days @ $300	$ 3,000
Geophysicist, 20 days @ $300	6,000
Soil Scientist, 10 days @ $300	3,000
Subtotal	$ 12,000
TOTAL FOR FIVE YEARS	$275,000

[1]Budget for five year period, but activities would occur primarily in the first and second years. In subsequent years the Engineering budget would accommodate technical expenses.

12.2	Environmental Subphase	
12.2.1	Capital	$ 0
12.2.2	Operations	5,000
12.2.3	Salaries and Wages[1]	
	Consultants:	
	General Biologist, 10 days @ $300	3,000
	Recreation Specialist, 5 days @ $300	1,500
	Sanitarian, 10 days @ $300	3,000
	Anthropologist, 10 days @ $300	3,000
	Subtotal	$ 15,500
	TOTAL FOR FIVE YEARS	$ 77,500

[1]Routine data collecting by Project Manager and Field Assistants (See Section 10).

12.3 Institutional Subphase		
12.3.1 Preconstruction Phase		
12.3.1.1 Operations		$ 5,000
12.3.1.2 Salaries and Wages		
Institutional Analyst and Public Inventory Specialist		17,000
Consultants:		
Financial Analysts		25,000
Institutional Analysts		17,000
	Subtotal	$ 64,000
12.3.2 Construction Phase		
12.3.2.1 Operations		$ 2,500
12.3.2.2 Salaries and Wages		
Institutional Analyst and Public Inventory Specialist		8,500
Consultants:		
Institutional Analysts		3,750
	Subtotal	$ 14,750
12.3.3 Operations and Monitoring Phases		
12.3.3.1 Operations		$ 22,500
12.3.3.2 Salaries and Wages		
Institutional Analyst and Public Inventory Specialist		59,500
Consultants:		
Institutional Analysts		26,250
	Subtotal	$108,250
	TOTAL FOR FIVE YEARS	$187,000

12.4	Legal Subphase	
12.4.1	Capital	$ 0
12.4.2	Operations	10,000
12.4.3	Salaries and Wages	
	Student	10,000
	Legal Consultant	20,000
	TOTAL FOR FIVE YEARS	$ 40,000

12.5	Economic Subphase	
12.5.1	Capital	$ 0
12.5.2	Operation	2,000
12.5.3	Salaries and Wages	
	Economist[1]	13,000
	Sociologist	15,600
	Consultants	
	Economist, 50 days @ $300	15,000
	TOTAL FOR FIVE YEARS	$ 45,600

[1]One month each year.

12.6 Engineering Subphase

12.6.1 Preconstruction Phase

12.6.1.1	Capital	
	Crawler tractor and accessories	$ 50,000
	Pick-up truck	7,000
	Water costs	10,000
12.6.1.2	Operations	
	Miscellaneous	25,000
12.6.1.3	Salaries and Wages	
	Consultants:	
	Hydrogeologist, 10 days @ $300	3,000
	Soil Scientist, 10 days @ $300	3,000
	Geologist, 5 days @ $300	1,500
	Civil Engineer, 20 days @ $300	6,000
	Project Manager (1)	20,000
	Field Assistants (2)	30,000
	Subtotal	$155,500

12.6.2 Construction Phase

12.6.2.1	In-Channel Recharge	
12.6.2.1a	Capital	
	Land costs	$ 20,000
	Weirs (4)	2,000
	Shop building	20,000
	Shop equipment	20,000
	Laboratory building	20,000
	Laboratory equipment:	
	Basic	20,000
	Full scale	50,000
	Chain-link fencing	5,000
12.6.2.1b	Operations	
	Miscellaneous	10,000
12.6.2.1c	Salaries and Wages	

	Consultants:	
	Hydrogeologist, 5 days @ $300	$ 1,500
	Soil Scientist, 3 days @ $300	1,500
	Civil Engineer, 10 days @ $300	3,000
	Project Manager	22,000
	Field-shop assistants (2)	33,000
	Subtotal	$228,000
12.6.2.2	Basin Recharge	
12.6.2.2a	Capital	
	Headgates (2)	$ 3,000
	Ditch liner or pipe	10,000
	Flow meters (4)	2,000
	Weirs (4)	2,000
	Gate valves (10)	500
	Culverts	2,000
	Steel pipe	3,000
	Portable dams	500
	Land costs	20,000
	Shop building	20,000
	Shop equipment	20,000
	Laboratory building	20,000
	Laboratory equipment:	
	Basic	15,000
	Full-scale	50,000
	Chain-link fencing	5,000
12.6.2.2b	Operations	
	Initial Construction:	
	Ditches	5,000
	Sedimentation pond	5,000
	Basins	10,000
	Miscellaneous	10,000
12.6.2.2c	Salaries and Wages	

	Consultants:	
	Hydrogeologist, 5 days @ $300	$ 1,500
	Soils Scientist, 5 days @ $300	1,500
	Civil Engineer, 20 days @ $300	6,000
	Project Manager	22,000
	Field-shop assistants (2)	33,000
	Subtotal	$276,000
12.6.2.3	Pit Recharge	
12.6.2.3a	Capital	
	Head gate (1)	1,500
	Ditch liner or pipe	10,000
	Flow meters (1)	500
	Weirs (1)	500
	Valves (3)	1,500
	Steel pipe or culvert	3,000
	Land costs	20,000
	Shop building	20,000
	Shop equipment	20,000
	Laboratory building	20,000
	Laboratory equipment:	
	Basic	15,000
	Full-scale	50,000
	Chain-link Fencing	5,000
12.6.2.3b	Operations	
	Construction of pit	60,000
	Construction, sedimentation basin	5,000
	Construction, ditches	5,000
	Miscellaneous	10,000
12.6.2.3c	Salaries and Wages	
	Consultants:	
	Hydrogeologist, 5 days @ $300	1,500
	Soils Scientist, 5 days @ $300	1,500
	Civil Engineer, 20 days @ $300	6,000
	Project Manager	22,000

	Field-shop assistants (2)	$ 33,000
	Subtotal	$311,000
12.6.2.4	Well Recharge	
12.6.2.4a	Capital	
	Head gates (1)	$ 1,500
	Ditch liner or pipe	10,000
	Flow meter (2)	1,000
	Rapid sand filter	20,000
	Chlorinator	10,000
	Steel pipe or culvert	3,000
	Valves (4)	2,000
	Land costs	20,000
	Shop building	20,000
	Shop equipment	20,000
	Laboratory building	20,000
	Laboratory equipment:	
	Basic	15,000
	Full-scale	50,000
	Chain-link fencing:	
	Shop laboratory complex	5,000
	Recharge well	2,000
	Well construction, $80/ft, for cased 20'-24 inch well, est. 700 ft	56,000
	Pumping plant	20,000
12.6.2.4b	Operations	
	Miscellaneous (including computer usage)	10,000
12.6.2.4c	Salaries and Wages	
	Consultants:	
	Hydrogeologist, 20 days @ $300	6,000
	Civil Engineer, 10 days @ $300	3,000
	Sanitary Engineer, 5 days @ $300	1,500
	Project manager	22,000
	Field-shop assistants (2)	33,000

	Laboratory superintendent	$ 18,000
	Laboratory technician	12,000
	Subtotal	$381,000
12.6.3	Operational Phase	
12.6.3.1	In-Channel Recharge	
12.6.3.1a	Capital	
12.6.3.1b	Operations	
	Repair and renovation of facilities	$ 10,000
	Laboratory analyses and quality control	2,000
	Miscellaneous (including computer usage, land taxes, etc.)	10,000
	Water costs	0
12.6.3.1c	Salaries and Wages	
	Project manager	$ 22,000
	Laboratory superintendent (1)	18,000
	Laboratory assistant (1)	12,000
	Field-shop assistants (2)	33,000
	Data analyst (1) (1/2 time)	10,000
	Secretary (1) (1/2 time)	7,000
	Student assistant	10,000
	Subtotal	$134,000
12.6.3.2	Basin Recharge	
12.6.3.2a	Capital	
	Replacements (Miscellaneous)	$ 5,000
12.6.3.2b	Operations	
	Repair and renovation	10,000
	Focculants	1,000
	Miscellaneous (including computer usage, land taxes, etc)	10,000
	Water, @ $16.00/ac. ft.	45,000
12.6.3.2c	Salaries and Wages	
	Project manager	22,000
	Laboratory superintendent (1)	18,000
	Laboratory assistant (1)	12,000

	Field-shop assistants (2)	$ 33,000
	Data analyst (1) (1/2 time)	10,000
	Secretary (1) (1/2 time)	7,000
	Student assistant	10,000
	Subtotal	$183,000
12.6.3.3	Pit Recharge	
12.6.3.3a	Capital	
	Replacements	$ 5,000
12.6.3.3b	Operations	
	Repair and renovation	$ 10,000
	Miscellaneous (including computer usage, land taxes, etc.)	10,000
	Water, @ $16.00/ac.ft.	45,000
12.6.3.3c	Salaries and Wages	
	Project manager	22,000
	Laboratory superintendent	18,000
	Laboratory assistant (1)	12,000
	Field-shop assistants (2)	33,000
	Data analyst (1) (1/2 time)	10,000
	Secretary (1) (1/2 time)	7,000
	Student assistant	10,000
	Subtotal	$182,000
12.6.3.4	Well Recharge	
12.6.3.4a	Capital	
	Replacements	$ 5,000
12.6.3.4b	Operations	
	Repairs	5,000
	Miscellaneous (including computer usage, land taxes, etc.)	10,000
	Water	12,000
12.6.3.4c	Salaries and Wages	
	Project manager	22,000
	Laboratory superintendent (1)	18,000
	Laboratory assistant (1)	12,000

Field-shop assistants (2)	$ 33,000
Data analyst (1) (1/2 time)	10,000
Secretary (1) (1/2 time)	7,000
Student assistant	10,000
Subtotal	$144,000

12.6.4 Monitoring Programs (General)

12.6.4.1 Capital

Tensiometers	$ 2,000
Psychrometer	2,000
Moisture blocks	2,000
Moisture meter	150
Suction cups	2,000
Neutron logger	11,000
Generator	5,000
Submersible pump	4,000
Composite sampler	1,500
Piezometer installation	20,000
Observation well installation	30,000
Access well installation	30,000
Water level sounder	500
Subtotal	$110,150

12.6.4.2 Operations

Miscellaneous (computer usage, land taxes, electricity, etc.)	$ 10,000

12.6.4.3 Salaries and Wages

Project manager	22,000
Laboratory superintendent (1)	18,000
Laboratory assistant (1)	12,000
Field-shop assistants (2)	33,000
Data analyst (1) (1/2 time)	10,000
Secretary (1) (1/2 time)	7,000
Student assistant	10,000
Subtotal	$232,150

12.6.5 Summary of Engineering Costs

Item				
Preconstruction	$ 155,500	$ 155,500	$ 155,500	$ 155,500
Construction	228,000	267,000	311,000	381,000
Monitoring	232,150	232,150	232,150	232,150
Operations	536,000	732,000	728,000	576,000
TOTAL FOR FIVE YEARS	$1,151,650	$1,386,650	$1,426,650	$1,344,650

12.7 Summary of Total Project Costs (estimated for five year period)

Budget Item	In Channel	Basins	Pit	Well
Technical	$ 275,000	$ 275,000	$ 275,000	$ 275,000
Environmental	77,500	77,500	77,500	77,500
Institutional	187,000	187,000	187,000	187,000
Legal	40,000	40,000	40,000	40,000
Economic	45,600	45,600	45,600	45,600
Engineering	1,151,650	1,386,650	1,426,650	1,344,650
Totals	$1,776,750	$2,011,750	$2,051,750	$1,969,750

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APPENDIX A

ARTIFICIAL RECHARGE - A REVIEW

by

L. G. Wilson

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INTRODUCTION

Artificial recharge represents a set of techniques for emplacing surface water into ground-water reservoirs. Specific purposes for recharge include: 1) water conservation, 2) underground storage of water, for the conjunctive operation of surface and ground-water reservoirs; 3) creation of sea water barriers within coastal aquifers, 4) flood control, 5) control of subsidence, 6) water quality managment and 7) waste disposal. The latter purpose encompasses techniques such as deep-well injection for the disposal of oil field brines, industrial wastes and cooling water. This review will be confined to methods for the first six purposes. (For a review of the technology of wastewater injection see Warner and Lehr, 1977).

Artificial recharge affords the means to conserve water supplies that normally would flow out of a basin or be lost by evapotranspiration. A water source placed into underground storage, is largely removed from the effects of evapotranspiration and water quality degradation. Water sources that could be conserved by recharge include flood water, urban runoff, treated sewage effluent, and industrial wastewater.

Conjunctive use entails the coordinated use of underground storage and surface water to augment the yield of a total water resource (Calif. Dept. of Water Resources, 1975). Conjunctive use methods involve the operation of surface storage facilities, locally or distant from the ground-water reservoir and delivery of surface water to a recharge area (ibid.). Artificial recharge methods serve as the link between surface and ground water reservoirs. Conjunctive use operations are widely employed in

California where the empty ground-water storage capacity is estimated to be 52,135,000 acre feet for 14 of the major basins. The total potential underground storage in California is estimated to be 450,000,000 acre feet. (Krieger and Banks, 1962). Conjunctive use operations, and ground-water basin management were greatly enhanced in California by two recent court decisions: City of Los Angeles vs. City of San Fernando, and Niles Sand and Gravel Co. vs. Alameda County Water District. As pointed out by Gleason (1976), these two decisions judicially established four public rights in California: "1) The right to store water in a natural underground basin without compensating overlying landowners; 2) The right to protect the stored water from expropriation by others and from inequitable operation burdens; 3) The right to recapture the stored water when it is needed; and 4) The public's priority to store water underground when there is a shortage of above ground storage space." In addition to utilizing the storage properties of underground reservoirs, conjunctive operations utilize the transmission properties of the underground flow system.

For effective operation, conjunctive use requires the maintenance of the ground water storage capacity by pumping. Basically, this approach is in opposition to the older philosophy of "safe yield", which deplored extraction or mining of ground water in quantities in excess of natural recharge. The importance of mining ground water to increase storage capacity was pointed out by Kazman (1967) and more recently by Ambroggi (1978). According to Ambroggi (ibid.): "The first condition for long term storage therefore is to deliberately increase the exploitation of an aquifer beyond the safe yield. If it is possible, the exploitation should carry the level of the reservoir below its natural outlets."

Undesirable side-effects may occur when ground-water levels are lowered during conjunctive use. For example, surface subsidence may result; energy costs for pumping will increase, and well casing and pump bowls may need to be installed at a greater depth (Calif. Department of Water Resources, 1975).

Artificial recharge methods have been employed in California, Long Island, Florida, Israel and elsewhere for the prevention or reduction of sea water intrusion in coastal aquifers. One approach entails spreading water in aquifer outcrop areas to increase the hydraulic gradient and flow to the region of ground-water extraction (Bruington, 1967). A more common approach is the pressure barrier method in which a line of injection wells is installed parallel to the coast, and fresh water is continually injected to maintain a pressure barrier or mound opposing inland movement of sea water. In California, recharge facilities used to promote sea water barriers have been constructed in Ventura, Los Angeles, and Orange Counties (Calif. Dept. of Water Resources, 1975).

Flood control and conjunctive use operations may be coupled. For example, the volume of storage in surface reservoirs could be reduced to accommodate all or a portion of runoff from upstream watersheds. Water released could be recharged in downstream facilities. Alternatively, flood waters could be diverted from a stream channel into off-stream recharge facilities.
Such off-channel recharge coupled with channel recharge would reduce downstream flood peaks.

Land subsidence related to ground-water extraction has been observed in California, Arizona and other areas heavily dependent on ground water. Schumann and Poland (1969) reported on subsidence in south-central Arizona in areas of heavy ground water pumpage. Similarly, subsidence has been observed in Avra Valley and near Picacho in southern Arizona (Carpenter, personal communication, 1978). As pointed out by Bouwer (1977), subsidence reflects an increase in the intergranular pressure of underground materials following a reduction in the hydraulic pressure. Bouwer also indicates that land subsidence, because of overdraft, is largely irreversible. Subsidence may be reduced or halted by cessation of pumping, coupled with ground-water recharge to prevent residual compression of clay layers.

Artificial recharge methods have been used for the in-aquifer mixing of waters of dissimilar quality. A thorough study of

underground mixing was conducted in Israel during the Underground Water Storage Study Project in Israel (Harpax, et al., 1968). Various combinations of water quality were used in recharge tests including treated and untreated lake water, fresh water of surface and ground-water origin, and wastewater (Harpaz, 1971). As a result of theories developed by laboratory, pilot and full-scale recharge studies, Israeli water managers are capable of combining surface water and ground waters of differing quality to produce and underground supply of a desired quality. In Israel the principal mode of recharge is wells. Studies by Nightingale and Bianchi (1977), at the Leaky Acres recharge facility showed that ground-water quality can also be managed by recharge basins using high quality water. Wilson and his associates at the University of Arizona (Wilson, 1971), conducted recharge well experiments similar to those of Israeli researchers, to study underground mixing in alluvium of the Tucson basin. They found that mixing in the alluvial system was similar to that in sandstone aquifers in Israel, with hydrodynamic dispersion being the primary mechanism for mixing. (In contrast, mixing in limestone aquifers in Israel is due to high ground-water velocities.)

ARTIFICIAL RECHARGE METHODS

For purposes of discussion, recharge methods will be catagorized as: 1) water spreading; 2) pits; and 3) wells and shafts. Selection of a particular method at a given location will depend on site-specific conditions, including land availability, water availability and water quality, hydrogeologic conditions, and economical considerations.

Water Spreading

Water spreading entails the release of water onto the land surface such that water movement is induced through the vadose zone into the zone of saturation. Spreading grounds are either

in off-channel areas, with structures for controlling and directing water movement, or comprise in-channel facilities.

As discussed below, spreading methods include the following techniques: 1) controlled surface flooding; 2) basins; 3) ditch and canals; 4) overirrigation; and 5) modified channel. In general, these methods are used on land areas not suitable for other uses, with the following hydrogeologic characteristics (Bouwer, 1978):

1. The surface soil is sufficiently permeable to yield acceptable infiltration rates (sands to sandy loams are preferred).
2. There are no layers in the vadose zone of such low hydraulic conductivity that they will form perched groundwater mounds that rise into the basins and restrict infiltration to unacceptably low rates.
3. The regional water table is sufficiently deep to keep the groundwater mound below the bottom of the basins, but not so deep that large quantities of water are needed to wet the vadose zone before any recoverable water reaches the water table.
4. The aquifer is unconfined and sufficiently transmissive to allow lateral movement of the recharge water without building up groundwater mounds that rise into the basins.

As pointed out by Bouwer as much information as possible should be obtained from the site of a potential spreading operation. Such information should include: results of soil surveys; data from geophysical surveys and test drilling; values of the hydraulic conductivity and storativity in the vadose zone and saturated zone; and values of the storage properties of the vadose zone and saturated zone. In addition demonstration or pilot studies should be conducted to determine long-term infiltration rates, management requirements (e.g., wet-dry cycling) and presence of perched ground water.

In order to estimate the size of a spreading area, information on the long-term infiltration rate, I, is of particular value.

Knowing I, and the available quantity of water for recharging, the total land area, A, required is:

$$A = Q/I$$

In practice, the required area may be several times greater than the calculated value because of the need for desilting works and alternative spreading areas to permit drying and renovation.

SPECIFIC METHODS

The following discussion on recharge methods is based mainly on an excellent review by the American Society of Civil Engineers (1961).

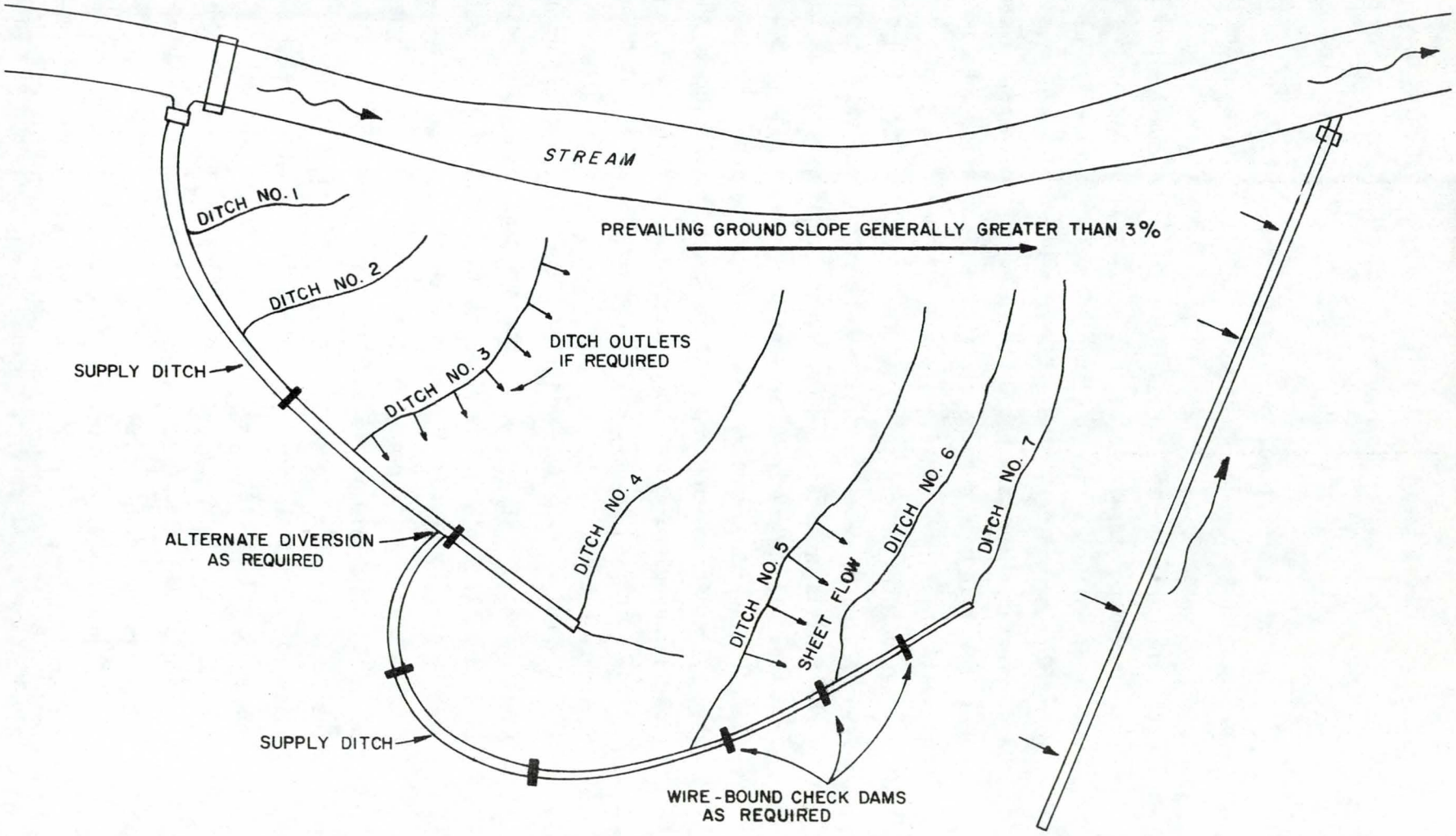
Flooding

A simple, effective method for water spreading is to pass water over the land surface in a thin sheet. Generally, the spreading area is undisturbed except for construction of supply ditches and lateral ditches. "The method is very effective and low in cost in areas in which slopes are gentle and uniform and gullies or ridges are small" (ibid.).

A schematic representation of a flooding type recharge area is illustrated in Figure A-1. This figure also illustrates appurtenant structures common to many spreading operations, including, diversion structure, flow measuring device, supply and lateral ditches, return flow collecting ditch and measuring device. If the main ditch and laterals are unlined additional recharge will be effected.

The management needs for the flooding method are generally minimal; with perhaps one or two individuals required to control flows on the area. If the land slope is sufficiently great, the flow velocity through the spreading grounds will be large enough to move clay and silt-size particles through the area. Thus, surface clogging will be reduced.

Figure A-1. TYPICAL PLAN OF DITCH AND FLOODING TYPE RECHARGE PROJECT
(After American Society of Civil Engineers, 1961)



Basins

In the basin method, recharge water is introduced into spreading areas bounded by levees. Two alternative methods of construction are possible: 1) dikes are constructed with fill out of the area and the land surface elevation remains about the same as under natural conditions; or 2) shallow basins are excavated below land surface, and the excavated material is used to form protective dikes. The difference between an excavated basin and a recharge pit (see below) is somewhat arbitrary. A structure less than five feet deep is classified as a basin, whereas an excavation greater than five feet is designated a recharge pit.

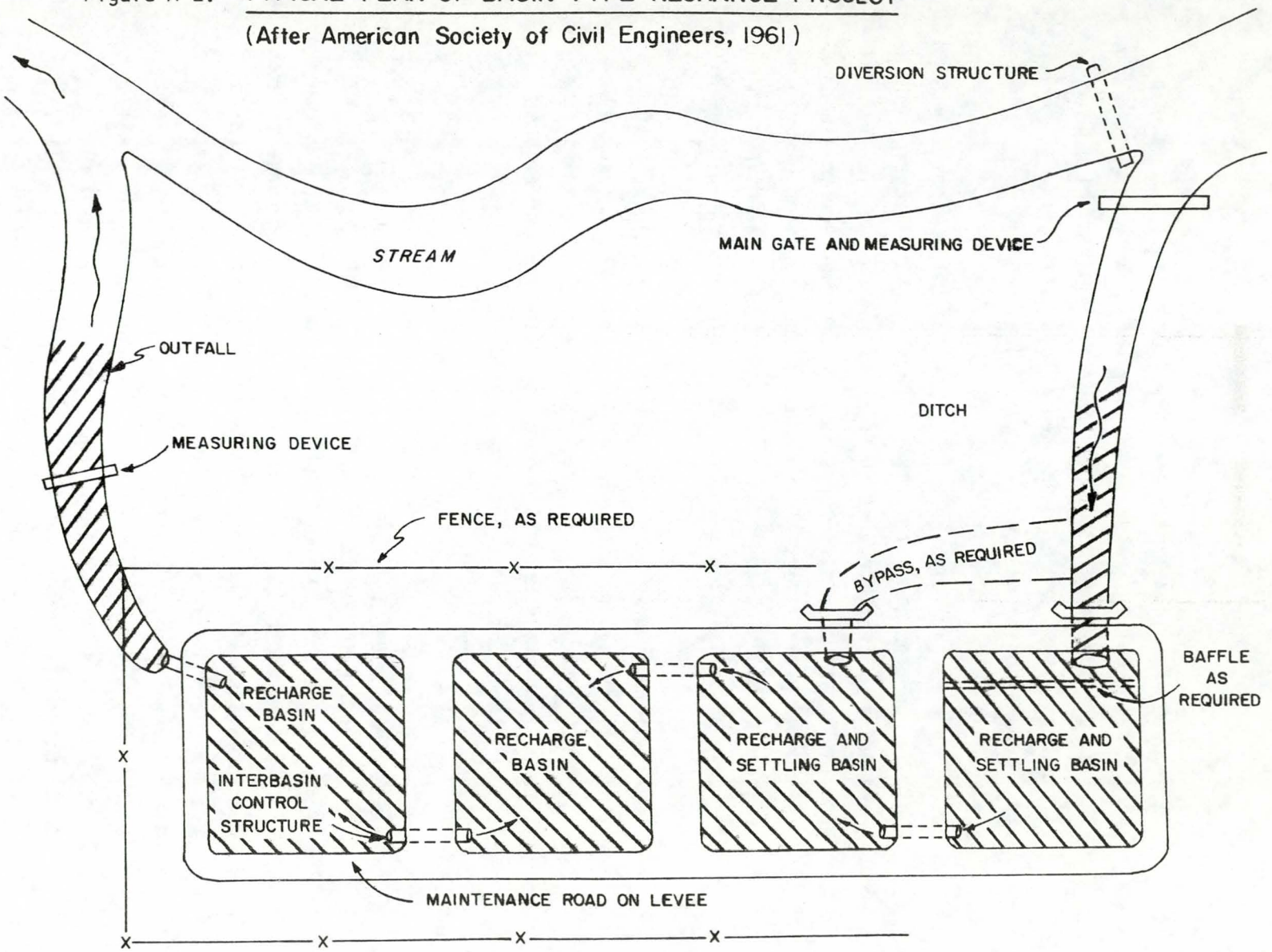
As pointed out in the American Society of Civil Engineers (1961) review of recharge methods, the purpose of basin type operations is to obtain the maximum ratio of wetted area to gross land area. In urban areas the ratio may be as high as 90%. Experience has shown that long and narrow basins are more efficient than basins for which the length is small in relation to the area (ibid.). Long and narrow ponds generate a greater lateral movement of water in the vadose zone and reduce the effect of mounds on intake rates.

A schematic representation of a basin-type spreading operation is illustrated on Figure A-2. For the case shown, the basins are in series, with flow passing from one basin to the next. In practice, a network of two or more such units would be constructed in parallel, to permit drying and renovation. The basins are at successively lower elevations to permit free flow through the system. The first basin may be larger in area and deeper than the other units to promote a reduction in velocity and hence settling of suspended solids. In some cases (e.g., the Rio Hondo spreading grounds in Los Angeles, see below), flocculants may be added to the recharge water at the head works and settling of flocculated clays occurs in the initial basin.

Figure A-2 also shows appurtenant facilities commonly associated with spreading basins. A diversion structure is used to divert flow to the spreading grounds. In Los Angeles, inflatable

Figure A-2. TYPICAL PLAN OF BASIN TYPE RECHARGE PROJECT

(After American Society of Civil Engineers, 1961)



rubber dams (Fabridams) have been used successfully. Such dams automatically collapse when flood flows reach a certain peak value. The figure illustrates a control gate and flow measuring device, at the head works, and a conveyance ditch. Similarly, a tail water ditch and measuring device are installed at the low point of the spreading grounds. Overflow from one basin to the next lower unit may occur through a pipe or culvert. Alternatively, each basin could be operated separately from lateral supply ditches. In the Leaky Acres project, located in Fresno (Bianchi, et al., 1978), pond inflow and drop structures were contructed such that each basin could be isolated. This method of construction permits separate measurements on each pond, to evaluate the effect on performance of soil sealing, vegetative growth, and rise in the water table.

Studies on basin recharge in California reported by Scott, et al. (1974), illustrated that recharge rates were greater for basins with steeper side slopes. The rationale for this effect is that, "...vertical currents generated by thermal differences tend to sweep the sides and deposit material toward the pond's center" (ibid).

Ditch-Canal Recharge

According to the American Society of Civil Engineers (1961) review of recharge methods, the ditch method of spreading utilizes ditches to transport water through the spreading grounds and concurrently increase the opportunity for recharge. Three basic types of designs are commonly employed: 1) contour, where the ditch follows the contour of the ground surface; 2) tree-shaped, with the main canal branching into subcanals; and 3) lateral, where lateral ditches extend outward from the main ditch. The ditch method is often used with other techniques, such as surface flooding (see Figure A-1). According to the American Society of Civil Engineers review, the ratio of wetted to gross area is low in projects exclusively using the ditch method, averaging about 10%.

Ditches are generally designed such that the flow velocities are great enough to keep fines in suspension. Consequently, surface clogging with fine sediment may not be too great a problem.

In addition to ditch recharge on areas specifically set aside for recharge, seepage losses in irrigation canals and farm laterals promote recharge. According to Ambroggi (1978), "Seepage from irrigation canals is one of the best techniques for artificially recharging ground-water reservoirs on a large scale. Accordingly, the lining of canals, which is often done to reduce seepage, is in fact a useless expenditure. It would be better to remodel the canals and enlarge them..." As an example of recharge from canals, Ambroggi (ibid.) cites the Indus Project in Pakistan. In 1965, recharge from irrigation canals in the project area was estimated to be 17 cubic kilometers per year (13.8 million acre-feet per year), compared with eight cubic kilometers per year (6.4 million acre-feet per year) of natural recharge. Recharge from canal seepage has also been observed in Fresno and in the Salt River Valley.

Irrigation Recharge

Recharge may be effected incidentally to normal irrigation practice, i.e., during the cropping season or by application of water to agricultural areas during the non-irrigation season. During normal irrigation practice, the quantity of water draining below the root zone may be estimated by the relationship (Jensen, 1973):

$$W_d = \Delta W_s - R_e + W_{et} \qquad (1)$$

Where W_d = total quantity drained from the effective root zone and not recovered by capillary rise

ΔW_s = change in soil water content

R_e = effective rainfall plus irrigation

W_{et} = evapotranspiration (calculated or determined by methods in Jensen, ibid).

In practice, excessive salts are leached from the root zone (leaching requirement). However, because of the low irrigation

efficiencies commonly observed in practice, the volume of water applied may be in excess of both crop and leaching requirements. Precise values of the amount of return flow to ground water resulting from overirrigation are generally unknown - an estimate of 40 to 50% return flow is sometimes used.

Application of water to irrigated areas during the non-irrigation season specifically for artificial recharge is described by Ambroggi (1978):

> Another means of artificially recharging ground water reservoirs in temperate zones is to spread high waters from the winter thaws over bare irrigable land, that is, to irrigate the land even though no crops are growing. The technique would provide both a temporary storage in the soil that would be useful to the crops when they are planted and a long term storage in the ground-water reservoir underlying the irrigated area.

Modified Channel Method

Experience in the West has shown that natural stream channels are generally highly efficient recharge units, particularly if the underlying alluvium comprises coarse alluvium. Consequently, techniques described above (e.g., basins) could be installed directly within such channels. The temporary dikes which would be required for flow control would be destroyed during floods. However, repair costs would probably be minimal.

Alternatively, the channel bottom could be reworked to increase the opportunity for natural recharge. For example, by widening, leveling and scarifying the channel in certain reaches, river flows would be spread out, velocities decreased, and infiltration rates augmented. Care must be exercised to insure that velocities are not reduced to the point that fine particles begin to settle out and clog the infiltration surface. According to the American Society of Civil Engineers (1961), upstream reservoirs are effective in controlling runoff rates so that flood water is not introduced at rates in excess of the absorptive capacity of the stream. Reservoirs also reduce sediment loads. This approach, controlled releases from reservoirs, was recommended by Babcock and

Cushman (1942) to augment natural recharge in Queen Creek, Arizona.

FACTORS AFFECTING THE PERFORMANCE OF WATER SPREADING OPERATIONS

A basic objective of water spreading operations is to maintain high intake rates. Consequently, factors promoting a reduction in such rates reduce the efficiency of the overall operation. Infiltration rates decrease in time because of the loss of energy required to overcome viscous forces as the wetting front increases in depth, or because of the presence of shallow perching layers. Other factors which affect intake rates include sediment, microorganisms, air, temperature and salinity.

Sediment

According to Bouwer (1978), clogging of coarse textured soils has been observed for recharge water with sediment concentrations as low as 50 mg/l. The clogging process resulting from sediment was described by Bouwer (ibid.) as follows:

> Clogging is primarily caused by settling of sediment, straining of suspended material as water moves through the sediment layer and into the soil, and bacterial and other biological action.... When water first enters a dry, clean basin, fine solids may actually move a considerable distance into the bottom soil, especially when this soil is coarse. If the soil becomes finer farther down, the solids could accumulate on these fine-soil layers, which can produce serious reductions in downward-flow rates.... When sediment begins to accumulate on top of the soil, however, the fine particles no longer move into the bottom material but are strained out on top of the sediment layer where they contribute to the hydraulic resistance of the clogging layer. Clogging thus is primarily a surface phenomenon that rarely extends more than 10 cm into the soil and often is restricted to the top centimeter or less. Clogging tends to cause the greatest relative reduction in infiltration rate if the bottom soil is coarse and the suspended sediment is fine.

The formation of a clogging layer at the infiltration surface leads to unsaturation throughout the vadose zone, unless water accumulates above perching layers. Flux in the vadose zone is concomitantly reduced.

Berend (1967) developed an empirical equation to describe the clogging process. As presented by Bouwer (1978), Berend's equation is:

$$V_i = V_o - aMI_t \ldots \quad (2)$$

Where V_i = infiltration rate at time t

V_o = initial infiltration rate

a = a coefficient describing the clogging properties of a system.

M = concentration of suspended matter in water that will be retained on the bottom.

I_t = accumulated infiltration.

Berend (1967) also presented an equation for the time, t_r, required to reach a minimum acceptable infiltration rate, V_{min}, before drying or otherwise improving the intake rate:

$$T_r = \frac{1}{aM} \ln (V_o/V_{min}) \ldots \quad (3)$$

The value of a is determined using equation 2, and measured values of V_o, V_i, M, and I_t. A difficulty with this approach is that the initial infiltration rate may approach infinity and decrease rapidly for the first few minutes. Thus a wide variety of V_o values are possible. Bouwer (personal communication, 1978) suggested that V_o should be taken as the rate after the initially high rates have been reduced, i.e. after several hours.

In addition to introducing sediment in the recharge water, wind action above shallow basins may promote erosion of banks and produce sediment. Tyley (1973), noted this effect in recharge basins in the Whitewater River area of California. He recommended that future basins be oriented to expose a minimum area of the banks to the predominant wind direction. This direction was determined using a continuous-

recording anemometer. Another construction technique for limiting the effects of sediment is to build the dikes of spreading basins with steep sides. Sediment eroded from the sides will accumulate at the base of the pond but the permeability of the sides will be sustained.

Control of Sediment

The most common method for reducing turbidity in the incoming recharge water is to construct settling basins at the head end of the recharge works. Settling basins are designed to slow down the flow velocity, i.e., reduce the carrying capacity of the water for sediment. Flocculants are frequently injected into the incoming water source to enhance sedimentation in the settling basins. Brown, et al. (1978) presented a conceptualized design of a settling basin for recharge projects in the southern high plains of Texas and New Mexico. The basin comprises a set of subunits. The subunits are separated by screen-wire baffles. Water is introduced into the first unit via a pipe containing vertical direction jets which promote flocculation. In order to sustain the capacity of settling basins it is recommended that sediment be removed when 30% of the basin capacity is filled. To avoid wind agitation and redispersion of the flocculated sediment the long axis of the basins should be oriented perpendicularly to the prevailing wind direction. The outlet line from the conceptualized basin contains a floating intake to obtain water near the pond surface. This assures that relatively sediment-free water will be diverted to the spreading grounds.

Wilson (1967) demonstrated that sediment concentrations in recharge water may be reduced by passing the water through grassed basins. In principle, vegetative screens reduce the flow velocity by increasing roughness, causing the sediment to deposit around and between the plants. Grass filtration was particularly effective in reducing the coarser particle-

sized fractions. Additional treatment (e.g., coagulation, use of settling basins) would be required for reduction of the colloidal-sized particles. Wilson noted that the interrelated factors affecting sediment removal included: length of grassed area, initial turbidity, application rate, slope, grass height and degree of ramification, and degree of submergence.

Polyelectrolytes have been successfully employed to reduce turbidity in storm runoff destined for recharge facilities. Rebhun and Hauser (1967) evaluated the flocculating characteristics of cationic (polyamines), anionic (copolymers of acrylamide and acrylates) and non-ionic (polyacrylamides) polymers, and alum. Montmorillonitic and kaolonitic clays were added to the test water. These studies showed that cationic polymers effectively clarified flood waters containing either stable or unstable suspensions. Anionic polymers were effective on unstable suspensions but not on stable suspensions. In field tests, 90% of the suspended solids were removed in a water source containing 200 mg/l suspended solids, using a cationic polyelectrolyte. More recent laboratory experiments by Brown, et al. (1978) in Texas showed that the most rapid settling of sediment in playa lake water was produced by a combination of organic and inorganic flocculants.

Despite the employment of the above procedures, spreading facilities generally become gradually clogged with sediment (and the by-products of microbial activity). In practice, therefore, the facilities are operated on a cyclic basis, e.g., one series of basins is allowed to dry while another is in operation. After drying, fines are physically removed from the surface of the basin. Subsequently the surface is scarified. Equation 3, may be used as a rough estimate of the operating time of a basin system.

Biological Clogging

As indicated by Fetter and Holzmacher (1974), dead organisms may settle on the bottom of a spreading facility, clogging the surface in a manner similar to sediment. The by-products of microbial activity (e.g., microbial polysaccharides) also are effective in clogging soil pores (ibid.). In addition, changes in pH of the water may result from algal activity, resulting in the precipitation of carbonates, possibly clogging the soil pores. Bouwer (personal communication, 1978) has observed this effect in the 23rd Avenue land treatment project in Phoenix.

When conditions are favorable for growth, extensive algal mats may develop on the surface of a spreading grounds. Intake rates may be reduced. However, because algae produce oxygen, bubbles of gas may accumulate under the mat. When the buoyancy is modified sufficiently, patches of mat float to the surface. Generally, algal mats also remove surface soil-particles as they rip loose. Consequently, patches of the soil surface are exposed and intake rates may increase.

Clogging problems related to microbial activity are particularly troublesome when sewage effluent is used as the source.

Control of Microbial Clogging

The clogging effects of microbial activity in spreading operations are commonly ameliorated by imposing wet-dry cycles on the area. For example, lysimeter studies by Worcester (1967) showed that cycling improved the intake rates of soils into which cotton-gin trash had been incorporated. Apparently, during desiccation the organic matter and microbial byproducts improved the soil structure and increased the size of voids.

Microorganisms could also be controlled by mixing suitable algacides or bactericides into the recharge supply. For

example, copper sulfate is a common algacide. However, care must be exercised to avoid introducing excessive levels of copper into ground water.

Air Effects and Intake Rates

Air may affect the intake rate of a spreading facility in two ways: 1) entrainment of air bubbles in the soil pore system and 2) confinement of air ahead of the wetting front. The first effect (called the Jamin effect) increases the resistance to flow because the air bubbles block pores in the same fashion as solid particles. Changes in temperature moderate this effect because of concomitant changes in air solubility and bubble volume.

Confinement of air ahead of the wetting front occurs mainly in large spreading areas underlain by shallow water tables or tight lenses. For smaller areas air escapes laterally with ease. Air pressure build up slows down the rate of advance of the wetting front, and accordingly also the intake rate. Eventually, the air pressure will exceed the bubble pressure of the system and air will vent at the surface, causing a momentary increase in intake rates. During recharge operations at the Leaky Acres Project, Bianchi, et al. (1978) noted the venting of confined air from the soil surface for several weeks after ponding was initiated. Gauge pressure heads up to 53 KPa (0.52 atmospheres) were noted on test wells (ibid.). The effect of confined air on project performance has not been ascertained.

Control of entrapped air may be difficult or impossible in most field spreading operations. Confined air pressure may be relieved by installing vent pipes at appropriate depths.

Temperature Effects

In their water spreading studies in Fresno, Bianchi, et al. (ibid).) observed: "Ponded water temerature is the

most significant ambient parameter affecting performance." For example, intake rates in the Leaky Acres project varied from 40 acre feet/day in winter to about 58 acre feet/day in the summer.

The effect of water temperature on intake rates of a spreading ground is mainly related to viscosity. The hydraulic conductivity is inversely related to viscosity, as shown by the equation:

$$K = k'\frac{\rho g}{\mu}$$

Where K = hydraulic conductivity

K' = intrinsic permeability

ρ = density

g = gravitational acceleration

μ = viscosity

Salinity Effects

It is well known by soil scientists and hydrologists that an excess of sodium on the exchange capacity of soils leads to a dispersion of clay-sized particles, and a reduction in the hydraulic conductivity. For example, fine textured soils are affected when the exchangeable sodium percentage (ESP) is greater than 10%. The ESP represents the fraction of the exchange capacity of a soil occupied by sodium. Coarse textured soils may not be affected until the ESP reaches 20% (U.S. Army Corps of Engineers and U.S. Department of Agriculture, 1977).

As a result of experimentation soil scientists have revised the above approach to account not only for the effects of sodium but also total salt concentration, on the hydraulic conductivity. For example, Quirk and Schofield (1955), as discussed by McNeal (1974), demonstrated that exchangeable calcium, magnesium and potassium tend to stabilize a soil against salt-associated structural changes. Nevertheless at decreasing salt concentrations, for a soil with a given ESP,

even systems saturated with these ions exhibited swelling, dispersion and a decrease in the hydraulic conductivity. This effect is demonstrated on Figure A-3, which illustrates that for a given ESP the hydraulic conductivity of a soil decreases as the salt concentration decreases. Quirk and Schofield (1955) defined the "Threshhold Salt Concentration" as the level to which the salt concentration of the soil solution would need to be decreased by 10 to 15 percent for a given conductivity.

The ESP of a soil may be calculated knowing the Sodium Adsorption Ratio (SAR) of the soil solution from the relationship (Richards, 1954):

$$ESP = \frac{100(-0.0126 \quad 0.01475\ SAR)}{1+(-0.0126 + 0.01475\ SAR)} \qquad (4)$$

$$\text{Where } SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{++}+Mg^{++})}{2}}} \qquad (5)$$

all units in meq/l.

Values of the SAR for an irrigation water have been used as a gauge of the effect of sodium on permeability. For example, SAR values greater than 6 to 9 in an irrigation water are expected to reduce the hydraulic conductivity in shrinking-swelling soils (Ayers and Westcot, 1976). However, carbonate and bicarbonate levels in an irrigation water also affect the permeability: "When drying of the soil occurs between irrigations, a part of the CO_3 and HCO_3 precipitates as Ca-$MgCO_3$ thus removing Ca and Mg from the soil water and increasing the relative proportion of Na which would increase the sodium hazard" (ibid). The older SAR procedure has been adjusted to accommodate the effect of lime dissolution or deposition by means of the following relationship:

$$\text{adj } SAR = SAR\ 1+(8.4-pH_c) \qquad (6)$$

SAR is calculated from equation (5). Values of pH_c are calculated from Table A-1, reproduced from the report of Ayers and Westcot (ibid.). Adjusted SAR values greater than 9.0

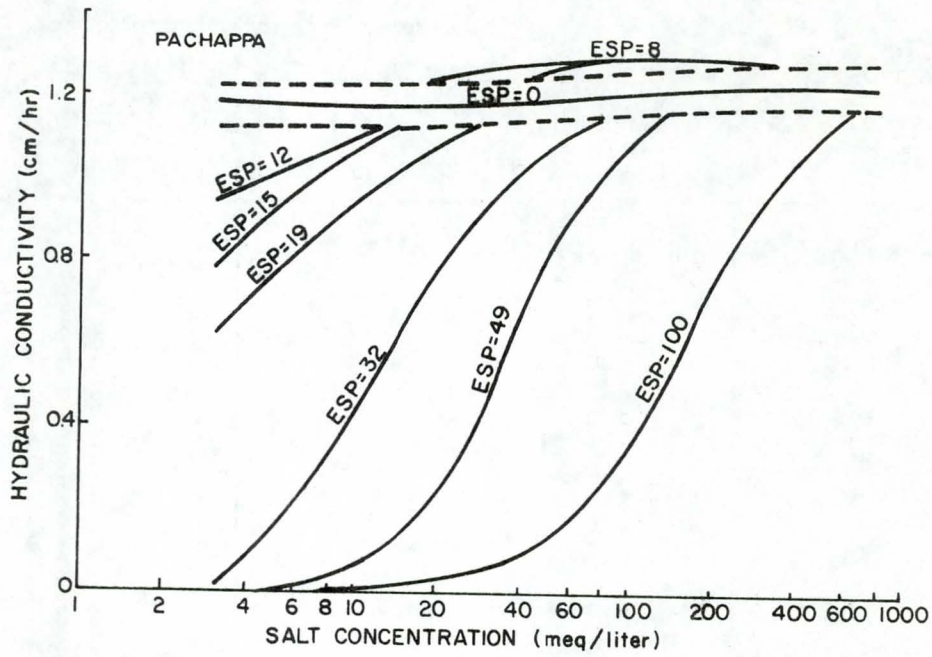


Figure A-3. Relationship Between Hydraulic Conductivity and Salt Concentration for Pachappa Sandy Loam (After McNeal, 1974).

Table A-1
CALCULATION OF ADJUSTED SODIUM ADSORPTION RATIO
(After Ayers and Westcot, 1976)

The adjusted Sodium Adsorption Ratio (adj. SAR) is calculated from the following equation 1/:

$$\text{adj.SAR} = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad [\,1 + (8.4 - pHc)\,]$$

where Na, Ca and Mg are in meq/l from the water analysis and pHc is calculated using the tables given below which relate to the concentration values from the water analysis. The table values are then substituted in the pHc equation:

$$pHc = (pK'_2 - pK'c) + p(Ca{+}Mg) + p(Alk)$$

------Tables for calculating pHc----------

$(pK'_2\text{-}pK'c)$ is obtained from using the sum of Ca + Mg + Na in meq/l

p(Ca+Mg) is obtained from using the sum of Ca + Mg in meq/l

p(Alk) is obtained from using the sum of CO_3 + HCO_3 in meq/l

Sum of Concentration (meq/l)	pK'_2-pK'c	p(Ca+Mg)	p(Alk)
.05	2.0	4.6	4.3
.10	2.0	4.3	4.0
.15	2.0	4.1	3.8
.20	2.0	4.0	3.7
.25	2.0	3.9	3.6
.30	2.0	3.8	3.5
.40	2.0	3.7	3.4
.50	2.1	3.6	3.3
.75	2.1	3.4	3.1
1.00	2.1	3.3	3.0
1.25	2.1	3.2	2.9
1.5	2.1	3.2	2.8
2.0	2.2	3.0	2.7
2.5	2.2	2.9	2.6
3.0	2.2	2.8	2.5
4.0	2.2	2.7	2.4
5.0	2.2	2.6	2.3
6.0	2.2	2.5	2.2
8.0	2.3	2.4	2.1
10.0	2.3	2.3	2.0
12.5	2.3	2.2	1.9
15.0	2.3	2.1	1.8
20.0	2.4	2.0	1.7
30.0	2.4	1.8	1.5
50.0	2.5	1.6	1.3
80.0	2.5	1.4	1.1

1/ pHc is a theoretical, calculated pH of the irrigation water in contact with lime and in equilibrium with soil CO_2.

create permeability problems in clay soils. Gypsum is commonly added to the water supply to counteract the effects of SAR on permeability.

Dispersion of clays resulting from the application of low salinity waters to a soil with a given ESP, may increase the turbidity of water moving into the profile. Nightingale and Bianchi (1977), for example, noted an increase in turbidity of water pumped from domestic wells near the Leaky Acres spreading area. Nightingale and Bianchi postulated that sieving of the dispersed clays could reduce the hydraulic conductivity of the underlying media.

Insect Activity

Control of insects is a management problem inherent with water spreading facilities. In the Rio Hondo spreading grounds in Los Angeles the control of insects has been effected by imposing wet-dry cycles. The procedure is described by Milne (1975):

> In general, the district has found the best control to be one of interruption of the life cycle of the insect. Most of the problems have originated with chironomid midges. These insects readily develop in moving water. (Mosquito problems have been minimal because they propagate best in stagnant-water conditions.) The life cycle is interrupted by an operation termed "battery spreading". This simply involves operating only a portion of the spreading grounds at a time; generally one third of the grounds is wet, one third is drying and one third is dry; the period of each lasting from seven to 10 days. This has been very effective for insect-control, much better than the application of insecticides. In fact, it seems that insecticides also tend to kill off the natural enemies of the midges, thereby disrupting the ecological balance, with the usual result that the midges return much more quickly than their natural enemies, thereby creating a greater infestation than existed before the application of insecticides. This battery spreading also seems beneficial in maintaining infiltration rates which tend to drop off under long-term wet conditions.

RECHARGE PITS

In contrast to spreading basins, recharge pits are excavations greater than five feet below land surface. According to Milne (ibid.), the selection of a pit rather than a shallow spreading-ground is based on the following considerations:

a) In areas of low permeability, the storage capacity of the pit provides a means of retaining a greater quantity of water for replenishment;

b) Deep pits can be constructed to penetrate tight surface-strata in order to provide access to deeper, more permeable materials;

c) In areas where problems of rights of way are critical, a pit requires less land to accomplish the same amount of replenishment under certain hydrogeological and operating conditions.

Experience in California indicates that spreading grounds are preferable to pits when the facilities are operated on a sustained basis. Spreading grounds offer more operating flexibility to sustain intake rates, control insects, and for routine maintenance (ibid.).

Recharge pits may either consist of existing excavations, such as gravel pits, or specificaly constructed cavities. Obviously using existing gravel pits is more economical than constructing special pits. However, abandoned pits may require modification or earth moving in order to remove fine sediment or trash and provide inlet facilities. In addition, it may be necessary to construct an upstream auxiliary pit for desilting. Some water management districts or communities enter into contractual agreements with gravel operators for the removal of gravel from a proposed recharge site; i.e., the contractor pays for the gravel and the water agency eventually obtains a recharge pit. Milne (ibid.) for example, reviewed such an agreement between the Los Angeles County Flood Control District (LACFCD), the City of Arcadia and a

gravel contractor. "The district receives no payment for the mixed gravel; as most of the land was owned by the City of Arcadia, it receives the payment, but development (of a pit) is proceeding at little cost to the district" (ibid.).

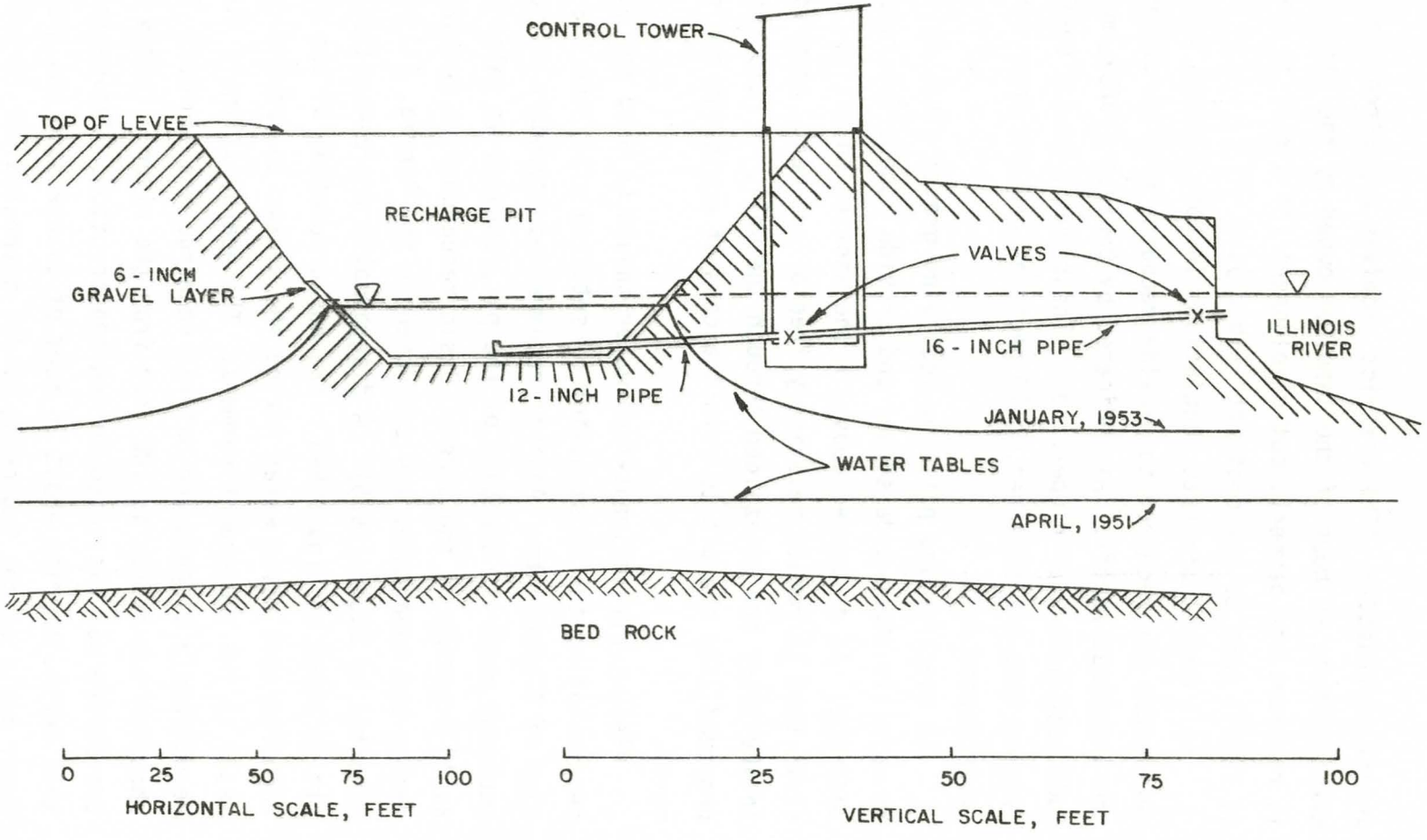
As a result of state regulations in Long Island, building developers are required to provide recharge pits to accommodate the increased runoff. As indicated by DeWiest (1975), more than 2000 such pits are in operation. These sumps have a surface area ranging from 0.2 hectares to 10 hectares and are from three to seven meters deep.

In constructing pits, or modifying gravel pits, it is essential to maintain steep side slopes and provide access for removal of sediment. As discussed above in the section on basins, steep sides tend to remain relatively free of sediment, ensuring that intake rates are maintained through the wall. A ramp should be provided into the pit to permit access of equipment for silt removal.

Relatively sediment-free water should be used for pit recharge, necessitating the construction of settling pits; and the introduction of flocculents. Another recommended procedure is to introduce recharge water at the base of the pit, through an inlet pipe, to avoid scouring of the sides. Basic research into recharge pit design and management was conducted on the Peoria, Illinois pits, reported by Suter (1956). A diagrammatic representation of the pit is shown on Figure A-4. The basic function of the pit was to recharge cool river water during the winter to provide cooling water in the subsequent summers. The nearby Illinois River had become badly clogged and natural recharge was minimal. The pit shown on the sketch is 100 feet from the river. Thirty feet of overburden was excavated during construction. Sediments below this depth comprise about 24 feet of coarse sand and gravel. The water table at the beginning of the operation was 10 feet below the base of the pit.

The sketch also illustrates appurtenances used with the pit operation. The intake pipe consists of 16-inch asbestos-cement

Figure A-4. CROSS-SECTION OF RECHARGE PIT AT PEORIA, ILLINOIS
(After Todd, 1963)



pipe. A control tower was provided to house appurtenant facilities such as a chlorinator, pumps and flow recorder. The discharge line is a 12-inch asbestos cement pipe terminating at the base of the pit. Control valves are in the inlet pipe, and in the 12-inch pipe. A flow measuring device is also located in the 12-inch line.

Two problems encountered in the operation of the Illinois pit were fines and microorganisms, which clogged the surface. The problem of sedimentation was largely overcome by installing a pea-sized gravel filter on the surface of the pit. Biological clogging was ameliorated by chlorination.

Wilson (1971) presented results of experiments using a recharge pit near Tucson, Arizona. Alluvium underlying the pit is typical of sediments of the Basin and Range physiographic province; that is, highly stratified, heterogeneous and anisotropic. During preliminary hydrogeologic investigations the vadose zone was found to contain a coarse gravel strata in the region 10 feet to 30 feet, underlying which the media comprises finer gravels, with stringers of sand, silt and clays. The upper 12 feet is primarily a fine sandy loam.

The pit was excavated into the coarse gravel region. The pit was constructed with relatively steep side slopes; 2½:1. Dimensions of the pit were 105 feet by 50 feet by 10 feet deep. Appurtenances at the site included 14 access wells, two batteries of piezometers and three observation wells. The access wells were logged routinely with a neutron moisture logger. Intake rates were determined using cumulative inflow data (from a flow meter) and a head-volume relationship for the pit. The water used for the recharge trials consisted of blowdown effluent from a nearby power plant.

A first test in 1966 entailed 142 days of continuous inundation, during which 45 acre-feet was recharged. Intake rates varied from 30 feet/day to 0.5 feet/day. During a second test in 1968, 15 wet-dry cycles were imposed on the pit with a total period of inundation of 80 days. The total quantity recharged in the second test was 40 acre feet.

Neutron moisture logs clearly manifested the growth and dissipation of perched ground water during the recharge tests. For example, Figure A-5 illustrates a series of water content profiles in the 1966 test. The initial profile (May 10) was essentially drained, although a residual mound was present above the water table at 80 feet. The second profile, on June 3, after about a month of recharging clearly showed the presence of an upper perched ground-water region, and a lower mound. The upper perched ground water occurred near the interface of the formation change discussed above. The lower mound developed in the vadose zone above the prerecharge water table. Apparently vertical flow velocities are reduced in the lower mound in the vicinity of the water table. Also, because of greater K values in the lateral than vertical direction, flow in the mound is preferentially oriented in the lateral direction. The water content profile for June 3 also shows that a region between the upper and lower mounds remained at prerecharge levels. That is, the region transmitted water without effecting a change in water storage.

Subsequent profiles on Figure A-5 reflect changes in water distribution within the vadose zone because of clogging at the pit surface. Thus, because of a reduced rate of supply, the perched ground water gradually drained. The final log shows no evidence of this upper perched ground water. Dissipation of the lower mound also occurred but at a slower rate than the overlying mound.

Problems in Recharge Pit Operations

The problems discussed above for operation of spreading grounds are identical to those for pits. That is, sediment, biological activity, air, temperature, and salinity may have a deleterious affect on intake rates. Insect problems also develop, requiring suitable management techniques.

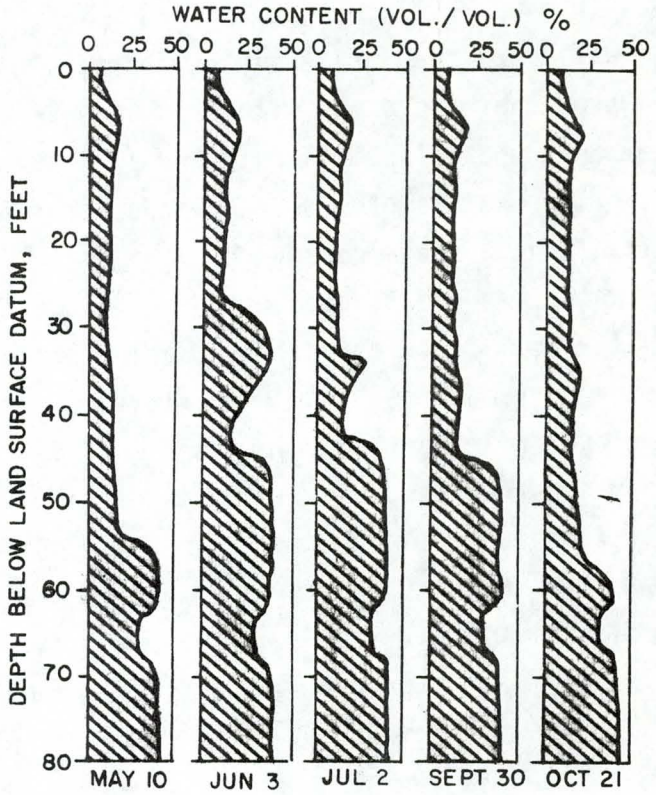


Figure A-5. Water Content Profiles Via Neutron Moisture Logging (After Wilson, 1971).

RECHARGE WELLS

For purposes of discussion in this report a recharge well is defined as a bore hole through which water is introduced into the ground-water zone by gravity (e.g., free-fall or conductor pipe). An injection well is defined as a well in which water is forced under pressure into an aquifer region.

Recharge wells are used primarily in hydrogeologic conditions in which the water table is deep, with a number of impeding layers in the vadose zone; where insufficient land is available (e.g. in urban areas) for spreading methods; and where clear (sediment free) water is available as a recharge source.

Recharge wells are constructed using techniques commonly employed by water well contractors. The cable tool technique is desirable over rotary methods because drillers mud is not used. Mud tends to clog formations and unless the well is thoroughly developed after construction, the yield (and intake) characteristics of the well will be impaired. In addition, the cable tool method facilitates sampling for drill cuttings, used in grain-size analyses. Particular attention should be paid to the completion of wells intended for recharge; perhaps more so than for production wells because of the tendency of recharge wells to clog. Completion may involve intensive surging and bailing, followed by pumping. The goal of these techniques is to develop a natural gravel pack around the perforations. Alternatively, for wells constructed by rotary methods, an artificial gravel pack is installed around the perforations.

Although wells are frequently constructed specifically for recharge purposes, an economical procedure is to use wells for both recharge and pumping, i.e., dual-purpose wells. Osborne (1969) reasoned that information on the intake characteristics of a pumping well could be obtained from the theoretical specific yield of the well. In other words, he assumed that well and formation losses were the same for both pumping and recharge in

a well. To test his hypothesis, he conducted a series of step drawdown tests by pumping an experimental well. These tests were followed by a parallel series of step intake tests by recharging the well. Using data from these tests he then determined the coefficients B, C and n in the Rorabaugh equation:

$$S_W = BQ + CQ^n \qquad (7)$$

Where S_W = drawdown in a pumping well, or rise in a recharge well

B = the aquifer loss coefficient

C = well-loss coefficient

n = an empirical constant

Q = discharge rate

This equation may be manipulated into the form:

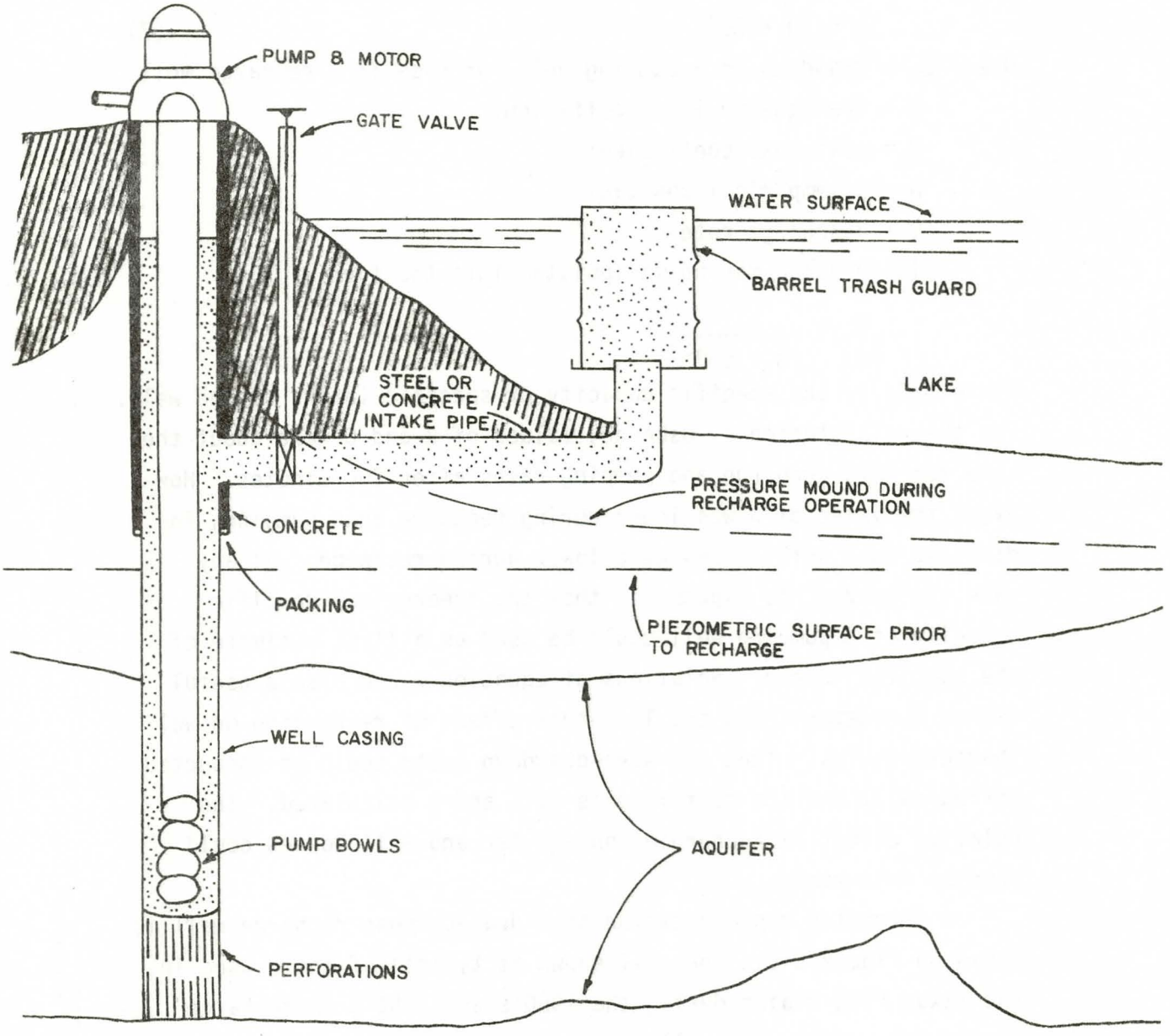
$$\frac{Q}{S_W} = \frac{1}{(B + CQ^{n-1})}$$

Where Q/S_W is the specific capacity or specific intake of the well. For the well studied by Osborne, values of B and C were about the same for both recharge and pumping cases after 200 minutes. However, the value of n was lower during recharge than pumping, indicating that well losses were lower during recharge. At any rate, he proved his hypothesis that the theoretical specific capacity of a pumping well could be used as a first estimate of the specific intake. Solutions of equation 7 are also a useful method for determining the long-term effect of recharging on well characteristics. That is, step-drawdown tests could be conducted periodically and the coefficients B, C and n calculated. The relative effect of recharging on aquifer and well losses could thus be determined.

A schematic representation of a dual-purpose recharge well is shown on Figure A-6. The well shown is typical of those used in the Texas High Plains during the 1950's and 1960's to recharge Playa Lake water. The well contains a turbine pump, which facilitates redevelopment after recharge. The upper portion of the well is grout encased to prevent caving. A screen is located at the inlet pipe, to reduce sediment from the playa lake water.

Figure A-6. TEXAS HIGH PLAINS DISTRICT TYPE RECHARGE WELL

(After American Society of Civil Engineers, 1961)



Also, a gate valve is installed in the line for flow control. Brown and Signor (1973) reported on the results of operations using such wells for replenishing the Ogallala Formation. They found that recharging playa lake water seriously impaired the life of the wells, because of the entrained sediment.

A cross-section of a dual-purpose well used for experimental purposes by the Water Resources Research Center of the University of Arizona, is shown on Figure A-7. The well is 20-inch diameter, 150 feet deep. Perforations, consisting of premilled slots, were installed in two locations: in the vadose zone, from 20 to 40 feet, and below the water table from 80 to 130 feet. The upper perforated region is separated from the lower region by a liner and packer assembly, i.e., the upper region is essentially a shaft. Inlet pipes are provided in the annulus between the pump column and liner, for recharging the water table (water free falls); in the annular region between the well casing and liner, for recharging the upper perforated region; and in the pump discharge pipe, for recharging through the pump column. A three-stage turbine pump was installed for determining the hydraulic characteristics of the aquifer; for conducting step-drawdown tests to determine well and aquifer loss coefficients in the Rorabaugh equation; and for redevelopment. Accessory equipment included a flow meter in the supply line, a flow meter in the discharge line; control valves; and bleed-off lines to an instrument shelter to provide water samples for chemical analyses. The well was constructed by the cable tool method. Completion included surging and bailing and pumping.

Problems of Well Recharge

Principal factors moderating intake rates in recharge wells include the following: 1) sediment, 2) microbial slimes, 3) air, 4) chemical reactions, and 5) physical reactions.

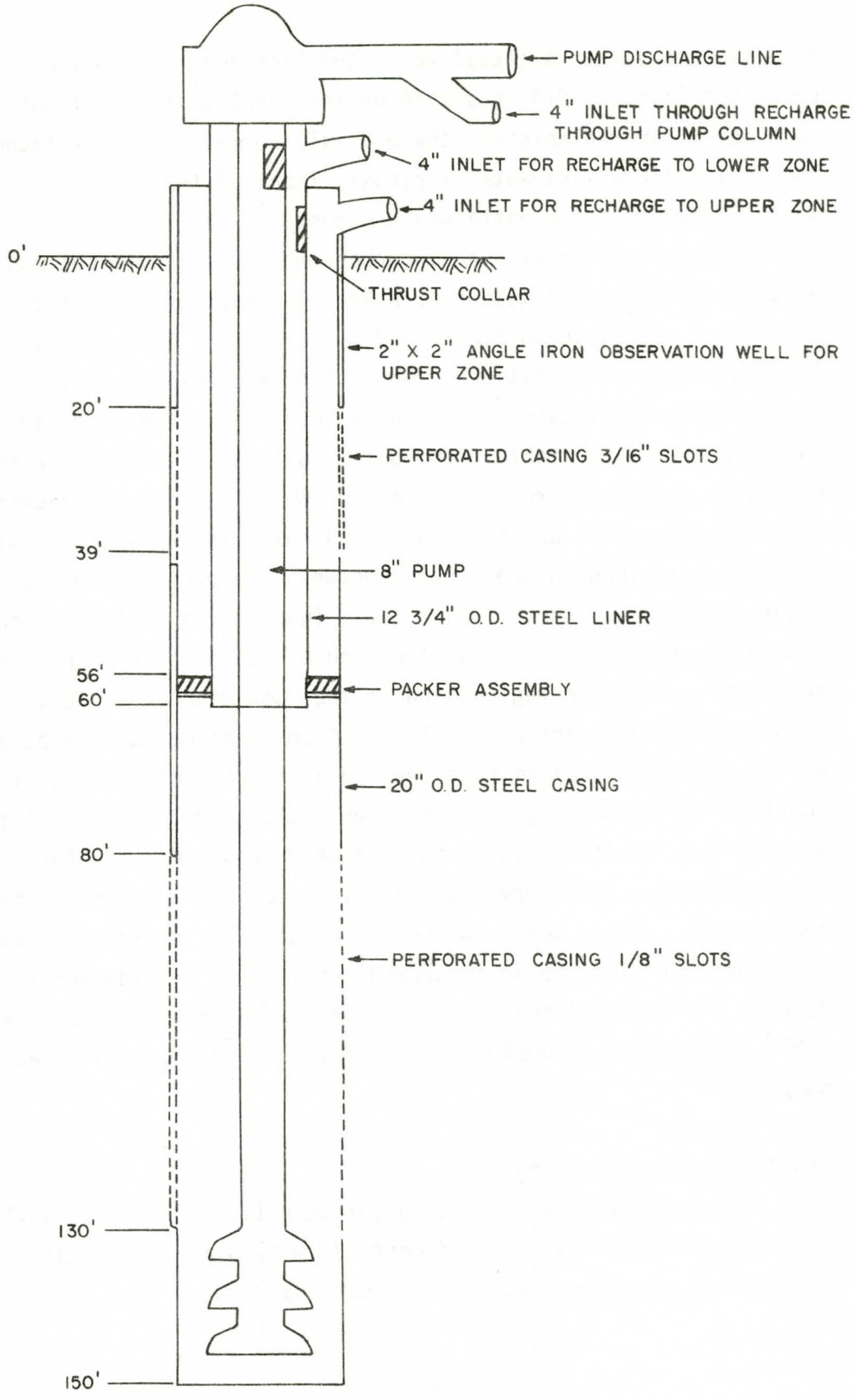


Figure A-7. Cross-section Recharge Well R-1.

Sediment

Entrained sediment, even in extremely low concentrations, may eventually clog the gravel pack and aquifer in the vicinity of well perforations. Intake rates decrease concomitantly with clogging. To prevent sedimentation it may be necessary to filter the recharge water or flocculate with polyelectrolytes. Rebhun and Hauser (1967) used anionic, cationic and neutral polyelectrolytes to reduce sediment in recharge water, as discussed above. In field trials using cationic polyelectrolytes, Rebhun and Hauser found a 90% reduction in turdibity in water originally containing 200 mg/l sediment. Even with this reduced sediment load the well gradually clogged. Redevelopment by bailing recovered the original intake rate.

Reduction in clogging due to sedimentation may be effected by bailing, as described above, or by pumping. To ensure that pumping will be effective it is probably advisable to recharge at a rate less than the potential yield of the well, for example, 80%. A recommended practice during a well recharge operation is to pump the well for an hour each day to remove sediment, and for several hours once each week. For extensive plugging it may be necessary to pull the pump and redevelop the well by surging and bailing, followed by step-drawdown pumping cycles.

Microbial Slimes

During recharge of a source containing even a small loading of organic matter, an organic mat may develop within the gravel filter near the well casing. This substrata leads to the activity of microorganisms, which in turn produce slimes that clog the formation. Chlorinating the recharge water may reduce the effect of microorganisms, but unfortunately may also produce chlorinated hydrocarbons.

Air Binding

A major problem with recharge well operation is that air

entrained with the water tends to clog the aquifer formation. This effect is called air binding. Consequently it is not generally recommended that water be permitted to free fall into a recharge well. Also a siphon should be avoided because of the danger of air bubble formation and subsequent aquifer clogging. Generally, these problems are avoided by ensuring that water pressure remain above atmospheric, for example, by installing a conductor pipe with a foot valve. Alternatively, water may be introduced through the pump column, provided the pump contains a non-reverse ratchet. Percious and Osborne (Private communication) found that even this technique did not prevent the formation of a siphon in a recharge well near Tucson (see Figure A-7). Brown, et al. (1978) presented a detailed design of a foot valve used in their tests in Texas.

Another precaution which should be taken to avoid air binding is to ensure that too great a difference in temperature does not exist between recharge water and native ground water. For example, if recharge water is much colder than ground water, air will come out of solution in the recharge source as its temperature is elevated. The resultant bubbles could clog the formation.

Chemical Reactions

According to Warner and Doty (1967), possible reactions between recharge water and native ground water leading to aquifer plugging include:

1. Precipitation of alkaline-earth metals such as calcium, barium, strontium, and magnesium, as relatively insoluble carbonates, orthophosphates, sulfates, fluorides, and hydroxides;
2. Precipitation of metals such as iron, aluminum, manganese, chromium, zinc, and cadmium, as insoluble carbonates, bicarbonates, hydroxides, orthophosphates, and sulfides;
3. Precipitation of oxidation-reduction reaction products.

Of these reactions, precipitation of calcium and magnesium carbonate, and iron compounds appear to be the most likely reaction products (ibid.). Warner and Doty presented a technique for estimating the stability of a mixture of recharge water and native ground water with respect to carbonate equilibrium.

A possible technique for avoiding chemical reactions is to pretreat the recharge source, e.g. by pH adjustment. Alternatively, a zone of non-reactive water could be recharged between the recharge water and native ground water.

Dispersion of clays within an aquifer may occur during recharge depending on factors such as those discussed above for spreading operations, namely: adj SAR of the water source, total salt content, and ESP of the exchange complex.

Physical Effects

Prolonged recharge may result in a rearrangement of particles within an aquifer, such that flow rates during both recharge and pumping are reduced. The problem would be particularly troublesome if recharge rates exceed pumping rates or if excessive recharge heads are applied. In these cases pumping may not provide sufficient energy head, compared to the head developed during recharge, to adequately redevelop the well.

If extensive redevelopment is required to sustain intake rate of a well a substantial amount of sand could be removed from the aquifer, creating a cavity. The overlying strata could eventually collapse into this cavity, causing extensive surface damage.

RECHARGE SHAFTS

A recharge shaft comprises a bore hole constructed through flow-impeding layers into permeable sediments above the water table. Shafts are sometimes referred to as "dry wells". Depending on the nature of the sediments in which the bore hole is excavated, shafts may be open or gravel filled, and cased or uncased. Signor, et al. (1968) list the following advantages of shafts over wells: "1)...less biological pollution hazard of the aquifer, 2) less chance of aquifer damage by sediments, and 3) less costly." Skodje (1969) also suggests that shafts might experience fewer problems associated with air binding than conventional recharge wells. The principal disadvantage of shafts is that once they

become plugged by sediment or microorganisms, redevelopment may be an expensive and difficult process. In contrast, recharge wells are readily developed by pumping.

Shafts have been used in operations in which recharge is the specific objective. Alternatively, shafts have been used primarily for drainage purposes. Pettyjohn (1968) reported on the use of a system of shafts or "hydraulic connectors" to recharge Souris River water at a site near Minot, North Dakota. The shafts are used to bypass a sandy clay aquiclude overlying a sand and gravel aquifer. The recharge facility comprises a pumping plant, pipe line, sedimentation pond and canal system. Thirty-six shafts were originally installed in the center line of the canals, followed later by an additional four units. The original units were 30 inches in diameter and varied in depth from 28 feet to 32 feet. The four additional units were 12 feet in diameter and 26 feet deep. A 72 inch diameter perforated culvert was placed in the larger cavity and washed gravel was placed inside the culvert and in the annulus between the culvert and wall of the bore hole. The combined 40 units permitted a maximum recharge rate of 4½ million gallons per day.

Signor, et al.(1968) reported on a recharge test using shafts constructed in and near a 110 acre playa lake at Bushland, Texas. The purpose of the test was to recharge the Ogallala formation by flood water collected in the lake. At the site the Ogallala formation is about 40 to 50 feet below land surface, overlain in some areas by a caprock of limestone. The depth to ground water was 156 feet. Three shafts were dug by bucket auger to 96 feet, within dry sediments of the Ogallala formation. Diameter of the shafts varied from 30 to 36 inches in diameter. Two of the shafts were partially backfilled with pea gravel. A gravel filter was not placed within the third shaft. During preliminary tests it was found that the intake rate in the unit without a gravel pack was about twice that in the other two units. The third unit was modified by excavating a cavity at the base of the hole. As a result of the cavity intake rates were subsequently increased

by 358%.

Shafts were employed by the city at Fresno, California, for disposal of storm water (Carozzo, Private communication). The original units were gravel packed. These units were not satisfactory because they became clogged with silt, leaves and debris. Subsequent units included a central, sedimentation sump. Overflow from the sump was piped to two drainage wells. The wells were lined with curved concrete block, containing seepage holes. Maximum depth of the wells was 50 feet.

Shafts are used extensively in the Phoenix area for disposal of stormwater runoff from parking lots, parks, hospital grounds, and residential developments. The most common design is the "MaxWell", introduced by the McGuckin Drilling, Inc. Two types of MaxWells are used. The type I unit shown on Figure A-8 consists of a fully lined combined catch basin and dry well. The upper catch basin is separated from the lower shaft by a concrete partition. An overflow pipe connects the upper and lower regions. The pipe contains a trash guard. The precast cement liner contains openings at the base of the settling chamber, and throughout the shaft region. The capacity of the settling/holding chamber is such that with a 0.5 cfs inflow the theoretical settling time is five minutes before water enters the dry well. The upper section of the unit comprises a man hole cover, covered with a metal grate.

The type II MaxWell is similar to the type I design except that only the sedimentation chamber is lined. The lower section is entirely backfilled with gravel. The connector pipe is joined to a length of perforated pipe which extends to the base of the shaft.

The bore holes for the MaxWells are constructed by a bucket auger. A four foot diameter cavity is first constructed and later reamed to six feet. The hole is excavated in depth until a section of clay free, permeable sands, gravel or cobbles is encountered. Generally the cavity is continued until at least five feet of permeable materials are encountered. The overall depth of the shafts may be as great as 130 feet, although most units are less than 85 feet.

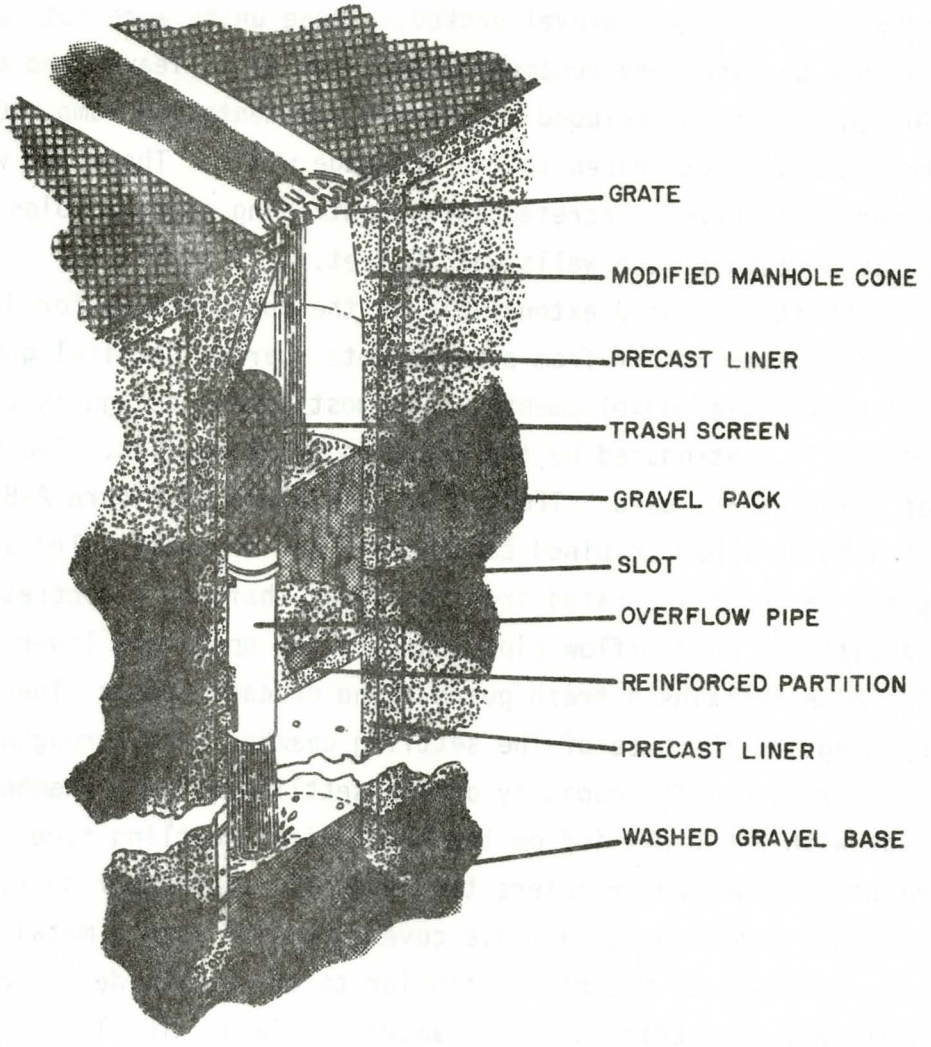


FIGURE A-8. TYPE I FULLY-LINED "MAXWELL" DRY WELL.

After emplacing the four foot inside diameter liner assembly, the annulus between liner and bore hole is backfilled with washed gravel.

Over 700 MaxWells are currently in operation in the Phoenix area (McGuckin, Personal communication). Apparently the units are operating successfully, although the potential for clogging of sediment is recognized.

Three recharge tests were conducted on the shaft component of the dual recharge well shown on Figure A-7. A general objective of the test was to examine the role of shafts for intermittant recharge of urban runoff in the Tucson area. Particular objectives were, 1) to determine head losses in the shaft during recharge, and 2) to examine changes in microbial concentrations during percolation of recharge water through unsaturated sediments above the water table. The water source was virtually free of sediment. Duration of each of the tests was three hours, seven hours and 31 hours. Flow rates varied from 193 to 200 gpm. Differences in chloride between effluent and ground water aided in detecting mixing. Water samples from nearby shallow wells were examined for chloride and the presence of E. Coli. Chloride concentrations changed in water samples from the shallow wells, indicating that recharge effluent had arrived at the water table. E. Coli were not present in any of the well water samples.

Problems of Shaft Recharge

The basic difficulties in the operation of a recharge shaft are the same as those for a recharge well, i.e., clogging of shaft perforations or gravel filter due to sediment, microorganisms, and air. Sediment levels could be reduced by using flocculants in conjunction with settling ponds. Chlorination of recharge water would moderate the effects of microorganisms. The use of a conductor pipe with foot valve could reduce air entrainment in the source.

As pointed out above, recharge shafts are difficult to redevelop once they have become clogged. For a recharge well,

redevelopment entails reversing the flow direction by pumping, thus carrying clogging substances into the well and back to the surface. Inasmuch as shafts terminate above the water table, water cannot be drawn in from aquifer to aid in redevelopment. An alternative approach employed on recharge shafts at the Leaky Acres Project near Fresno, comprises backflushing water through a gravel pack surrounding a conductor pipe (McCormick, 1975). By imposing on-off cycles on a pump mounted within the conductor pipe the water within the gravel pack is surged. Water is then discharged from the pipe, carrying particulate matter to the surface. Recharge tests on one shaft following redevelopment showed a regenerated recharge rate that was nine percent greater than the original rate.

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APPENDIX B

A REVIEW OF INDIAN WATER RIGHTS RELATIVE TO ARTIFICIAL RECHARGE PROJECTS

by

Michael D. Bradley

APPENDIX B

A REVIEW OF INDIAN WATER RIGHTS RELATIVE TO ARTIFICIAL RECHARGE PROJECTS

by Michael D. Bradley

INTRODUCTION

The doctrine that Indians have a special type of "reserved water right" began in 1908, when the Supreme Court held in Winters vs. United States [207 U.S. 564 (1908)] that the creation of an Indian reservation in a western state also created a water right that would enable the Indians to live on and use the land of the reservation. In arid states with more land than water and more demand than supply, the Winters doctrine makes water a limiting factor on development and gives it an unusual importance. The Supreme Court also determined Indian water rights in the famous Arizona vs. California decision [373 U.S. 546 (1963)]. These and other decisions have cast Indian water rights into a confused and uncertain state. Indian water rights are as critical for Indian well-being and development now as land rights were in the late ninteenth century (Price and Weatherford, 1976, p. 101). The question is less who owns the water and more how can it best be used - that is - for the reservations with relatively few inhabitants or for the industrial metropolises of the Southwest.

INDIAN RIGHTS AND APPROPRIATION

A sharp contrast is evident between western water law and Indian water rights. Under the traditional doctrine of "prior appropriation," one may assert title to a specified quantity of water by making beneficial use of it. When confronted with a shortage, a senior appropriator can satisfy this right in full before a junior appropriator can obtain his share. This is a

harsh and pragmatic doctrine that firmly roots the idea of protecting present beneficial uses.

By contrast, Indian water rights depend upon future need instead of present use. In Winters this future right was first enunciated, and from this decision many of the ambiguities of Indian water rights stem. The Court barred non-Indians from interferring with the flow of the Milk River in Wyoming. Even though the treaty was silent as to water rights, the government's reservation of lands for the Indians implicitely carried with it a reservation of water needed to make the lands "adequate and valuable" for the inhabitants. These rights cannot be diminished by state laws. However, the court did not decide the precise standard for measuring the quantity of water reserved, and subsequent courts have not agreed on such a standard.

THE QUANTIFICATION ISSUE

The enormous implications of Winters and its potential for conflict between Indian and non-Indian users were highlighted when the issue was addressed again in Arizona vs. California. In Arizona, the claims to water of the Colorado River Indian tribes were measured by the irrigable acres doctrine. This means that the quantity of an Indian tribe's reserved water is measured by the reservation's practicably irrigable acres. However, doubt still exists as to whether the doctrine is a measure of all Indian reserved rights or whether it is limited to the five tribes named in Arizona. Uncertainty about dealing with future-oriented rights also pervades the quantification issue. But by far the most difficult question is the exact purpose of the reservation of land to which Indian water rights are tied. Was the intent of the federal reservation of Indian lands to create farmers of a nomadic people? A glance at the map of most reservations will show a variety of legitimate needs for water that could occur on any reservation - irrigation, dry land farming, stock grazing, industrial and minerals development (Nelson, 1977, p. 1).

Changes in purpose imply changed water demands. The irrigible acres doctrine works well for agricultural purposes, but many other purposes can be imagined. If the purpose in settling Indians on reservations was not limited to transforming Indians into agricultural people but to integrate them into the mainstream of American life by any appropriate and suitable use of the reservation land, the different standards for quantification most certainly apply (Maxfield et al, 1977, pp. 219-220). Alternative standards for quantifying Indian water rights include the "Reasonably Necessary" standard, the "Past Experience" standard, the "Variable Needs" standard, the "Highest and Best Use" standard, and the "All Water on the Reservation" standard (Wordlaw, 1975, pp. 379-381).

The above review illustrates the uncertainty as to how best to quantify Indian water rights. So far, one purpose has not been found sufficient for a uniformly applicable quantification standard. And the Indians themselves are divided and uncertain as to their own purposes and ultimate goals. Quantifying Indian water rights remains an important and controversial topic on the water resources planning agenda throughout the Southwest.

INDIAN WATER RIGHTS AND THE PROPOSED RECHARGE PROJECT

The only Indian reservation in the vicinity of the proposed recharge project area is the Salt River-Pima-Maricopa Indian Reservation located in Township two north, Range five east. The Tribe has potential federal water rights and actual state water rights. The potential federal rights stem from the Winters doctrine. Even in the absence of specific language detailing a specific water entitlement, the reservation of the land by the federal government was enough to imply a water right sufficient for "the purposes of the reservation." In theory, Indian reserved rights are not subject to the beneficial use and other requirements of the prior appropriation system (Veeder, 1965). Indians do not lose

their rights by non-use or by failure to occupy the land to which the water right is appurtenant.

In addition, the Salt River-Pima-Maricopa Indian Reservation was allotted a portion of the surface flows of the Salt River by the Kent Decree of 1910. A decree is a court judgment based upon a hearing and an examination of all the points in the issue, and determining the rights of all parties to the suit, according to equity and good conscience. The Kent Decree, handed down by the Arizona Territorial District Court, divides water among all users in the Salt River Valley and grants the Salt River Reservation 700 miner's inches of water to irrigate approximately 2,500 acres of land (Kent Decree, 1910). The 700 miner's inches are equal to 13 cubic feet per second.

The proposed demonstration recharge project deals with ground water, a resource with a different and more confusing legal character. In Arizona, ground-water rights are not governed by the principle of prior appropriation, instead they are governed by the principles of ownership by the overlying landowner and reasonable use. For project purposes, Indian rights to ground water should be considered the same as surface water; that is, an unquantified Winters doctrine sufficient for an unspecified purpose of the reservation and an overlying owners right to the water that oozes, seeps, and percolates in the soil. Although a recharge project should increase available ground water in the short-run, the increase will eventually be available for use creating future conflicts. Indian water rights must be considered by all well-planned water development projects in the arid Southwest.

In summary, Indian water rights are reserved to Indian lands for future uses and in unquantified amounts. The Salt River Reservation has such an implicit right, and a decreed right to 700 miner's inches (13 cubic feet per second) from the Salt River. Reservation rights have a special nature - that is - they are not lost by non-use, but developing the right requires capital investment rarely found at the local level. Indian water rights are of crucial

economic importance, but the nature and scope of these rights remain unclear and uncertain.

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APPENDIX C

LIST OF CONTACTS, INTERVIEWS AND COORDINATION

APPENDIX C

LIST OF CONTACTS, INTERVIEWS AND COORDINATION

INTRODUCTION

This appendix documents the principal contacts, interviews and coordination with representatives of various agencies, organizations and other institutions which took place throughout the study effort. Much of this activity was of an informal nature involving a combination of personal interviews, brief meetings and discussion sessions to acquire existing information, identify data deficiencies and determine general attitudes and interests. The following list indicates those individuals at various institutional levels who were contacted during the course of this study effort.

Federal Agencies

Agency/Department	Individual(s) Contacted	Date(s)
U.S. Bureau of Reclamation	Thomas Burbey	July 12-14, 1978
	Steven Magnussen	July 12-14, 1978
U.S. Fish and Wildlife Service	Susan Monroe	July 26, 1978
U.S. Geological Survey	Robert Laney	June 23, 1978
		July 12-14, 1978
	Herbert Schumann	June 23, 1978
U.S. Water Conservation Laboratory	Herman Bouwer	June 23, 1978

Indian Communities

Salt River-Pima-Maricopa Indian Community	Roger Evans	July 24-25, 1978
		July 27, 1978

State Agencies

Arizona Department of Health Services	Barry Abbott	June 23, 1978
	James Douthit	June 29, 1978
	Edwin Swanson	July 26, 1978
Arizona State Land Department	William Allen	July 24-29, 1978
	James Becker	July 18, 1978
	Dempsey Helms	July 18-19, 1978
	Charles Vergith	July 18-19, 1978
Arizona Water Commission	Phil Briggs	July 12-14, 1978
	Thomas Clark	July 12-14, 1978
Arizona State University Department of Geology Environmental Studies Center	Troy Pewe	July 12-14, 1978
	John Lounsbury	July 26, 1978
Groundwater Management Study Commission	Kathy Ferris	July 12-14, 1978
		July 18-19, 1978
	Frank Brophy	July 18-19, 1978
Office of Economic Planning and Development	Jackie Rich	July 12-14, 1978
State Environmental Planning Commission	Carol Sakato	July 26, 1978

Local Agencies

City of Mesa	Wayne Balmer	July 24-25, 1978
	Dean Sloan	July 24-25, 1978
City of Scottsdale	Ross Smith	July 24-25, 1978
City of Tempe	Larry Horner	July 24-25, 1978

Local Agencies, (continued)

Maricopa Association of Governments	Bill Hernandez	July 24-25, 1978
Maricopa County Assessors Office	Clerical Staff	July 18-19, 1978

Other Organizations, Institutions and Individuals

California Water Law Commission	Clerical Staff	July 25, 1978
League of Women Voters	Sue Lofgren	July 24, 1978
Maricopa Audubon Society	Robert Witzeman	July 18, 1978 July 26, 1978
Metropolitan Water District of Southern California	Victor Gleason	July 13, 1978
Private Consultant to Orange County Water District	Dwight Baier	July 13, 1978
Private Consultant to Corps 208 Program	Kenneth Schmidt	June 22, 1978 August 4, 1978
Salt River Project	Richard Juetten Gary Small Carl Sparks	July 18, 1978 July 12-14, 1978 July 12-14, 1978
Valley Forward Association	Board of Directors	July 27, 1978

APPENDIX D

MISCELLANEOUS ENVIRONMENTAL DATA

APPENDIX D

MISCELLANEOUS ENVIRONMENTAL DATA

Wildlife in Project Area

Invertebrates (200 orders, thousands of species)

Scorpions	Bees	Butterflies	Flies
Spiders	Wasps	Moths	Ants
Earwigs	Termites	Crickets	Beetles

Aquatic Invertebrates

Mayflies	Mosquitoes	Fresh water shrimp
Damselflies	Flatworms	Fresh water clams
Caddiceflies	Snails	

Vertebrates

Fish

Threadfin shad	Flathead Catfish	Warmouth
Northern Pike	Channel Catfish	Green Sunfish
Carp	Black Bullhead	Bluegill
Goldfish	Sailfin Molly	Redear Sunfish
Golden Shiner	Mexican Molly	Rock Bass
Red Shiner	Guppy	White Crappie
Beautiful Shiner	Mosquitofish	Black Crappie
Fathead Minnow	Yellow Bass	Walleye
Bigmouth Buffalo	Smallmouth Bass	Yellow Perch
Black Buffalo	Striped Bass	Rainbow Trout
Smallmouth Buffalo	Largemouth Bass	Little Colorado River Sucker

Reptiles and Amphibians

Couch's Spadefoot	Great Plains Toad	Leopard Frog
Colorado River Toad	Red-spotted Toad	Desert Tortoise
Woodhouse's Toad	Canyon Treefrog	Reticulate Gila Monster

Reptiles and Amphibians, (Continued)

Desert Banded Becko
Desert Iguana
Collared Lizard
Desert Spiny Lizard
Tree Lizard
Western Blind Snake
Red Racer
Regal Ringneck Snake
Sonora Gopher Snake
Arizona Glossy Snake
Western Long-nosed Snake
Common Kingsnake
Western Shovel-nosed Snake
Southwestern Lyre Snake
Desert Night Snake
Arizona Coral Snake
Western Diamondback Rattlesnake
Black-tailed Rattlesnake
Mohave Rattlesnake
Speckled Rattlesnake
Sonoran Sidewinder

Birds

Cooper's Hawk
Red-tailed Hawk
Zone-tailed Hawk
Harris' Hawk
Golden Eagle
Bald Eagle
Marsh Hawk
Sparrow Hawk
Gambel's Quail
Common Galli
American Coot
Killdeer
Common Snipe
Spotted Sandpiper
Least Sandpiper
American Avocet
Ring-billed Gull
White-winged Dove
Mourning Dove
Roadrunner
Common Screech Owl
Gay Phoebe
Great Horned Owl
Ferruginous Owl
Elf Owl
Poor-Will
Lesser Nighthawk
Vaux's Swift
White-throated Swift
Costa's Hummingbird
Gilded Flicker
Gila Woodpecker
Ladder-backed Woodpecker
Wied's Crested Flycatcher
Ash-throated Flycatcher
Eastern Phoebe
Black Phoebe
Gray Flycatcher
Hammond's Flycatcher
Traill's Flycatcher
Western Flycatcher
Western Wood Pewee
Olive-sided Flycatcher

Birds, (Continued)

Vermillion Flycatcher
Tree Swallow
Rough-winged Swallow
Purple Martin
Steller's Jay
Scrub Jay
Common Raven
Common Crow
Mountain Chickadee
Bridled Titmouse
White-breasted Nuthatch
Red-breasted Nuthatch
House Wren
Bewick's Wren
Cactus Wren
Long-billed Marsh Wren
Canyon Wren
Rock Wren
Mockingbird
Bendire's Thrasher
Curve-billed Thrasher
Crissal Thrasher
Sage Thrasher
Robin
Swainson's Thrush
Western Bluebird
Towsend's Solitaire
Blue-gray Gnatchatcher
Black-tailed Gnatcatcher
Ruby-crowned Kinglet
Water Pipit
Cedar Waxwing
Phainopepla
Logger Shrike
Starling
Hutton's Vireo
Bell's Vireo
Gray Vireo
Solitary Vireo
Warbling Vireo
Black and White Warbler
Orange-crowned Warbler
Nashville Warbler
Virginia's Warbler
Lucy's Warbler
Yellow Warbler
Audubon's Warbler
Black-throated Gray Warbler
Towsend's Warbler
Hermit Warbler
Northern Waterthrush
MacGilivray's Warbler
Common Yellowthroat
Yellow-breasted Chat
Wilson's Warbler
American Redstart
Western Meadowlark
Yellow-headed Blackbird
Redwinged Blackbird
Hooded Oriole
Bullock's Oriole
Rusty Blackbird
Brewer's Blackbird
Boat-tailed Grackle
Brown-headed Cowbird
Bronzed Cowbird
Western Tanager
Summer Tanager

Birds, (Continued)

Cardinal
Blue Grosbeak
Black-headed Grosbeak
Evening Grosbeak
House Finch
Pine Siskin
American Goldfinch
Lesser Goldfinch
Lawrence's Goldfinch
Green-tailed Towhee
Rufous-sided Towhee
Brown Towhee
Abert's Towhee
Vesper Sparrow
Black-throated Sparrow
Sage Sparrow
Oregon Junco
Chipping Sparrow
Brewer's Sparrow
White-crowned Sparrow
White-throated Sparrow
Lincoln's Sparrow
Swamp Sparrow
Song Sparrow

Mammals

Desert Shrew
California Leaf-nosed bat
Yuma Myotis
Cave Myotis
California Myotis
Western Pipistrelle
Big Brown Bat
Red Bat
Hoary Bat
Spotted Bat
Pallid Bat
Western Mastiff Bat
Black-tailed Jackrabbit
Desert Cottontail
Rock Squirrel
Harris' Antelope Squirrel
Round-tailed Ground Squirrel
Valley Pocket Gopher
Arizona Pocket Mouse
Desert Pocket Mouse
Long-tailed Pocket Mouse
Rock Pocket Mouse
Merriam's Kangaroo Rat
Desert Kangaroo Rat
Southern Grasshopper Mouse
Western Harvest Mouse
Cactus Mouse
Deer Mouse
White-throated Wood Rat
Coyote
Kit Fox
Gray Fox
Ringtail
Raccoon
Badger
Spotted Skunk
Striped Skunk
Mountain Lion
Bobcat
Javelina
Mule Deer

Archaeological Sites in Project Area

(Refer to Plate 4 for Location)

1) Description: 200 ft. diameter shard area on terrace north of Salt River
   Location: T1N, R5E, S4, SW 1/4, NW 1/4
   Classification: Sensitivity 1, Condition 2
   Comments: Recommended for excavation

2) Description: Village on flood plain of Salt River along terrace
   Location: T1N, R5E, S5, SW 1/4, SW 1/4
   Classification: Sensitivity 1, Condition 2
   Comments: Recommended for preservation

3) Description: Scattered shards on flood plain
   Location: T1N, R5E, S5, SW 1/4, SW 1/4
   Classification: Sensitivity 2, Condition 2
   Comments: Disturbed by erosion

4) Description: Minor site
   Location: T1N, R5E, S5, NW 1/4, SW 1/4
   Classification: Sensitivity 2, Condition 5

5) Description: Two compounds
   Location: T1N, R5E, S11, SE 1/4, NW 1/4
   Classification: Sensitivity 1, Condition 1

6) Description: Pima Wattle and daub house
   Location: T2N, R5E, S24, SW 1/4, SW 1/4 and S25, NW 1/4, NW 1/4
   Classification: Sensitivity 2, Condition 5

7) Description: Scattered shards on first bench north of Salt River
   Location: T2N, R5E, S26, NE 1/4, SW 1/4
   Classification: Sensitivity 2, Condition 2

8) Description: Shards on first bench
   Location: T2N, R5E, S26, NE 1/4, SW 1/4
   Classification: Sensitivity 2, Condition 2

Archaeological Sites (Continued)

9) Description: Shards immediately above Salt River, on lower bajada area
   Location: T2N, R5E, S26, SW 1/4, SW 1/4
   Classification: Sensitivity 1, Condition 2

10) Description: Village on first bench of the Salt River
   Location: T2N, R5E, S26, SW 1/4, NE 1/4
   Classification: Sensitivity 2, Condition 2

11) Description: Shard area on first bench of the Salt River
   Location: T2N, R5E, S26, NE 1/4, SW 1/4
   Classification: Sensitivity 2, Condition 5

12) Description: Shard area on lower bajada close to first bench
   Location: T2N, R5E, S26, SE 1/4, NW 1/4
   Classficiation: Sensitivity 2, Condition 2

13) Description: Two historic houses on lower bajada area
   Location: T2N, R5E, S26, SE 1/4, SE 1/4
   Classification: Sensitivity 2, Condition 1
   Comments: Testing recommended

14) Description: House
   Location: T2N, R5E, S26, NE 1/4, NE 1/4
   Classification: Sensitivity 2, Condition 1
   Comments: Excavation recommended

15) Description: Medium Hohokam Canal
   Location: T2N, R5E, S34, SW 1/4, NW 1/4 and S33, Center E 1/2
   Classification: Sensitivity 2, Condition 3

16) Description: Shard area
   Location: T2N, R5E, S34, NW 1/4, NE 1/4
   Classification: Sensitivity 1, Condition 2

17) Description: Shards and pit houses on first bench of Salt River
   Location: T2N, R6E, S21, SW 1/4, SE 1/4
   Classification: Sensitivity 2, Condition 1

18) Description: Shards and pit houses on first bench of Salt River
   Location: T2N, R6E, S21, NE 1/4, SW 1/4
   Classification: Sensitivity 2, Condition 1

Archaeological Sites (Continued)

19) Description: Shard area
Location: T2N, R6E, S27, SW 1/4, NW 1/4
Classification: Sensitivity 1, Condition 5

20) Description: Shard area
Location: T2N, R6E, S27, SW 1/4, NW 1/4
Classification: Sensitivity 2, Condition 5

21) Description: Shard area
Location: T2N, R6E, S27, NW 1/4, SW 1/4
Classification: Sensitivity 2, Condition 5

22) Description: Shard area
Location: T2N, R6E, S27, NW 1/4, SW 1/4
Classification: Sensitivity 1, Condition 2

23) Description: Shard area
Location: T2N, R6E, S28, NE 1/4, NW 1/4
Classification: Sensitivity 2, Condition 5

24) Description: Shard area
Location: T2N, R6E, S33, NE 1/4, NW 1/4
Classification: Sensitivity 1, Condition 2

Source: Professor Ditter, Arizona State University, Tempe, AZ.

APPENDIX C

LIST OF CONTACTS, INTERVIEWS AND COORDINATION

APPENDIX C

LIST OF CONTACTS, INTERVIEWS AND COORDINATION

INTRODUCTION

This appendix documents the principal contacts, interviews and coordination with representatives of various agencies, organizations and other institutions which took place throughout the study effort. Much of this activity was of an informal nature involving a combination of personal interviews, brief meetings and discussion sessions to acquire existing information, identify data deficiencies and determine general attitudes and interests. The following list indicates those individuals at various institutional levels who were contacted during the course of this study effort.

Federal Agencies

Agency/Department	Individual(s) Contacted	Date(s)
U.S. Bureau of Reclamation	Thomas Burbey	July 12-14, 1978
	Steven Magnussen	July 12-14, 1978
U.S. Fish and Wildlife Service	Susan Monroe	July 26, 1978
U.S. Geological Survey	Robert Laney	June 23, 1978
		July 12-14, 1978
	Herbert Schumann	June 23, 1978
U.S. Water Conservation Laboratory	Herman Bouwer	June 23, 1978

Indian Communities

Salt River-Pima-Maricopa Indian Community	Roger Evans	July 24-25, 1978
		July 27, 1978

State Agencies

Arizona Department of Health Services	Barry Abbott	June 23, 1978
	James Douthit	June 29, 1978
	Edwin Swanson	July 26, 1978
Arizona State Land Department	William Allen	July 24-29, 1978
	James Becker	July 18, 1978
	Dempsey Helms	July 18-19, 1978
	Charles Vergith	July 18-19, 1978
Arizona Water Commission	Phil Briggs	July 12-14, 1978
	Thomas Clark	July 12-14, 1978
Arizona State University Department of Geology Environmental Studies Center	Troy Pewe	July 12-14, 1978
	John Lounsbury	July 26, 1978
Groundwater Management Study Commission	Kathy Ferris	July 12-14, 1978
		July 18-19, 1978
	Frank Brophy	July 18-19, 1978
Office of Economic Planning and Development	Jackie Rich	July 12-14, 1978
State Environmental Planning Commission	Carol Sakato	July 26, 1978

Local Agencies

City of Mesa	Wayne Balmer	July 24-25, 1978
	Dean Sloan	July 24-25, 1978
City of Scottsdale	Ross Smith	July 24-25, 1978
City of Tempe	Larry Horner	July 24-25, 1978

Local Agencies, (continued)

Maricopa Association of Governments	Bill Hernandez	July 24-25, 1978
Maricopa County Assessors Office	Clerical Staff	July 18-19, 1978

Other Organizations, Institutions and Individuals

California Water Law Commission	Clerical Staff	July 25, 1978
League of Women Voters	Sue Lofgren	July 24, 1978
Maricopa Audubon Society	Robert Witzeman	July 18, 1978 July 26, 1978
Metropolitan Water District of Southern California	Victor Gleason	July 13, 1978
Private Consultant to Orange County Water District	Dwight Baier	July 13, 1978
Private Consultant to Corps 208 Program	Kenneth Schmidt	June 22, 1978 August 4, 1978
Salt River Project	Richard Juetten Gary Small Carl Sparks	July 18, 1978 July 12-14, 1978 July 12-14, 1978
Valley Forward Association	Board of Directors	July 27, 1978

APPENDIX D

MISCELLANEOUS ENVIRONMENTAL DATA

APPENDIX D

MISCELLANEOUS ENVIRONMENTAL DATA

Wildlife in Project Area

Invertebrates (200 orders, thousands of species)

Scorpions	Bees	Butterflies	Flies
Spiders	Wasps	Moths	Ants
Earwigs	Termites	Crickets	Beetles

Aquatic Invertebrates

Mayflies	Mosquitoes	Fresh water shrimp
Damselflies	Flatworms	Fresh water clams
Caddiceflies	Snails	

Vertebrates

Fish

Threadfin shad	Flathead Catfish	Warmouth
Northern Pike	Channel Catfish	Green Sunfish
Carp	Black Bullhead	Bluegill
Goldfish	Sailfin Molly	Redear Sunfish
Golden Shiner	Mexican Molly	Rock Bass
Red Shiner	Guppy	White Crappie
Beautiful Shiner	Mosquitofish	Black Crappie
Fathead Minnow	Yellow Bass	Walleye
Bigmouth Buffalo	Smallmouth Bass	Yellow Perch
Black Buffalo	Striped Bass	Rainbow Trout
Smallmouth Buffalo	Largemouth Bass	Little Colorado River Sucker

Reptiles and Amphibians

Couch's Spadefoot	Great Plains Toad	Leopard Frog
Colorado River Toad	Red-spotted Toad	Desert Tortoise
Woodhouse's Toad	Canyon Treefrog	Reticulate Gila Monster

Reptiles and Amphibians, (Continued)

Desert Banded Becko
Desert Iguana
Collared Lizard
Desert Spiny Lizard
Tree Lizard
Western Blind Snake
Red Racer
Regal Ringneck Snake
Sonora Gopher Snake
Arizona Glossy Snake
Western Long-nosed Snake
Common Kingsnake
Western Shovel-nosed Snake
Southwestern Lyre Snake
Desert Night Snake
Arizona Coral Snake
Western Diamondback Rattlesnake
Black-tailed Rattlesnake
Mohave Rattlesnake
Speckled Rattlesnake
Sonoran Sidewinder

Birds

Cooper's Hawk
Red-tailed Hawk
Zone-tailed Hawk
Harris' Hawk
Golden Eagle
Bald Eagle
Marsh Hawk
Sparrow Hawk
Gambel's Quail
Common Galli
American Coot
Killdeer
Common Snipe
Spotted Sandpiper
Least Sandpiper
American Avocet
Ring-billed Gull
White-winged Dove
Mourning Dove
Roadrunner
Common Screech Owl
Gay Phoebe
Great Horned Owl
Ferruginous Owl
Elf Owl
Poor-Will
Lesser Nighthawk
Vaux's Swift
White-throated Swift
Costa's Hummingbird
Gilded Flicker
Gila Woodpecker
Ladder-backed Woodpecker
Wied's Crested Flycatcher
Ash-throated Flycatcher
Eastern Phoebe
Black Phoebe
Gray Flycatcher
Hammond's Flycatcher
Traill's Flycatcher
Western Flycatcher
Western Wood Pewee
Olive-sided Flycatcher

Birds, (Continued)

Vermillion Flycatcher
Tree Swallow
Rough-winged Swallow
Purple Martin
Steller's Jay
Scrub Jay
Common Raven
Common Crow
Mountain Chickadee
Bridled Titmouse
White-breasted Nuthatch
Red-breasted Nuthatch
House Wren
Bewick's Wren
Cactus Wren
Long-billed Marsh Wren
Canyon Wren
Rock Wren
Mockingbird
Bendire's Thrasher
Curve-billed Thrasher
Crissal Thrasher
Sage Thrasher
Robin
Swainson's Thrush
Western Bluebird
Towsend's Solitaire
Blue-gray Gnatchatcher
Black-tailed Gnatcatcher
Ruby-crowned Kinglet
Water Pipit
Cedar Waxwing
Phainopepla
Logger Shrike
Starling
Hutton's Vireo
Bell's Vireo
Gray Vireo
Solitary Vireo
Warbling Vireo
Black and White Warbler
Orange-crowned Warbler
Nashville Warbler
Virginia's Warbler
Lucy's Warbler
Yellow Warbler
Audubon's Warbler
Black-throated Gray Warbler
Towsend's Warbler
Hermit Warbler
Northern Waterthrush
MacGilivray's Warbler
Common Yellowthroat
Yellow-breasted Chat
Wilson's Warbler
American Redstart
Western Meadowlark
Yellow-headed Blackbird
Redwinged Blackbird
Hooded Oriole
Bullock's Oriole
Rusty Blackbird
Brewer's Blackbird
Boat-tailed Grackle
Brown-headed Cowbird
Bronzed Cowbird
Western Tanager
Summer Tanager

Birds, (Continued)

Cardinal
Blue Grosbeak
Black-headed Grosbeak
Evening Grosbeak
House Finch
Pine Siskin
American Goldfinch
Lesser Goldfinch
Lawrence's Goldfinch
Green-tailed Towhee
Rufous-sided Towhee
Brown Towhee
Abert's Towhee
Vesper Sparrow
Black-throated Sparrow
Sage Sparrow
Oregon Junco
Chipping Sparrow
Brewer's Sparrow
White-crowned Sparrow
White-throated Sparrow
Lincoln's Sparrow
Swamp Sparrow
Song Sparrow

Mammals

Desert Shrew
California Leaf-nosed bat
Yuma Myotis
Cave Myotis
California Myotis
Western Pipistrelle
Big Brown Bat
Red Bat
Hoary Bat
Spotted Bat
Pallid Bat
Western Mastiff Bat
Black-tailed Jackrabbit
Desert Cottontail
Rock Squirrel
Harris' Antelope Squirrel
Round-tailed Ground Squirrel
Valley Pocket Gopher
Arizona Pocket Mouse
Desert Pocket Mouse
Long-tailed Pocket Mouse
Rock Pocket Mouse
Merriam's Kangaroo Rat
Desert Kangaroo Rat
Southern Grasshopper Mouse
Western Harvest Mouse
Cactus Mouse
Deer Mouse
White-throated Wood Rat
Coyote
Kit Fox
Gray Fox
Ringtail
Raccoon
Badger
Spotted Skunk
Striped Skunk
Mountain Lion
Bobcat
Javelina
Mule Deer

Archaeological Sites in Project Area

(Refer to Plate 4 for Location)

1) Description: 200 ft. diameter shard area on terrace north of Salt River
   Location: T1N, R5E, S4, SW 1/4, NW 1/4
   Classification: Sensitivity 1, Condition 2
   Comments: Recommended for excavation
2) Description: Village on flood plain of Salt River along terrace
   Location: T1N, R5E, S5, SW 1/4, SW 1/4
   Classification: Sensitivity 1, Condition 2
   Comments: Recommended for preservation
3) Description: Scattered shards on flood plain
   Location: T1N, R5E, S5, SW 1/4, SW 1/4
   Classification: Sensitivity 2, Condition 2
   Comments: Disturbed by erosion
4) Description: Minor site
   Location: T1N, R5E, S5, NW 1/4, SW 1/4
   Classification: Sensitivity 2, Condition 5
5) Description: Two compounds
   Location: T1N, R5E, S11, SE 1/4, NW 1/4
   Classification: Sensitivity 1, Condition 1
6) Description: Pima Wattle and daub house
   Location: T2N, R5E, S24, SW 1/4, SW 1/4 and S25, NW 1/4, NW 1/4
   Classification: Sensitivity 2, Condition 5
7) Description: Scattered shards on first bench north of Salt River
   Location: T2N, R5E, S26, NE 1/4, SW 1/4
   Classification: Sensitivity 2, Condition 2
8) Description: Shards on first bench
   Location: T2N, R5E, S26, NE 1/4, SW 1/4
   Classification: Sensitivity 2, Condition 2

Archaeological Sites (Continued)

9) Description: Shards immediately above Salt River, on lower bajada area
   Location: T2N, R5E, S26, SW 1/4, SW 1/4
   Classification: Sensitivity 1, Condition 2

10) Description: Village on first bench of the Salt River
   Location: T2N, R5E, S26, SW 1/4, NE 1/4
   Classification: Sensitivity 2, Condition 2

11) Description: Shard area on first bench of the Salt River
   Location: T2N, R5E, S26, NE 1/4, SW 1/4
   Classification: Sensitivity 2, Condition 5

12) Description: Shard area on lower bajada close to first bench
   Location: T2N, R5E, S26, SE 1/4, NW 1/4
   Classficiation: Sensitivity 2, Condition 2

13) Description: Two historic houses on lower bajada area
   Location: T2N, R5E, S26, SE 1/4, SE 1/4
   Classification: Sensitivity 2, Condition 1
   Comments: Testing recommended

14) Description: House
   Location: T2N, R5E, S26, NE 1/4, NE 1/4
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   Comments: Excavation recommended

15) Description: Medium Hohokam Canal
   Location: T2N, R5E, S34, SW 1/4, NW 1/4 and S33, Center E 1/2
   Classification: Sensitivity 2, Condition 3

16) Description: Shard area
   Location: T2N, R5E, S34, NW 1/4, NE 1/4
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17) Description: Shards and pit houses on first bench of Salt River
   Location: T2N, R6E, S21, SW 1/4, SE 1/4
   Classification: Sensitivity 2, Condition 1

18) Description: Shards and pit houses on first bench of Salt River
   Location: T2N, R6E, S21, NE 1/4, SW 1/4
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Archaeological Sites (Continued)

19) Description: Shard area
Location: T2N, R6E, S27, SW 1/4, NW 1/4
Classification: Sensitivity 1, Condition 5

20) Description: Shard area
Location: T2N, R6E, S27, SW 1/4, NW 1/4
Classification: Sensitivity 2, Condition 5

21) Description: Shard area
Location: T2N, R6E, S27, NW 1/4, SW 1/4
Classification: Sensitivity 2, Condition 5

22) Description: Shard area
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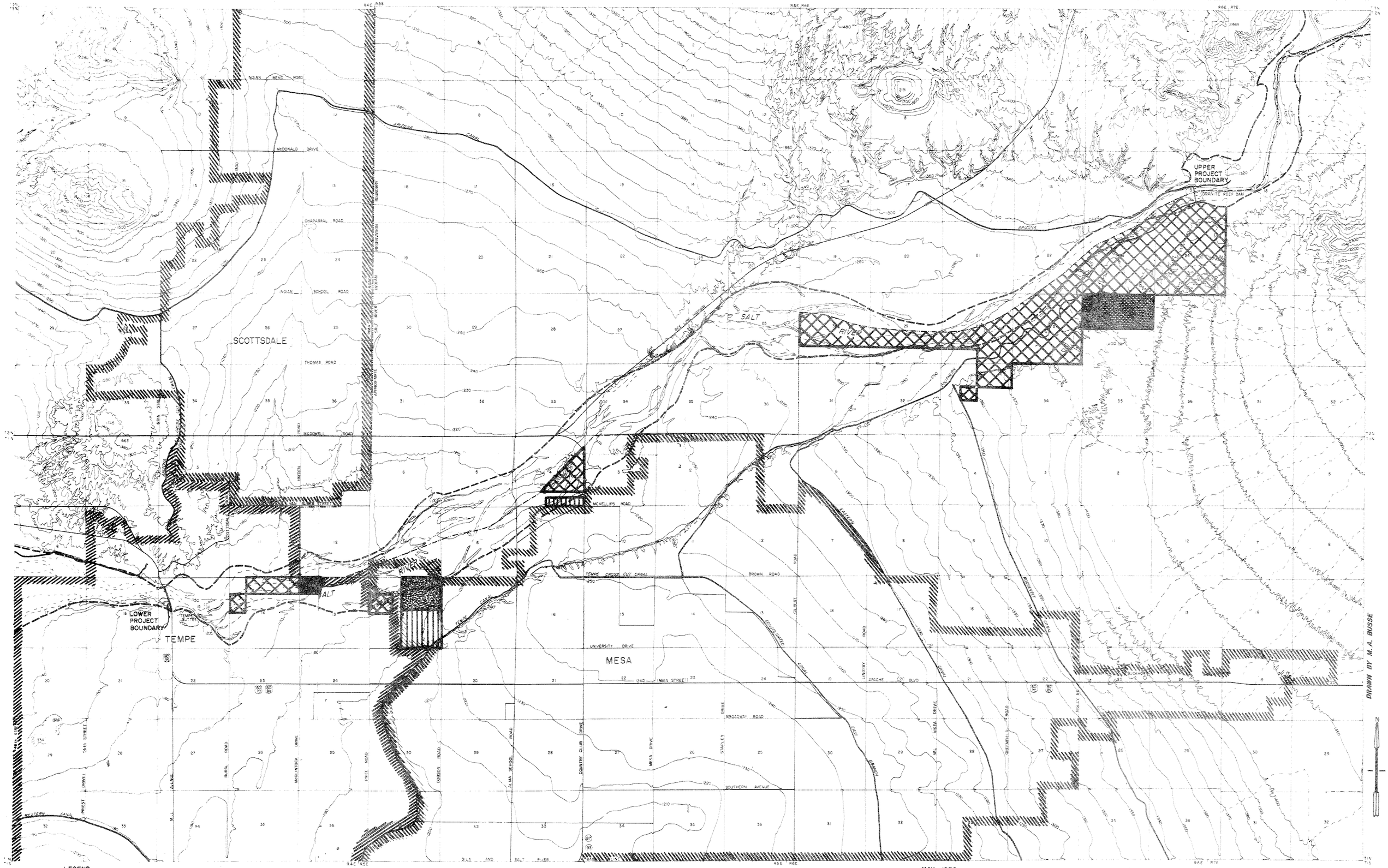
Classification: Sensitivity 1, Condition 2

23) Description: Shard area
Location: T2N, R6E, S28, NE 1/4, NW 1/4
Classification: Sensitivity 2, Condition 5

24) Description: Shard area
Location: T2N, R6E, S33, NE 1/4, NW 1/4
Classification: Sensitivity 1, Condition 2

Source: Professor Ditter, Arizona State University, Tempe, AZ.



LEGEND

- CORPORATE BOUNDARY
- PROJECT AREA AND FLOOD PLAIN BOUNDARY
- STATE SURFACE TRUST LANDS
- BLM - NATIONAL RESOURCES LANDS
- PRIVATE LAND, EXTENSIVELY SUBDIVIDED
- PRIVATE LAND

SOURCES: GENERAL HIGHWAY MAP, D.O.T. FROM STATE LAND DEPARTMENT
ASSESSOR'S MAPS, MARICOPA COUNTY

MAY, 1979

0 1 Kilometer
0 1 Mile

U.S. ARMY CORPS OF ENGINEERS, LOS ANGELES DISTRICT
PHOENIX URBAN STUDY

PLATE 5. INSTITUTIONAL BOUNDARIES AND LAND OWNERSHIP

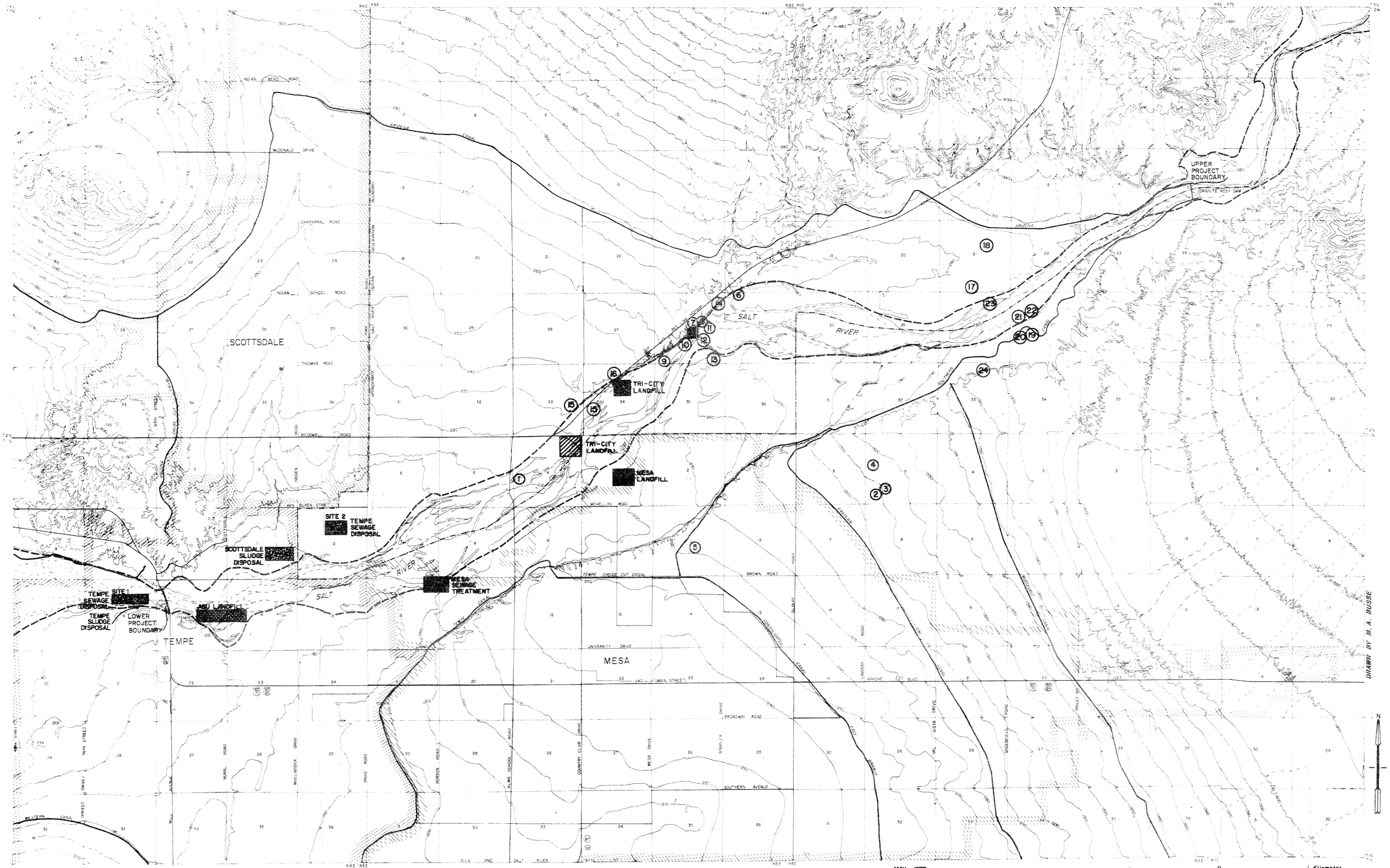


PLATE 4. ARCHAEOLOGICAL, SEWAGE DISPOSAL AND LANDFILL SITES.

U. S. ARMY CORPS OF ENGINEERS, LOS ANGELES DISTRICT
PHOENIX URBAN STUDY

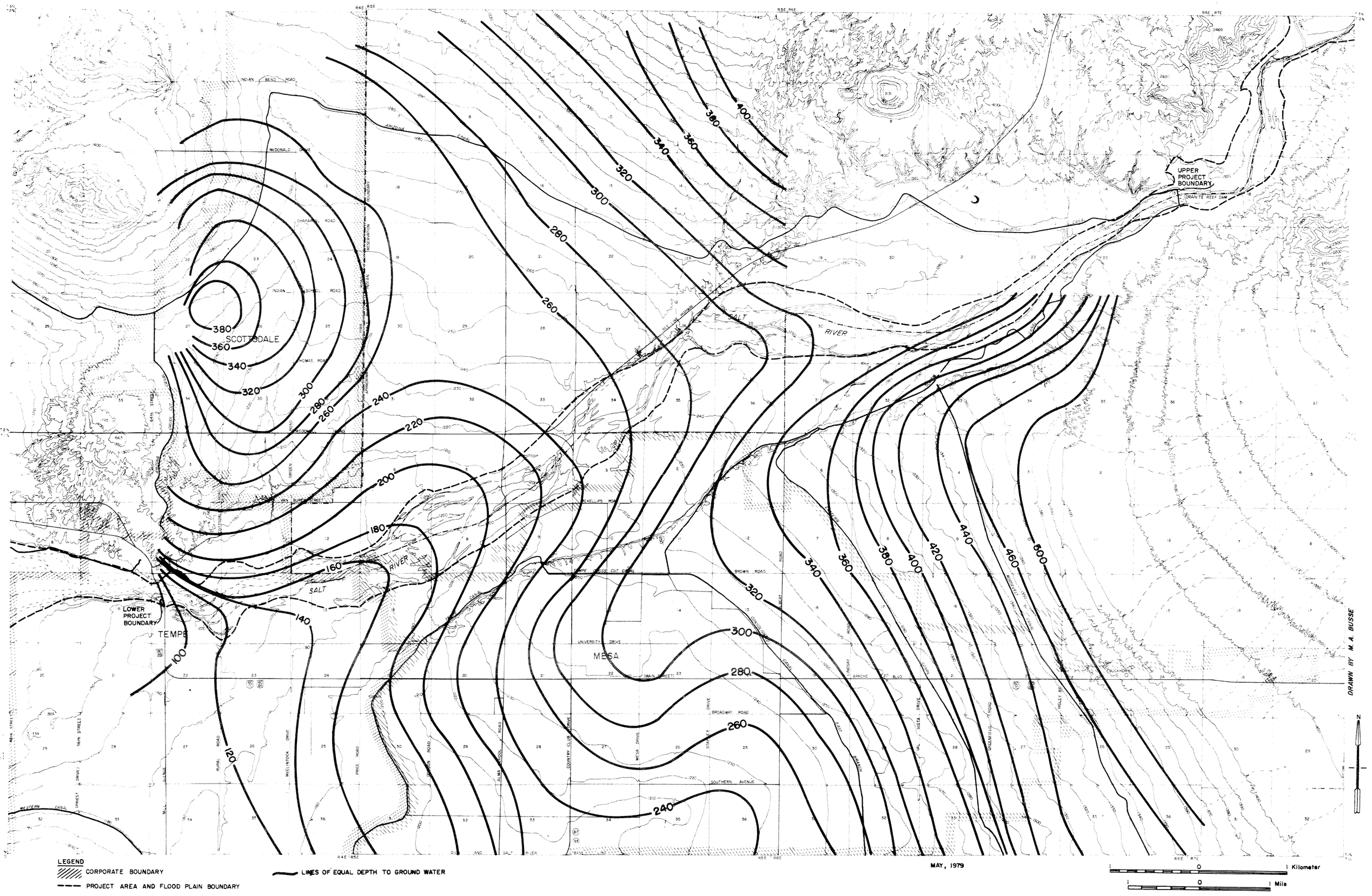
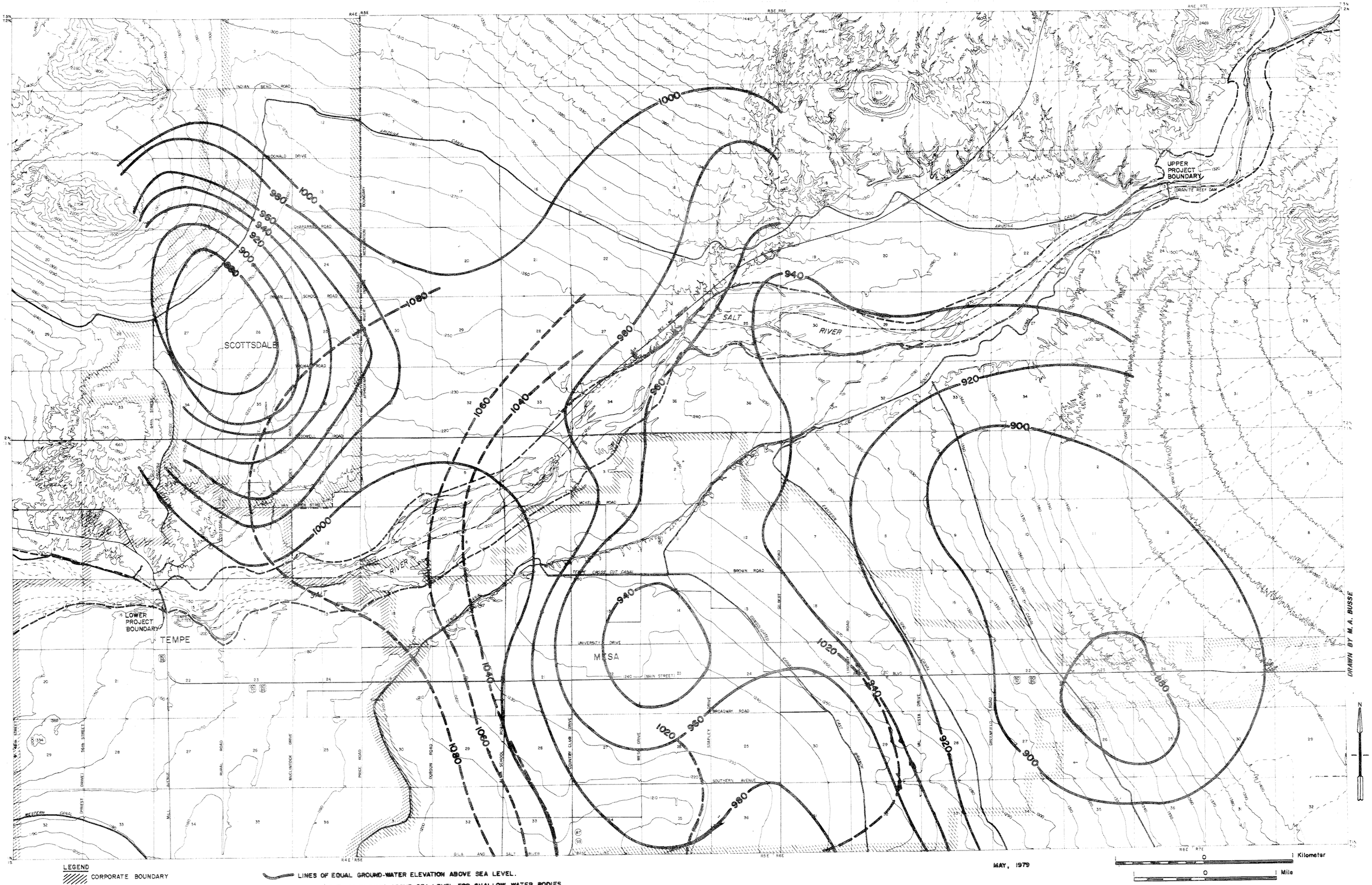


PLATE 3. GROUND WATER DEPTHS IN PROJECT AREA AND ENVIRONS, 1972.
AFTER U.S. BUREAU OF RECLAMATION, 1977

U.S. ARMY CORPS OF ENGINEERS, LOS ANGELES DISTRICT
PHOENIX URBAN STUDY



LEGEND

CORPORATE BOUNDARY

PROJECT AREA AND FLOOD PLAIN BOUNDARY

LINES OF EQUAL GROUND-WATER ELEVATION ABOVE SEA LEVEL.

WATER LEVEL ELEVATIONS ABOVE SEA LEVEL FOR SHALLOW WATER BODIES.

MAY, 1979

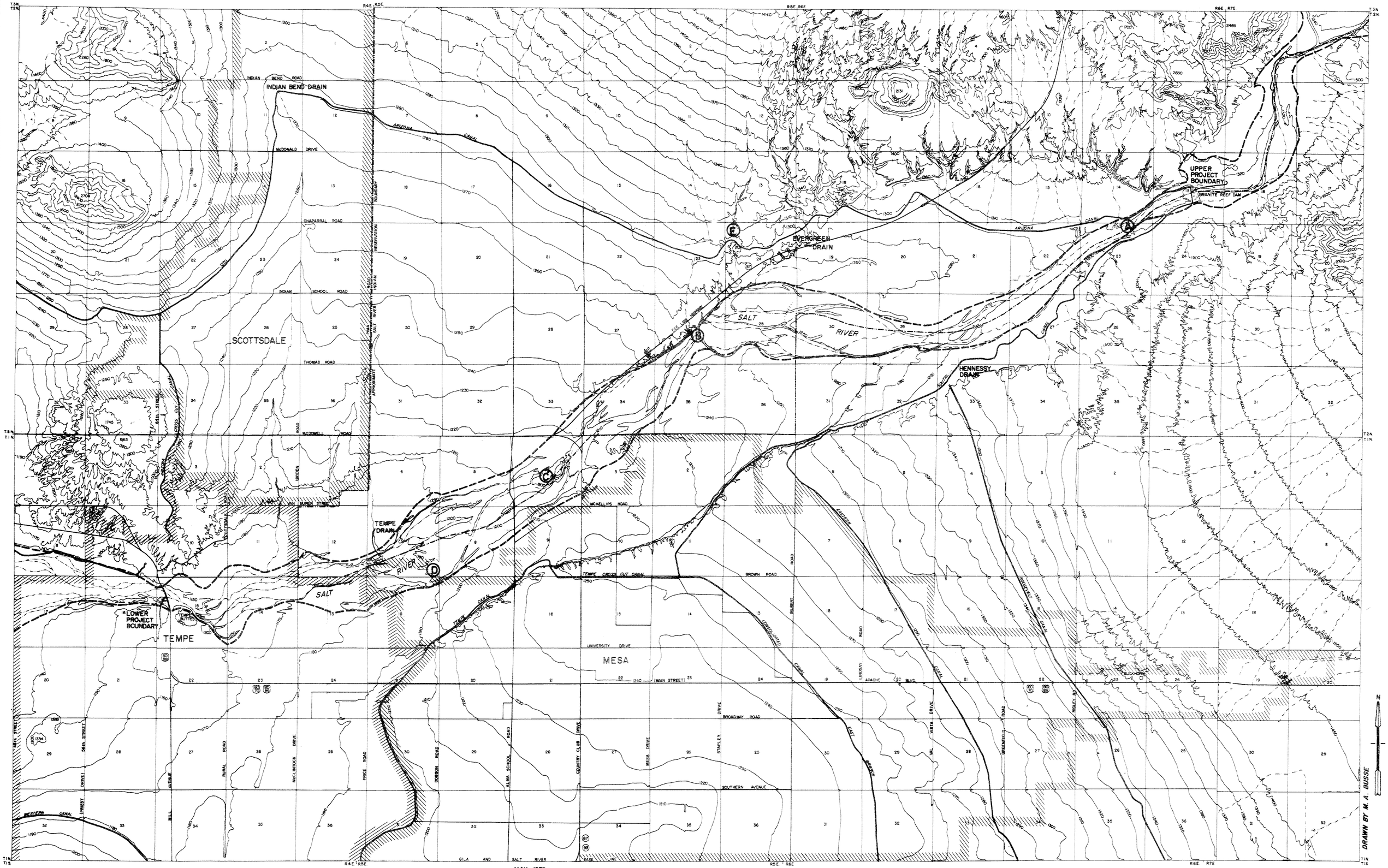
0 1 Kilometer

0 1 Mile

DRAWN BY M. A. BUSSE

PLATE 2. GROUND WATER ELEVATIONS IN PROJECT AREA AND ENVIRONS, 1972.
AFTER U. S. BUREAU OF RECLAMATION, 1977.

U.S. ARMY CORPS OF ENGINEERS, LOS ANGELES DISTRICT
PHOENIX URBAN STUDY



MAY, 1979

PLATE I. ALTERNATIVES FOR ARTIFICIAL RECHARGE SITES.

LEGEND

CORPORATE BOUNDARY

PROJECT AREA AND FLOOD PLAIN BOUNDARY

SITE LEGAL DESCRIPTION:
A- NW 1/4 NE 1/4 23, T2N, R6E
B- NW 1/4 SE 1/4 26, T2N, R5E
C- N 1/2 SW 1/4 and S 1/2 SE 1/4 4, T1N, R5E
D- SE 1/4 SE 1/4 7, T1N, R5E
E- NW 1/4 NW 1/4 24, T2N, R5E

Kilometer

Mile

U.S. ARMY CORPS OF ENGINEERS, LOS ANGELES DISTRICT
PHOENIX URBAN STUDY