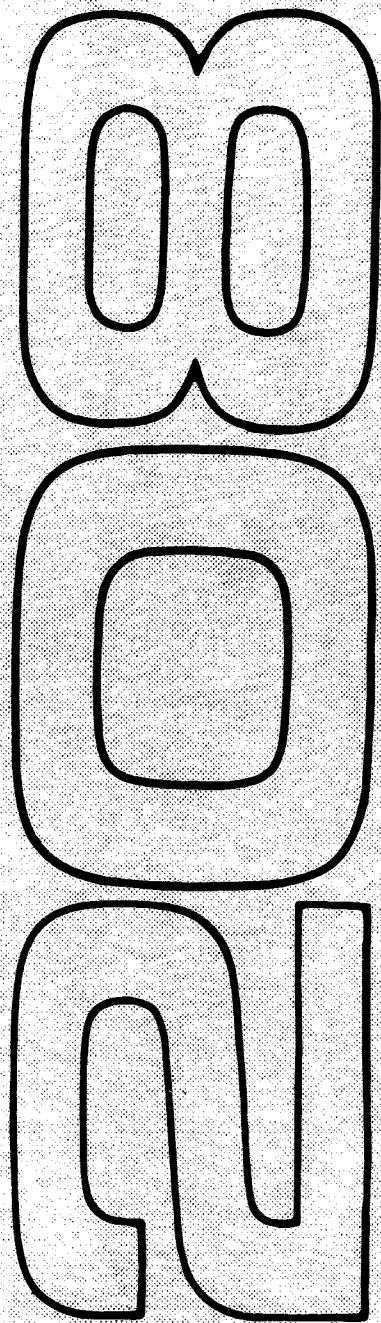


NONPOINT SOURCES
OF GROUNDWATER
POLLUTION

JUNE 1979



water
quality
management
program



MARICOPA ASSOCIATION OF GOVERNMENTS

NONPOINT SOURCES OF GROUNDWATER POLLUTION
IN THE MAJOR BASINS OF MARICOPA COUNTY
FINAL REPORT

MARICOPA ASSOCIATION OF GOVERNMENTS
208 PROGRAM

JUNE 1979

PREPARED BY

U.S. ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

MARICOPA COUNTY

MAG MEMBER AGENCIES

CONSULTANTS

Kenneth D. Schmidt,
Groundwater Quality Consultant

Boyle Engineering Corporation

TABLE OF CONTENTS

	<u>Page</u>
LIST OF TABLES	iii
LIST OF ILLUSTRATIONS	iv
SUMMARY AND CONCLUSIONS	v
CHAPTER I - INTRODUCTION	I-1
REFERENCE	I-2
CHAPTER II - REGULATORY ASPECTS	II-1
LOCAL AND STATE REGULATIONS	II-1
Individual Sewage Disposal Systems	II-1
Sewage Systems and Treatment Works	II-1
Landfills	II-1
Pesticides and Pesticide Containers	II-2
Hazardous Wastes	II-2
Radioactive Wastes	II-2
State Water Pollution Control	II-2
State Drinking Water Regulations	II-3
FEDERAL REGULATIONS	II-3
Water Pollution Control Act Amendments of 1972	II-3
Safe Drinking Water Act	II-3
Resources Conservation and Recovery Act	II-4
REFERENCES	II-5
CHAPTER III - POTENTIAL SOURCES OF POLLUTION	III-1
URBAN	III-1
Sewage Collection, Treatment and Disposal	III-1
Septic Tanks	III-4
Storm Runoff	III-6
Lawn Irrigation	III-8
Landfills	III-8
INDUSTRIAL	III-10
Phoenix Urban Area	III-10
Petroleum Refinery	III-11
Palo Verde Nuclear Generating Station	III-12
AGRICULTURAL	III-12
Irrigation	III-12
Feedlots and Dairies	III-14
Pesticide Wastes	III-15

TABLE OF CONTENTS (CONT.)

	<u>Page</u>
HYDROLOGIC MODIFICATIONS	III-16
NATURAL FACTORS	III-19
REFERENCES	III-20
CHAPTER IV - BASIN PROBLEM EVALUATION	IV-1
POTENTIAL SOURCES OF GROUNDWATER POLLUTION IN THE SALT RIVER VALLEY	IV-2
Municipal and Industrial	IV-2
Agricultural	IV-5
Hydrologic Modification	IV-6
EFFECT OF MAN'S ACTIVITIES IN THE SALT RIVER VALLEY	IV-7
East Basin	IV-7
West Basin	IV-8
THE AGUILA AREA	IV-9
LOWER HARQUAHALA VALLEY	IV-10
LOWER HASSAYAMPA AREA	IV-11
RAINBOW VALLEY	IV-12
GILA BEND BASIN	IV-13
AGUA CALIENTE - HYDER AREA	IV-14
REFERENCES	IV-14
CHAPTER V - PROPOSED CONTROL MEASURES	V-1
LANDFILLS	V-2
INDUSTRIAL WASTES	V-3
HYDROLOGIC MODIFICATIONS	V-3
REFERENCES	V-4
CHAPTER VI - PROPOSED MONITORING	VI-1
EXISTING KNOWLEDGE AND MONITORING	VI-1
Salt River Valley	VI-1
Other Groundwater Basins in Maricopa County	VI-3
RELATED ON-GOING PROGRAMS	VI-4
RECOMMENDED MONITORING	VI-4
Salt River Valley	VI-5
Other Groundwater Basins in Maricopa County	VI-10
IMPLEMENTATION ASPECTS	VI-13
REFERENCES	VI-13

LIST OF TABLES

<u>No.</u>	<u>Title</u>	<u>Page</u>
III-1	Chemical Analyses of Effluent from the 91st Avenue Sewage Treatment Plant	III-3
III-2	Trace Element Composition of Typical Sew- age Sludges	III-5
III-3	Chemical Composition of Urban Storm Runoff	III-7
III-4	Chemical Composition of Landfill Leachate	III-9

LIST OF ILLUSTRATIONS

Salt River Valley

<u>Plate No.</u>	<u>Title</u>
1	Municipal and Industrial Waste Disposal Facilities in 1978
2	Storm Runoff Disposal Facilities in 1978
3	Urban Lawn Irrigation in 1978
4	Agricultural Irrigation and Feedlots and Dairies in 1978

Other Basins

<u>Plate No.</u>	<u>Title</u>
5	Agricultural Irrigation and Other Potential Sources in the Aguila Area
6	Agricultural Irrigation in the Lower Harquahala Valley
7	Agricultural Irrigation and Other Potential Sources in the Lower Hassayampa Area
8	Agricultural Irrigation and Other Potential Sources in Rainbow Valley
9	Agricultural Irrigation and Other Potential Sources in Gila Bend Basin
10	Agricultural Irrigation in the Agua Caliente - Hyder Area

SUMMARY AND CONCLUSIONS

1. Nonpoint sources that can potentially impact groundwater quality in the major groundwater basins of Maricopa County have been delineated. These sources have been grouped into urban, industrial, agricultural, hydrologic modifications, and natural factors.
2. Municipal sources include sewage collection, treatment and disposal, septic tanks, storm runoff, lawn irrigation, and landfills. Agricultural sources include irrigation and feedlots and dairies.
3. Important hydrologic modifications include well construction, altered groundwater flow directions, and imported water.
4. Groundwater quality problems have been reviewed and the probable effect of man's activities has been assessed.
5. In most cases, there are inadequate data on which to base sound control measures. However, some control measures are discussed for landfills, industrial wastes, and hydrologic modifications.
6. Groundwater quality monitoring programs have been proposed to obtain information so that it can be determined if control measures are necessary, and if so, the nature of such control measures. Proposed monitoring has been grouped into hydrogeologic, regional groundwater quality, and site-specific. This monitoring requires a cooperative effort with local water-supply agencies and others presently conducting monitoring.

I INTRODUCTION

CHAPTER I

INTRODUCTION

This report has been prepared to assess nonpoint sources of groundwater pollution in Maricopa County. The assessment is being done in accordance with Section 208 of the Water Pollution Control Act Amendments of 1972 (Public Law 92-500). The U.S. Environmental Protection Agency has designated the Maricopa Association of Governments (MAG) as the agency responsible for 208 planning in Maricopa County. The U.S. Army Corps of Engineers, Los Angeles District, is conducting the Phoenix Urban Study, which involves numerous aspects of water resources. MAG contracted with the U.S. Army Corps of Engineers to complete the 208 planning for the Salt River Valley portion of the county as part of the Corps' Urban Study Program. For the remainder of the county, the Maricopa Association of Governments is performing the 208 study. This report was prepared by Kenneth D. Schmidt, Groundwater Quality Consultant, under sub-contract to Boyle Engineering Corporation, a contractor to the Maricopa Association of Governments and the U.S. Army Corps of Engineers. Boyle Engineering Corporation provided some information on potential sources of groundwater pollution in the Salt River Valley and prepared Plates 1-4. Bill Chase was project manager for the U.S. Army Corps of Engineers, and Mark Frank and Susan Mitchell were project coordinators for the Maricopa Association of Governments.

There is usually no surface water flow in the major groundwater basins of Maricopa County, except for short periods following heavy rainfall. However, there is often some flow along reaches of some river channels where sewage effluent, irrigation spills and tailwater, and drainage pumpage are disposed. Even where wastewaters are disposed to streams, a substantial percentage often becomes groundwater recharge due to seepage losses. As such, nonpoint source contributions are primarily to groundwater. Thus groundwater quality has been a major consideration in the Maricopa County 208 program. A previous report summarized groundwater quality in the major basins of the county (Schmidt, 1978). The basins include the Salt River Valley, the Aguila Area, the Lower Harquahala Area, the Lower Hassayampa Area, Rainbow Valley, the Gila Bend Basin, and the Agua Caliente-Hyder Area. The distribution of various constituents of importance to groundwater use was examined and problem areas delineated. Historical trends in quality were also determined in the Salt River Valley. The importance of both natural and man-made factors in influencing groundwater quality was established. All of this information provides necessary background material for this report.

In this report, regulatory aspects relevant to groundwater are first discussed. Potential nonpoint sources of groundwater pollution are then reviewed in a general manner. Next, the impacts of the major sources in each of the major basins are evaluated, as can be determined from present data. Lastly, control measures are proposed, where applicable, and a monitoring program is recommended. Substantial consideration is given in this report to natural factors that affect groundwater quality. Although problems due

to natural factors may not be considered "pollution" in the true sense, these factors exert an important influence on groundwater quality in the major basins of Maricopa County. A number of existing problems are due to these factors, and they are thus given careful consideration in terms of proposed monitoring.

REFERENCE

Schmidt, K.D., 1978, "Groundwater Quality in the Major Basins of Maricopa County", prepared for Los Angeles District, U.S. Army Corps of Engineers, Phoenix Urban Study and Maricopa Association of Governments, Maricopa County 208 program.



REGULATORY ASPECTS

CHAPTER II

REGULATORY ASPECTS

There are a number of local, state, and federal regulations that pertain to nonpoint sources and potential for groundwater pollution.

LOCAL AND STATE REGULATIONS

Individual Sewage Disposal Systems

Section 8 of Chapter II of the Maricopa County Health Code deals with individual sewage disposal systems. Under Regulation 4, part a, such systems are prohibited where groundwater or soils conditions are such that an individual sewage disposal system may cause pollution of the groundwater. Also, according to part h of Regulation 4, the effluent from such systems may not discharge onto the surface of the ground, into any water course, abandoned well, pit, mine, or similar excavation, or create a hazard to any potential or actual water supply or water supply system.

Arizona Revised Statutes 36-136.G.9 establish the authority for control of the disposal of septic tank pumpage by the Arizona Department of Health Services. Under regulations ACRR R9-8-1231, it is stipulated that all collected wastes of human excreta shall be disposed in accordance with recommendations of the local county health department. Disposal may be to a sanitary landfill.

Sewage Systems and Treatment Works

The Department of Health Services is authorized to make and enforce regulations concerning plans or specifications for construction, improvement, alteration, or operation of sewage systems and disposal plans for treatment of sewage (Arizona Revised Statutes 36-132.A.12). Regulations shall be prescribed by the Department with regard to sewage collection, treatment, disposal, and reclamation systems to prevent sewage contamination of surface or underground water. Regulations prohibit the discharge of sewage effluent into any well or into any crevice, sinkhole, or other opening, if such discharge could result in the pollution of groundwater (ACRR R9-8-331 through R9-8-332).

Landfills

Arizona Revised Statutes 36-136.G.10 establish the authority for refuse standards. Under regulations ACRR R9-8-432, sanitary landfills must be approved by the Arizona Department of Health Services, Bureau of Sanitation.

Landfills shall be located so that seepage will not create a health hazard, nuisance, or cause pollution of any watercourse or water-bearing strata. Also, adequate and proper surface drainage shall be provided to prevent ponding or erosion of the finished fill by rainwater.

Pesticides and Pesticide Containers

Pesticide control in Arizona is by the State Board of Pesticide Control through the Pesticide Use and Application Act, State of Arizona Revised (1974) Statutes. According to Section 3-387, it is "unlawful for any person to store, dump, or leave unattended any pesticide, or empty pesticide containers or parts thereof, at any place or under any condition where they may present a hazard to persons, animals, or crops".

Hazardous Wastes

The Department of Health Services, Bureau of Sanitation is presently formulating a state hazardous wastes plan. This plan will cover the generation and disposal of hazardous wastes. As part of this plan, the first approved disposal site in Arizona specifically for hazardous wastes is to be developed.

Radioactive Wastes

The Arizona Atomic Energy Commission has the power to provide standards for the disposal of radioactive materials into the air, water, and sewers, and burial in the soil. The standards must be in conformance with Code of Federal Regulations 10, part 20 (Arizona Office of Economic Planning and Development, 1977).

State Water Pollution Control

Arizona Revised Statutes 36-1856 establish the authority for water pollution control by the Arizona Department of Health Services, Bureau of Water Quality Control. ARS 36-1853 established a state water quality control council. ARS 36-1858 states that "it shall be unlawful for any person to discharge any wastes into the waters of the State and thereby reduce the quality of such waters below the water quality standards established therefor by the council in violation of an order issued pursuant to Section 36-1854". Although ARS 36-1851 defines "waters of the State" to include underground water, no standards have been established to date for groundwater quality.

State Drinking Water Regulations

The Arizona Department of Health Services, Bureau of Water Quality Control, has established drinking water regulations for the state pursuant to the Safe Drinking Water Act of 1974. These regulations apply to all water sold or distributed to the public, or used in the production, processing, storing, handling, serving, and transportation of food and drink. All public and semi-public water systems shall obtain water from an approved source or sources and shall be located, constructed, and operated in a manner to protect the water against entrance of any pollution, contamination, or unclean substance (Arizona Department of Health Services, 1978).

FEDERAL REGULATIONS

Water Pollution Control Act Amendments of 1972

Section 208 of Public Law 92-500 specifies that a 208 plan shall include a number of elements. Elements specifically related to groundwater include the following:

- 1) A process to identify agriculturally related nonpoint sources of pollution and to set forth procedures and methods to control, to the extent feasible, such sources.
- 2) A process to control the disposition of all residual waste generated which could affect water quality.
- 3) A process to control the disposal of pollutants on land or in sub-surface excavations to protect groundwater.

Safe Drinking Water Act

Two specific aspects of the Safe Drinking Water Act (SDWA) important in the evaluation of nonpoint sources are 1) the Underground Injection Control (UIC) Program, and 2) the Surface Impoundment Assessment (SIA).

The U.S. Environmental Protection Agency (EPA) is promulgating regulations for the control of injection wells. This type of disposal is of special concern because large portions of the vadose zone may be bypassed and pollutants disposed directly into the aquifer. Injection wells have been grouped into a number of categories, usually related to the source and character of the injected waste. Injection wells include "dry wells", which do not reach the water table, wells tapping the aquifer, and deep wells tapping formations far below the usable groundwater. Wells are used for disposal of storm runoff, cooling water, and industrial wastes in the Phoenix area.

Also pursuant to the SDWA, the Arizona Department of Health Services, Bureau of Sanitation is presently conducting an assessment of surface impoundments in the state. Pits, ponds, and lagoons are being located and their groundwater pollution potential assessed according to EPA guidelines (Silka and Swearington, 1978). This survey is to be completed by the end of 1979. The EPA (1978) defined a "surface impoundment" as follows:

"Either a natural topographic depression, artificial excavation, or dike arrangement with the following characteristics: 1) it is used primarily for storage, treatment, or disposal of wastes in the form of fluids; 2) it may be constructed above, below, or partially in the ground; 3) it may or may not have a permeable bottom and/or sides potentially allowing contamination of groundwater by infiltration of its contents".

Surface impoundments covered by the assessment are only those whose surface dimension is greater than the depth. Dry wells whose depth is greater than the surface dimension will be covered by the UIC regulations of the SDWA.

There are many surface impoundments which may be excluded from the assessment either because they are not deemed to be a problem or contain fluids only intermittently. The following may be excluded from the assessment:

- farm ponds
- product storage tanks
- ponds for sand and gravel operations
- swimming pools
- natural lakes and fresh water ponds
- furrow irrigated fields
- rice paddies
- irrigation tail water sumps
- sedimentation basins
- borrow pits
- stormwater basins
- domestic septic tank systems
- well drilling mud pits
- emergency pits

Resources Conservation and Recovery Act

The Resources Conservation and Recovery Act (RCRA) pertains to the disposal of solid wastes and contains provisions for landfills and hazardous wastes. An inventory of solid waste disposal sites is being conducted by the Arizona Department of Health Services, Bureau of Sanitation, under Section 405, Subtitle D. These sites will be classified according to EPA criteria into 1) sanitary landfills, and 2) open dumps.

According to RCRA, a "hazardous waste" means a solid waste, or combination of solid wastes, which, because of its quantity, concentration, or physical, chemical, or infectious characteristics, may 1) cause or significantly

contribute to an increase in mortality or and increase in serious irreversible or incapacitating reversible illness; or 2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed. The term "hazardous waste" includes liquids containing components in solution or suspension that, when reduced to solid form, would meet the definition of a hazardous waste. "Hazardous waste management" means the systematic control of the collection, sources, separation, storage, transportation, processing, treatment, recovery, and disposal of hazardous wastes.

Subtitle C of RCRA provides regulations for hazardous waste management. This subsection requires the EPA to develop and promulgate criteria for identifying the characteristics of hazardous wastes and a listing of existing hazardous wastes. The EPA shall also promulgate regulations establishing performance standards for owners and operators of facilities used for the treatment, storage, or disposal of hazardous wastes. In addition to operating standards, standards will also be promulgated for the location, design, and construction of hazardous waste treatment, disposal, or storage facilities.

There are three current EPA programs related to surface impoundments. Under Subtitle C of RCRA, the EPA will regulate facilities receiving hazardous wastes, including surface impoundments and landfills. Under Subtitle D of RCRA, the EPA is required to promulgate criteria for determining which waste disposal facilities should be classified as sanitary landfills and which should be classified as open dumps. The definition of "solid waste" and "disposal" in RCRA indicate that surface impoundments will be covered by these criteria (EPA, 1978). The EPA must publish an inventory of open dumps within one year of publication of the criteria. However, this requirement is virtually impossible to meet due to numerous factors, and the inventory will be phased in over the next few years.

The first year of the RCRA inventory is to focus on municipal solid waste landfills and sludge sites, which are not covered by the SIA. The SDWA assessment is to focus on surface impoundments (industrial, oil and gas, mining, municipal, and agricultural). In the second year, based upon the SIA, the RCRA inventory is to cover those industrial impoundments with high potential for groundwater contamination identified through the assessment. This inventory is to include industrial landfills. In later years, the inventory would cover agricultural and mining sites with emphasis on those impoundments identified as potential problems during the assessment program (EPA, 1978).

REFERENCES

Arizona Department of Health Services, 1978, "Drinking Water Regulations for the State of Arizona", Bureau of Water Quality Control, 39p.

Arizona Office of Economic Planning and Development, 1977, "Arizona's Role in Water Quality Management: State Agency Programs and Land and Water Resource Controls.

Silka, L.R., and T.L. Swearington, 1978, "A Manual for Evaluating Contamination Potential of Surface Impoundments", U.S. Environmental Protection Agency, Report EPA 570/9-78-003, 73p.

U.S. Environmental Protection Agency, 1978, "Guidance for the Conduct of the Surface Impoundment Assessment", SIA Technical Guidance #1, Office of Drinking Water, Ground Water Protection Branch, 27p.



POTENTIAL SOURCES OF POLLUTION

CHAPTER III

POTENTIAL SOURCES OF POLLUTION

Several documents prepared by the EPA (1973a, 1973b, and 1977a) deal with nonpoint sources. However, they are oriented toward surface water and the humid eastern U.S. Sources affecting groundwater are generally less well known and understood than those affecting surface water. However, there is abundant literature available documenting the potential pollutants in many types of wastes. Also there are numerous case histories of groundwater pollution from most sources in diverse hydrogeologic situations. Boyle Engineering Corporation (1977a) reported on agricultural practices and other nonpoint sources in the Salt River Valley. The Maricopa Association of Governments (1977a and b) reported on nonpoint sources in Maricopa County. Such data have been utilized to evaluate the potential sources of groundwater pollution in the major basins of Maricopa County. The sources have been grouped into 1) urban, 2) industrial, 3) agricultural, 4) hydrologic modifications, and 5) natural.

URBAN

Urban potential sources can be grouped into: 1) sewage collection, treatment and disposal, 2) septic tanks, 3) storm runoff, 4) lawn, garden, and park irrigation, and 5) landfills. Although sewage effluent has been previously termed a "point source" in the Maricopa County 208 program, several aspects of sewage collection, treatment, and disposal can be termed nonpoint sources in terms of potential impact on groundwater.

Sewage Collection, Treatment and Disposal

Potential sources of groundwater pollution associated with sewage include: 1) leaking sewers, 2) effluent disposal, 3) sludge disposal, and 4) seepage from storage facilities. Clark and Viessman (1965) discussed sewage treatment and disposal. Generally, the constituents in raw sewage and sewage effluent from different treatment processes are well known. At present, disposal of sewage sludge from secondary sewage treatment facilities and land disposal of effluent are important concerns. Sopper and Kardos (1973) and Loehr (1977) described land treatment of sewage effluent. Bouwer, Lance, and Riggs (1974) reported on land treatment of sewage effluent at the Flushing Meadows Project west of Phoenix. The EPA (1973c, 1975, 1977b and c) reported on the composition of sewage sludge and its disposal.

Leaking sewers have only recently been recognized as a significant source of pollution. This source has only been evaluated in several areas, such as Long Island, New York. This source may be important in areas where extensive networks of large sewers are in proximity to urban well fields and water levels are below major sewers.

Sewage Effluent: The impact of sewage effluent disposal on groundwater quality in arid lands has been studied by several investigators. Schmidt (1973) described the impact of irrigation with City of Tucson sewage effluent on groundwater in the Cortaro Area. Wilson, Herbert, and Ramsey (1975) discussed changes in water quality as Tucson sewage effluent percolated from the Santa Cruz River. Sewage effluent disposal in Maricopa County is primarily to stream channels, ponds, and irrigation. The use of sewage effluent for irrigation in the Buckeye Irrigation District is one of the largest such projects in the western U.S. Constituents in the effluent of most concern as potential groundwater pollutants include nitrogen, boron, fluoride, salinity, trace elements, and organic chemicals.

Boyle Engineering Corporation (1977b) presented chemical analyses of effluent from the 91st Avenue sewage treatment plant (Table III-1). Bouwer, Lance, and Riggs (1974) indicated that the total nitrogen content of this effluent ranged from 20 to 40 mg/l. If the effluent was percolated and all of this nitrogen nitrified and not lost by denitrification, the nitrate content of the recharged water would range from about 90 to over 170 mg/l. However, both plant uptake of nitrogen and denitrification can significantly decrease the nitrate content of percolated effluent. Boron content in Phoenix sewage effluent has normally ranged from 0.5 to 1.0 mg/l. Boron was mobile during percolation of effluent through soil and alluvium at the Flushing Meadows project. Fluoride content of the effluent averaged over 4 mg/l between 1968 and 1972. However, fluoride content in recharged effluent decreased substantially during movement through the soil and alluvium. The salinity of recharged effluent is only slightly greater than that of the effluent for high-rate percolation. However, for irrigation disposal of effluent, there are usually substantial increases in salinity of the percolated water due to evapotranspiration.

Some trace elements in effluent from the 91st Avenue plant were analyzed in 1972. Average contents of zinc, copper, and lead ranged from 0.08 to 0.19 mg/l. Bouwer, Lance, and Riggs (1974) indicated that zinc, cadmium, and lead were somewhat mobile as recharged effluent percolated through soil and alluvium at the Flushing Meadows project. Arsenic, barium, cadmium, hexavalent chromium, mercury, selenium, and silver contents were determined in samples of effluent collected in 1976-77. All of these constituents occurred in very low concentrations except arsenic, which averaged 0.04 mg/l and hexavalent chromium, which averaged 0.66 mg/l. There are some constituents for which little or no data are available, such as cyanide and organic chemicals.

Bouwer (1976) reported that during percolation of sewage effluent, the total organic carbon content is not reduced to zero, but may exceed several mg/l. The remaining organic carbon in the recharged effluent is termed "refractory organic carbon". This material is of concern in direct use of percolated effluent for drinking water, as the health effects are presently largely unknown.

Sewage effluent normally contains substantial amounts of bacteria and viruses. Bouwer, Lance, and Riggs (1974) reported that most fecal coliform

TABLE III-1
CHEMICAL ANALYSES OF EFFLUENT FROM
THE 91ST AVENUE SEWAGE TREATMENT PLANT

<u>Constituent (mg/l)</u>	<u>1/11/67</u>	<u>1969</u>	<u>3/27/73</u>	<u>5/26/73</u>
Calcium	64	82	60	57
Magnesium	26	36	12	18
Sodium	125	200	165	204
Potassium	-	8	-	3
Bicarbonate	-	381	-	324
Sulfate	100	107	80	83
Chloride	275	213	234	246
Nitrate	2	0	1	1
Total Hardness (CaCO ₃)	268	344	224	216
Total Nitrogen	32	-	24	54
Total Organic Carbon	-	-	-	31
pH	7.3	7.9	7.3	7.8
Electrical Conductivity (micromhos @ 25°C)	-	-	-	1,320
Total Dissolved Solids	900	837	803	765

Data modified from Boyle Engineering Corporation (1977b).

were immobilized in the upper few centimeters of soil below basins flooded with sewage effluent. Viruses are potentially more mobile than bacteria in the soil and alluvium. However, Gilbert, et al (1976) reported that no viruses were detected in percolated effluent after eight years of operation at Flushing Meadows. These authors reported that it is difficult to predict the virus removal potential of individual soils without detailed evaluations at specific sites.

Sewage Sludge: Sewage sludge can pollute groundwater when it is placed in sludge drying beds from which percolation can occur. Also sludge in stockpiles, landfills, or on farmland can be leached if a source of water is present. The composition of sewage sludge is generally well known. Boyle Engineering Corporation (1977b) reported on chemical constituents in typical sewage sludge. Numerous trace elements in raw sewage become concentrated in the sludge after treatment (Table III-2). Primary digested sludge contains an average of about 23,000 ppm nitrogen and activated digested sludge about 30,000 ppm on a dry-weight basis. Nitrogen, salinity, lead, chromium, and arsenic would be of concern as potential groundwater pollutants. Presently, most of the sludge from the 91st Avenue sewage treatment plant is either transported out of state for processing or stockpiled at a site near 87th and Southern Avenues for further processing. In the future, most of the sludge from the 91st Avenue plant is apparently to be disposed to landfills or on farmlands.

Septic Tanks

There are a number of excellent references on septic tanks. The Proceedings of the National Home Sewage Disposal Symposium (American Society of Agricultural Engineers, 1975) contain a number of articles on the characteristics of septic-tank effluent, including chemical quality. Also discussed are state-of-the-art individual on-site disposal systems. The Proceedings of the Rural Environmental Engineering Conference (Jewell and Swan, 1975) contain a number of articles on disposal of septic-tank effluent and the impact on groundwater. The Proceedings of the National Conferences on Individual On-Site Wastewater Systems (McClelland, 1977a,b,c, and 1978) contain substantial information on disposal of septic-tank effluent. Schmidt (1977) summarized evaluations of the impact of septic tanks on groundwater quality in diverse hydrogeologic situations, including arid lands.

Generally, the composition of septic-tank effluent is similar to that of sewage effluent, but contains less pollutants. Septic-tank effluent comprises domestic wastes only, whereas sewage effluent commonly also contains industrial wastes and storm runoff, which contribute additional pollutants. The trace element content of septic-tank effluent is thus usually negligible, however nitrogen, and boron are still of concern as potential pollutants.

In Maricopa County, two situations can be considered for disposal of septic-tank effluent. The first is in alluvial valleys where water tables are greater than about fifty feet deep. This situation is usually present away

TABLE III-2
TRACE ELEMENT COMPOSITION OF TYPICAL SEWAGE SLUDGES

<u>Constituent (oxide)</u>	<u>Content on a dry-weight basis (ppm)</u>	
	<u>Digested</u>	<u>Activated</u>
Copper	10,000	460
Barium	600	610
Zinc	12,400	160
Lead	8,100	2,225
Nickel	-	50
Cobalt	-	2
Chromium	3,700	2,190
Arsenic	1,300	130
Boron	-	40
Iodine	-	10

Source: Modified from Boyle Engineering Corporation (1977b).

from floodplains of the major rivers. The second is in alluvial valleys where water tables are near the land surface and in areas near the mountain fronts or in mountainous areas, where septic-tank effluent may be disposed into fractured or weathered consolidated rocks. In the first situation, nitrate content is the major concern and total organic carbon content may be another. In the second situation, both of these concerns exist, and in addition, bacteriological constituents and viruses are of concern. Disposal of septic-tank effluent at too great a density of septic tanks can produce high nitrate contents in groundwater. Fecal coliform or virus contamination can occur if effluent is improperly disposed directly into fractures in consolidated rocks or into alluvium where depth to groundwater is too shallow or the alluvium is saturated.

Storm Runoff

The American Public Works Association (1969), Sartor and Boyd (1972), and Bradford (1977) reported on storm runoff and potential pollutants. The Proceedings of the Symposium on Urbanization and Water Quality Control included a number of articles on storm runoff and control measures (Whipple, 1975). The constituents in storm runoff of some areas are well known. Table III-3 summarizes information on the chemical quality of storm runoff. In general, there can be significant differences in chemical quality, depending on land use. Runoff from residential, commercial, and industrial areas would be of distinct chemical quality. For example, in residential areas significant amounts of pollutants, such as nitrogen and pesticides, can be picked up by runoff from irrigated areas. In industrial areas, chemicals from spills and leaks could be picked up by storm runoff. Commercial areas may introduce substantial amounts of oil and gas from parking lots to storm runoff. However, there have been few evaluations of the effect of storm runoff disposal on groundwater quality. Peterson and Hargis (1973) discussed the disposal of storm runoff by injection wells in Hawaii, and Nightingale (1975) investigated trace elements in solids of storm runoff percolation ponds at Fresno, California.

The primary source of urban runoff in Maricopa County is in the Phoenix urban area, where disposal is primarily to dry wells, canals, channels of the Salt River and its tributaries, and percolation basins. The wells used for disposal of storm runoff water usually extend only to a depth for sufficient penetration of permeable strata. In the Phoenix urban area, depths of these wells are believed to range from 20 to over 50 feet. Wells allow bypassing of the topsoil and part of the vadose zone, where significant pollutant attenuation would otherwise occur.

Potential groundwater pollutants of most importance in storm runoff are trace elements, such as lead, zinc, copper, and cadmium. Organic chemical constituents may also be important, particularly where wells are used for disposal.

TABLE III-3
CHEMICAL COMPOSITION OF URBAN STORM RUNOFF

<u>Constituent (mg/l)</u>	<u>Maximum</u>	<u>Minimum</u>	<u>Mean</u>
Calcium	31	1	5
Magnesium	24	4	10
Total Alkalinity	124	24	56
Kjeldahl Nitrogen	11.6	0.1	1.0
Total Organic Carbon	384	5.5	42
Aluminum	36	6	16
Cobalt	0.47	0.04	0.16
Chromium	0.47	0.06	0.23
Copper	0.50	0.04	0.15
Iron	58.7	1.3	12.0
Lead	2.9	0.1	0.46
Manganese	3.2	0.12	0.67
Nickel	0.9	0.09	0.15
Zinc	4.6	0.09	0.36

Analyses of 501 samples from 36 storm events on a 1,093-acre urban watershed in Durham, North Carolina, from Colston and Tafuri (1975).

Lawn Irrigation

A portion of the water used to irrigate lawns, gardens, parks, and golf courses returns to the groundwater as return flow. Irrigation of farmland is considered in more detail in another section of this report. Flood irrigation is used widely in the Phoenix urban area. Irrigation return flow is generally of much higher salinity than the irrigation water due to evapotranspiration, which removes part of the applied water but leaves the salt behind. Also, fertilizers and pesticides contain potential pollutants. Some of these materials may be picked up by rainfall and contributed to storm runoff. Potential pollutants of importance are nitrogen, salinity, and possibly organic chemicals.

Landfills

Hughes, Landon, and Farvolden (1971), Schneider (1970), and the California Department of Water Resources (1969) discussed the characteristics and composition of solid wastes. The University of Southern California (1954) investigated the leaching of landfills. "Leachate" is the liquid formed by the interaction of water and solid wastes in a landfill or dump. The composition of leachate depends on the character of the wastes, operations at the disposal site, and climatic conditions. The impact of solid waste disposal sites on groundwater in humid areas has received much attention, as evidenced by Apgar and Langmuir (1971), Kimmel and Braids (1974), and Pettijohn (1977).

A number of constituents can be leached from solid materials in landfills. Table III-4 indicates the composition of landfill leachate. Salinity, nitrate, hardness, and trace elements are of greatest concern, although organic chemical constituents may also be important. In large part, the trace element content of leachate depends on the components of the solid waste, particularly the type of industrial wastes. Sewage sludge and septic tank pumpage are commonly disposed in landfills and may also contribute potential pollutants.

In areas of low rainfall such as the alluvial valleys of Maricopa County, leachate would not be expected to form where:

- 1) surface water does not enter the landfill,
- 2) groundwater does not enter the landfill,
- 3) liquids are not indiscriminantly disposed in the landfill,
- 4) other sources of water, such as irrigation tailwater and storm water, are kept out of the landfill.

The low precipitation and high evapotranspiration rates in Maricopa County minimize leachate formation due to rainfall. However, many landfills in the county are located in floodplains. As such, they are subject to contact with surface water during flood periods. Seepage from the river channels during flow can directly enter some landfills. Secondly, some landfills are excavated to the groundwater level. This level fluctuates

TABLE III- 4
CHEMICAL COMPOSITION OF LANDFILL LEACHATE

<u>Constituent (mg/l)</u>	<u>No. 1</u>	<u>No. 2</u>	<u>No. 3</u>
Calcium	125	60	7,200
Magnesium	26	17	15,600
Sodium	64	62	767
Potassium	-	-	68
Sulfate	84	102	1,190
Chloride	322	210	660
Nitrate-Nitrogen	13	6	-
Ammonia-Nitrogen	56	7	0
Organic Nitrogen	56	20	-
pH	5.2	5.1	5.8
Total Organic Carbon	1,230	2,130	-
Total Hardness (CaCO ₃)	450	370	22,800
Iron	9	4	2,820
Electrical Conductivity (micromhos @ 25°C)	-	-	9,860

Modified from Wilson, Martin, and Lonergan (1977).

seasonally and is higher during periods of less pumping. Rises in water level of tens of feet are common beneath floodplains following floods. Such landfills are thus exposed to direct contact with the groundwater. Thirdly, there are several instances where irrigation tailwater and storm runoff have directly entered landfills in the county. Lastly, construction of golf courses or other facilities requiring irrigation on completed landfills creates great potential for leachate formation due to irrigation return flow.

INDUSTRIAL

Industrial wastes have considerable potential to adversely impact groundwater quality. In Arizona, production of industrial wastes is centered in Maricopa County, particularly in the Phoenix urban area. In the future, additional industrial wastes will be produced at the Palo Verde Nuclear Generating Station in the Lower Hassayampa Area. Also, industrial wastes will be produced if a petroleum refinery is built at one of two proposed locations. One location is near Mobile in the upper part of the Waterman Wash area. The second location is southwest of the Palo Verde Nuclear Generating Station.

Phoenix Urban Area

Many industrial wastes from the Phoenix urban area are presently disposed to sewers or landfills. In the future, as pre-treatment standards are imposed on industries connected to sewage treatment facilities, numerous industries may turn to on-site disposal. Also, the implementation of the Resources Conservation and Recovery Act will limit the disposal of industrial wastes to landfills. Thus there is considerable potential for on-site disposal of industrial wastes in the future. This may significantly adversely impact local groundwater supplies.

In June 1974, the Arizona Department of Health Services, Bureau of Sanitation, completed an industrial solid waste survey in an effort to develop a state solid waste management program. The objectives of the survey were to identify sources of industrial waste production in Arizona, determine the quantities and characteristics of wastes, and identify methods utilized in handling, processing, and disposing of the materials. After the original survey was completed, the ADHS determined that a larger number of manufacturers should be surveyed. In addition, the new survey was to include on-site plant inspection. A contract was awarded to Behavioral Health Consultants, Inc. in March 1975 to conduct the second survey.

The "Arizona Directory of Manufacturers" categorizes manufacturers within Standard Industrial Classifications, referred to as SIC groups. Thirteen groups were selected:

- SIC 19 Ordinance and accessories
- 22 Textile mill products

- 24 Lumber and wood products
- 26 Paper and allied products
- 27 Printing, publishing, and allied industries
- 28 Chemical and allied products
- 29 Petroleum refining and related industries
- 30 Rubber and miscellaneous plastic products
- 33 Primary metal industries
- 34 Fabricated metal products
- 36 Electrical machinery, equipment, and supplies
- 38 Professional, scientific, and controlling instruments
- 39 Miscellaneous manufacturing products

These thirteen groups were selected because they were considered to be potentially generating a greater amount and variety of industrial and hazardous wastes than other groups. Five hundred manufacturers were selected from the thirteen SIC groups. Maricopa County was chosen as the prime target area because seventy-five percent of these manufacturers were located therein.

Results of the second survey (Behavioral Health Consultants, Inc., 1975) indicate that as of 1975, industrial wastes were primarily disposed to landfills, sewers, on-site, or shipped out of state. On-site disposal included ponds, land spreading, and stockpiles.

Present methods of disposal of industrial wastes are poorly documented. Current practices that pose a threat to groundwater quality include:

- 1) disposal of liquid wastes to ponds,
- 2) disposal of solid wastes to landfills located in floodplains, where leachate may be produced,
- 3) use of seepage pits for disposal,
- 4) disposal to normally dry stream channels,
- 5) leaks and spills of industrial wastes,
- 6) disposal to sewers where pollutants may enter sewage effluent or sludge.

There are many potential pollutants in industrial wastes, particularly salinity, trace elements, and organic chemicals.

Petroleum Refinery

Two sites are in the planning stage for a petroleum refinery along the gas pipeline that passes through the southern part of Maricopa County. One potential site is located near Mobile in the upper part of Rainbow Valley. The second site is southwest of the Palo Verde Nuclear Generating Station in the Lower Hassayampa Area. Petroleum refining results in several types of wastes with potential for groundwater pollution. Although disposal practices are unknown at present, on-site disposal of some wastes is likely. Spills and leaks, disposal of wastes to normally dry stream channels, and seepage from unlined ponds could present considerable pollution potential

in a local area. Trace elements and organic chemical would be the major potential pollutants of concern.

Palo Verde Nuclear Generating Station

There are several potential sources of pollution associated with the construction and operation of the Palo Verde Nuclear Generating Station:

- 1) sewage effluent produced on site,
- 2) wastes from the water treatment plant,
- 3) seepage from evaporation pond,
- 4) stockpiles of salt produced by evaporation,
- 5) leakage of sewage effluent from incoming pipeline.

Of most concern are seepage from the evaporation ponds and the stockpiles of salt that will eventually be produced from the desalinization plant. Detailed monitoring of the evaporation ponds will be required by the Nuclear Regulatory Commission. Detailed plans for disposal or storage of the salt from the evaporation pond are unknown. However, if 107,000 acre-feet per year of sewage effluent at an average salinity of 800 mg/l are imported, the amount of imported salt is about 117,000 tons per year.

AGRICULTURAL

Agricultural potential sources include irrigation, feedlots and dairies, and pesticide wastes.

Irrigation

Water quality changes in the topsoil as related to irrigation practices have been widely investigated. Willrich and Smith (1970) edited a textbook on the effect of agricultural practices on water quality. The EPA (1972) discussed the management of irrigated agriculture to improve water quality. Jenke (1974) evaluated the salinity aspects of irrigation return flows, and King and Hanks (1973) discussed irrigation management for control of the quality of irrigation return flow. In the literature, "return flow" has been used to designate both tailwater and percolation of excess applied water. In this report, water that runs off fields after irrigation is termed "tailwater". The portion of the applied water that percolates past the root zone and eventually reaches the groundwater is termed "irrigation return flow".

Rible, et al (1975) described sampling in the vadose zone beneath irrigated lands to evaluate the impacts on groundwater quality. Rhoads, et al (1974) discussed minimizing the salt burdens of irrigation return flow. The Proceedings of the National Conference on Irrigation Return Flow Quality Management (Law and Skogerboe, 1977) contain a number of papers relevant to this subject.

The impact of irrigation return flow on groundwater quality in Maricopa County can be considered in at least two situations. One is where irrigation has been practiced for a long period of time and depth to water is not excessive. The Salt River Project, Buckeye Irrigation District, and Roosevelt Irrigation District are examples in the Salt River Valley. Parts of the Lower Hassayampa Area and the Gila Bend Basin near the Gila River also fit this situation. In this case, deposits above the water table are generally at field capacity and water percolating past the root zone can readily move downward to the water table. However, it may still take years or decades for water to travel from the land surface to the water table. Because of the length of time that irrigation has been practiced in these areas, substantial volumes of return flow are now present in the groundwater. The presence of perching layers in the alluvium and shallow perforations in numerous wells in many areas results in cascading water. Materials above the perching layers become saturated, water enters the well through openings above the water level, and falls or "cascades" down the well to the water table.

The second situation occurs where water levels are relatively deep and large-scale irrigation has only been practiced for several decades or less. Examples include the Aguila Area, Rainbow Valley, and the Lower Harquahala Valley. The alluvial deposits above the water table in areas away from floodplains were moisture deficient under natural conditions. In this case, the materials above the water level must be wetted and the moisture content increased to field capacity before there is significant movement of return flow. This wetting requires a substantial amount of water. Also, significant water-level declines are generally occurring in such areas. In this situation, irrigation return flow may have not yet reached the water table due to a combination of these factors.

Salinity and nitrate content are of prime importance in assessing the impact of irrigation on groundwater quality. In general, evapotranspiration increases the salinity of the return flow compared to that of the irrigation water. In areas where groundwater is the sole water supply and water levels are relatively shallow, there could be substantial increases in salinity as the return flow is recycled several times. This process was well documented in the Wellton-Mohawk area near Yuma. One factor that counterbalances the salinity increase due to evapotranspiration is the precipitation of salts, such as gypsum and calcium carbonate, in the soil horizon between irrigations. Much of this salt may not be brought back into solution during future irrigations.

Nitrogen fertilizers are a prime concern in some areas because of the past over-application of nitrogen and subsequent leaching of nitrate to the groundwater. In general, crops take up a certain percentage of the applied nitrogen, and this may not be leached if the crops are harvested and removed. Denitrification can potentially remove some of the nitrogen, and the extent of this process largely depends on the soil type. In general, sandy soils have less potential for denitrification and can allow large leaching losses of nitrogen. Pesticides applied to cropland are not generally of concern to groundwater quality in alluvial valleys, because of degradation

and adsorption processes. That is, most pesticides degrade in the topsoil or are adsorbed by the alluvial deposits as water percolates through the topsoil and vadose zone. However, if tailwater is disposed down wells extending to the water table, pesticides could be a concern. In this case, much of the attenuation processes may be nullified because of the bypassing of the vadose zone.

Tailwater is commonly disposed to stream channels or stored in basins from which seepage may occur. This water is often recycled into the irrigation water on an individual farm. This water is commonly mixed with canal water prior to its disposal.

The impact of irrigation on groundwater quality must be considered in the context of the regional hydrologic system. That is, all components of the water budget must be considered. Important factors include canal seepage, other sources of recharge, and the effects of surface water retention and importation. For example, seepage of canal water of low salinity can substantially dilute underlying groundwater of higher salinity. Retention of floodwaters behind storage reservoirs and subsequent use for irrigation has provided a new source of recharge. This recharge may be of a different quality than that occurring under natural conditions.

Feedlots and Dairies

Animal production systems vary from open-range types to total confinement. According to federal regulations, a feedlot or concentrated animal operation is defined as any facility where animals are confined and fed or maintained for a total of 45 days or more in any 12-month period; and crops, vegetation, and postharvest residues are not sustained in the normal growing season over any portion of the lot or facility (ASCE Environmental Engineering Division, 1978). Feedlots discharging pollutants into navigable waters are directly subject to discharge regulations according to Public Law 92-500. However, of primary concern in this report is how animal wastes can affect groundwater quality.

In terms of groundwater, the concentrated animal wastes are the primary concern. The two main wastes to be handled are manure or wastewater, and storm runoff from feedlot areas. Proper diking to exclude outside drainage reduces the runoff to be handled. Animal wastes may be collected and handled as either solids or liquids. Liquid wastes are handled either as slurries (raw waste) or as diluted waste from a flushing system. For dairies, washwater is a major component of the wastes. Runoff and direct evaporation are the two major factors in the water balance for a feedlot surface. Miner and Smith (1975) reported in some detail on the volume of storm runoff from feedlots. Infiltration is essentially limited to water stored in the manure and soil-manure mixture on the feedlot surface. Once a manure pack is formed on the surface of a continuously used feedlot, movement of water into the soil profile is generally insignificant. This has been confirmed by subsurface monitoring below a liquid manure holding pond in southern California (Oliver, et al, 1974).

Numerous studies have been conducted on the composition of animal wastes and impact on groundwater quality. Stewart, et al (1967) evaluated nitrates and other constituents beneath feedlots in Colorado. The American Society of Agricultural Engineers (1971), Miner (1971), and the EPA (1973d) discussed management of animal wastes. The amounts and concentrations of waste from a livestock production facility are primarily dependent upon the total weight of animals present and the amount of washwater used. Water use, depending on management practices, can easily result in a 10-fold difference in wastewater volumes.

The quantity of feedlot runoff is highly variable, and depends on many factors, such as cattle density, operation techniques, soil moisture, soil characteristics, topography, and rainfall intensity. The composition of feedlot runoff depends upon time of year and management techniques. The concentration of the various pollutants in feedlot runoff is highest during the initial phase of rainfall and decreases as runoff continues. After the feedlot surface becomes covered with manure, the quality of runoff is no longer affected by manure depth, but by manure composition, rainfall intensity, water content of the manure pack, and the type of feedlot surface. The ASCE Environmental Engineering Division (1978) stated that animal waste and feedlot runoff concentrations are much higher than sewage effluent. Lagoons or oxidation ponds are used extensively for partial treatment and storage of liquid wastes. Fairbank, Olson, and Hutton (1972) discussed dairy waste storage ponds used in the San Joaquin Valley of California. Such ponds provide a system for collection, settling, and storing liquefied dairy manure and washwater for re-use.

Land disposal of animal wastes has been encouraged by EPA regulations on discharge to surface waters. When animal wastes are applied to agricultural land, liquids usually are irrigated, and solids or slurries applied by a spreader. According to the ASCE Environmental Engineering Division (1978), the application of animal wastes to croplands for the purpose of disposal is a relatively new idea. If long-term water pollution is to be avoided, rates of manure application must match the assimilative capacity of the site. In arid areas, very high manure applications may be made for one year, followed by several resting years for assimilation. Heavy applications of manure to certain soils may lead to nitrate pollution of groundwater. Also, over-application of waste-pond effluents can result in nitrate pollution (Miner and Smith, 1975).

There have been few studies of the impact of feedlot and dairy wastes on groundwater quality in the southwest. Potential pollutants in farm animal wastes are generally similar to those in sewage effluent. Nitrogen, salinity, boron, and organic chemical constituents are of most concern.

Pesticide Wastes

Pesticide wastes are grouped into three categories: 1) pesticide residuals, 2) dilute pesticide solutions, and 3) pesticide containers. Pesticide residuals comprise materials such as pesticide residues and excess

pesticides. Pesticide residues generally are obsolete pesticides owing to age or to cancellation or suspension of their registration by EPA. Excess pesticides are the result of overproduction by the local processor for specific contracts or small amounts of residues remaining after application has been completed. Dilute pesticide solutions are generated by container rinsing, equipment washing, water from pesticide fire-fighting operations, spill clean-ups, and drum reconditioning operations. Ferguson, Morris, & Simpson, Inc. (1976) presented an inventory of empty pesticide containers in Arizona. Most of the empty pesticide containers accumulate in Arizona at pesticide plant processing sites and at staging sites for commercial applicators. Empty pesticide containers may be disposed in certain landfills if they are first properly rinsed. Most of the pesticide wastes other than rinsed containers can be classified as hazardous wastes.

Pesticide wastes pose a threat to groundwater if they are not disposed at a suitable site. Implementation of the state hazardous waste plan will enable more suitable disposal practices for pesticide wastes.

HYDROLOGIC MODIFICATIONS

Hydrologic modifications have usually been considered on a national scale in terms of surface water (EPA, 1973b and 1977a). This category pertains to changes in the water quantity aspects which indirectly influence water quality, as opposed to more direct types of pollution. There are usually numerous hydrologic modifications in developed areas. Some modifications may be beneficial. For example, percolation of streamflow in the Salt River Valley has been enhanced by lowered water levels due to pumping. Also, the retention of low salinity surface water runoff in storage reservoirs and subsequent controlled releases provide recharge of lower salinity than might occur naturally.

Important hydrologic modifications directly related to groundwater in the major basins of Maricopa County include:

- 1) lowered water levels due to pumping,
- 2) irrigation return flow,
- 3) canal seepage,
- 4) well construction,
- 5) creation of perched groundwater zones,
- 6) changes in direction of groundwater flow due to pumpage patterns,
- 7) imported water,
- 8) drainage well pumpage.

Lowered water levels can either improve or degrade the quality of water pumped from wells. For example, dewatering of shallow strata in many parts of the Salt River Valley has resulted in pumpage of lower salinity water. This is because prior to large-scale pumpage, the shallow strata contained water of a higher salinity. As this water was removed by overdrafting, the underlying strata became the major source of water to wells. The underlying strata frequently contain groundwater of lower salinity and thus the well

water salinity decreased over several decades. On the other hand, substantial dewatering of deposits in some areas such as near the centers of basins may result in deterioration of the quality of water pumped from wells. This can occur in areas where evaporite deposits occur at depth and deep groundwater is of high salinity. Lowered water levels also result in a thick vadose zone, which can mitigate potential problems from wastes disposed at the land surface. A thick vadose zone signifies a longer travel time for pollutants percolating to the water table and greater pollutant attenuation.

Irrigation can both improve and degrade groundwater quality. In large part, this depends on the quality of the irrigation water supply and the irrigation efficiency. The relative proportion of canal seepage to irrigation return flow is also important. Irrigation and canal seepage are considered in a separate section of this report, and not under "hydrologic modification".

Well construction is one of the most important factors determining the quality of water pumped from a well. Well construction is most important in relation to the vertical distribution of constituents in the groundwater. At one location in alluvial valleys, groundwater at different depths may be under different hydraulic heads. Also, groundwater at these different depths may be of different quality. Clay and other strata of low permeability may impede the vertical movement of groundwater and allow vertical differences in groundwater quality to persist. Wells may penetrate numerous strata and if perforated opposite a large depth interval, allow rapid vertical movement of groundwater from one depth to another. Movement of water can occur both inside and outside the well casing. Where gravel packs are present, they may also enhance the vertical movement of groundwater. Potential problems in the major groundwater basins of Maricopa County include:

- 1) upward movement of poor quality water from depth near the center of basins where evaporite deposits are present,
- 2) downward movement of shallow groundwater of poor quality into the production zones of wells,
- 3) cascading water where perforations extend above the water table.

Perched groundwater may have been present in some areas under natural conditions, particularly near floodplains. However, because water levels were relatively shallow, there was little opportunity for perched levels to develop. With the application of irrigation water and canal seepage at the land surface and deepened water levels due to pumpage, conditions were enhanced for development of perched groundwater zones. Although these zones are limited in both extent and well production potential, they are significant in terms of groundwater quality.

Changes in both the vertical and horizontal directions of groundwater flow have resulted from large-scale pumping. For example, in the Salt River Valley, groundwater is now moving toward pumping depressions in the Scottsdale area, east of Mesa, in the Queen Creek area, Deer Valley, and Luke Air

Force Base. There are two areas where this alteration in groundwater flow direction is causing groundwater quality deterioration. Near Chandler in the East Basin and Goodyear in the West Basin, groundwater of poor quality is moving into areas of better quality. This situation is possible along much of the Gila River in Maricopa County. Water-level changes due to pumping can also induce substantial vertical movement of groundwater from one depth to another. The resulting changes in the quality of water pumped from wells can be beneficial or adverse.

The imported Colorado River water from the Central Arizona Project will introduce substantial amounts of salt to the major groundwater basins of Maricopa County that use such water. While this water is highly beneficial in terms of alleviating overdraft, an accompanying potential adverse impact is increasing salinity of the groundwater. The total dissolved solids in Central Arizona Project water is estimated to be about 730 mg/l, assuming salinity control measures are successfully implemented upstream of Lake Havasu. If salinity control measures are not inacted, then the salinity could be several hundred mg/l greater by the year 2000. For purposes of this report, a salinity of 735 mg/l is used. The major deliveries of CAP water in Maricopa County will be to parts of the Salt River Valley, Lower Harquahala Valley, and Lower Hassayampa Area.

The long-term average salinity of Verde River water below Bartlett Dam is about 250 mg/l and that of Salt River water below Stewart Mountain Dam is about 550 mg/l. The average salinity of Salt and Verde River water at the Granite Reef Diversion Dam is about 400 mg/l. Thus the salinity of the Central Arizona Project water will likely be at least 90% greater than Salt-Verde River water. Using an estimated volume of 735,000 acre-feet of Central Arizona Project water estimated to be available to Maricopa County in 1990 (Arizona Water Commission, 1978), the annual amount of salt imported in this water would be 735,000 tons.

The importance of such deliveries to groundwater quantity should not be neglected, because in some cases continued production of groundwater would eventually no longer be feasible without such imports. Thus the impacts of imported water on groundwater quality may be a secondary consideration compared to groundwater quantity. Imported water can also alleviate some groundwater quality problems, such as in Paradise Valley, by providing an alternative source of water. The fact that Central Arizona Project water will result in an increased salt input to Maricopa County does not necessarily mean that the groundwater salinity will markedly increase. There are several factors which mitigate a buildup of salinity in groundwater. This topic is discussed in more detail under "Basin Problem Evaluation" in a subsequent chapter of this report.

Export of drainage pumpage from the Buckeye Irrigation District and tail-water from the Roosevelt Irrigation District and Buckeye Irrigation District provides a source of salt export from the Salt River Valley, however these salts eventually enter the Lower Hassayampa Area and the Gila Bend Basin. Export of sewage effluent to the Palo Verde Nuclear Generating Station will remove substantial amounts of salt from the Salt River Valley.

About 117,000 tons of salt would be exported per year, if 107,000 acre-feet of effluent were used.

NATURAL FACTORS

Natural factors exert a substantial influence on groundwater quality in the major basins of Maricopa County. Two major factors are the quality of water from recharge sources and the subsurface geology. The major sources of recharge prior to development were mountain-front recharge and percolation of streamflow from the major streams. Mountain-front recharge and water in the Agua Fria, New, and Verde Rivers and Queen Creek are of low salinity. Water in the Salt and Gila Rivers is of much higher salinity. Subsurface geologic factors of importance include:

- 1) distribution of evaporites at depth near the centers of basins,
- 2) presence of the middle fine-grained unit,
- 3) occurrence of deep conglomerate layers near the basin edges,
- 4) deposits of the ancestral Salt and Gila Rivers.

Evapotranspiration by phreatophytes can significantly affect groundwater quality in areas of shallow groundwater. Under natural conditions, there was substantial growth of phreatophytes along stream channels. These plants tap shallow groundwater. As this water is used, the salts accumulate in the groundwater, which thus increases in salinity. Some native plants, such as mesquite, could also take nitrogen from the atmosphere and possibly introduce nitrate to the groundwater.

A companion report on groundwater quality in the major basins of Maricopa County (Schmidt, 1978) indicates that salinity and fluoride content are often related to natural factors. The distribution of many important constituents in groundwater of the Salt River Valley is often related to natural factors. Examples are salinity, chloride, sulfate, hardness, nitrate, fluoride, chromium, arsenic, and lead.

Of equal importance are the physical, chemical, and biological processes that combine to exert controls on the concentrations of various constituents in groundwater. Examples include filtering, dissolution of minerals, precipitation of salt, adsorption, ion exchange, oxidation, and reduction. These processes not only partly determine the concentration of constituents in the natural system without man's influence, but govern the fate of potential pollutants in wastes disposed by man.

In order to formulate meaningful control measures and monitoring, both natural factors and man's activities must be evaluated. In the following chapter, potential sources of pollution and their effects on groundwater quality are analyzed for each basin.

REFERENCES

- American Public Works Association, 1969, "Water Pollution Aspects of Urban Runoff", prepared for Federal Water Pollution Control Administration, 272p.
- American Society of Agricultural Engineers, 1971, "Livestock Waste Management and Pollution Abatement", Proceedings, International Symposium on Livestock Wastes, St. Joseph, Michigan, 360p.
- American Society of Agricultural Engineers, 1975, "Home Sewage Disposal", Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 1974, ASAE Publication PROC-175, St. Joseph, Michigan, 242p.
- Apgar, M.A., and D. Langmuir, 1971, "Ground-Water Pollution Potential of a Landfill above the Water Table", Ground Water, vol 9, no 6, pp 77-94.
- Arizona Water Commission, 1978, "Current and Expected Water Supplies and Demands and Groundwater Conditions in Maricopa County", prepared for Maricopa Association of Governments.
- ASCE Environmental Engineering Division, 1978, "Animal Waste Management: State-of-the-Art", Journal of the Environmental Engineering Division, ASCE, vol 104, no EE6, pp 1239-1262.
- Behavioral Health Consultants, Inc., 1975, "A Report on Industrial and Hazardous Wastes", prepared for Arizona Department of Health Services, 110p.
- Bouwer, H., 1976, "Use of the Earth's Crust for Treatment or Storage of Sewage Effluent and Other Waste Fluids" in CRC Critical Reviews in Environmental Control, pp 111-130.
- Bouwer, H., Lance, J.C., and M.S. Riggs, 1974, "High-Rate Land Treatment, II: Water Quality and Economic Aspects of the Flushing Meadows Project", Journal Water Pollution Control Federation, vol 46, no 5, pp 844-859.
- Boyle Engineering Corporation, 1977a, "Agricultural Practices and other Non-Point Sources", prepared for U.S. Army Corps of Engineers, Los Angeles District, 51p.
- Boyle Engineering Corporation, 1977b, "Potential Reuse Options for Wastewater Effluent and Residual Solids", prepared for U.S. Army Corps of Engineers, Phoenix Urban Study, 122p.
- Bradford, W.L., 1977, "Urban Stormwater Pollutant Loadings: A Statistical Summary Through 1972", Journal Water Pollution Control Federation, vol 49, no 4, pp 613-622.
- California Department of Water Resources, 1969, "Sanitary Landfill Studies", Bulletin 147-5, Groundwater Basin Protection Projects, Appendix A: Summary of Selected Previous Investigations, 115p.

- Clark, J.W., and W. Viessman, 1965, "Water Supply and Pollution Control", International Textbook Company, Scranton, Pennsylvania, 575p.
- Colston, N.V., and A.N. Tafuri, 1975, "Urban Land Runoff Considerations", in Urbanization and Water Quality Control, American Water Resources Association, Proceedings No. 20, pp 120-128.
- Fairbank, W.C., Olson, E.H., and G.A. Hutton, Jr., 1972, "Dairy Waste Storage Ponds for Soil-Plant Recycling", University of California Agricultural Extension, Agricultural Sanitation and Waste Management Series, 6p.
- Ferguson, Morris, & Simpson, Inc., 1976, "An Inventory and Analysis of Empty Pesticide Containers", Arizona Pesticide Control Program, prepared for Arizona Department of Health Services, 45p.
- Gilbert, R.G., Gerba, C.P., Rice, R.C., Bouwer, H., Willis, C., and J.L. Melnick, 1976, "Virus and Bacterial Removal from Wastewater by Land Treatment", Applied and Environmental Microbiology, vol 30, no 3, pp 333-338.
- Hughes, G.M., Landon, R.A., and R.N. Farvolden, 1971, "Hydrology of Solid Waste Disposal Sites in Northeastern Illinois", Illinois State Geological Survey, prepared for U.S. Environmental Protection Agency, 154p.
- Jenke, A.L., 1974, "Evaluation of Salinity Created by Irrigation Return Flows", U.S. Environmental Protection Agency, Office of Water Program Operations, Report EPA 430/9-74-006, 128p.
- Jewell, W.J., and R. Swan, 1975, "Water Pollution Control in Low Density Areas", Proceedings of a Rural Environmental Engineering Conference, University Press of New England, Hanover, New Hampshire, 498p.
- Kimmel, G.E. and O.C. Braids, 1974, "Leachate Plumes in a Highly Permeable Aquifer", Ground Water, vol 12, no 6, pp 388-393.
- King, L.G., and R.J. Hanks, 1973, "Irrigation Management for Control of Quality of Irrigation Return Flow", U.S. Environmental Protection Agency Report EPA-R2-73-265, 307p.
- Law, J.P., and G.V. Skogerboe, 1977, "Irrigation Return Flow Quality Management", Proceedings of National Conference, Colorado State University, Fort Collins, 451p.
- Loehr, R.C., 1977, "Land as a Waste Management Alternative", Proceedings of the 1976 Cornell Agricultural Waste Management Conference, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 811p.
- Maricopa Association of Governments, 1977a, "Working Paper, Non-Point Sources of Pollution, 35p.

- Maricopa Association of Governments, 1977b, "Working Paper, Current Agricultural Practices, Inventory & Review, Non-Point Sources of Pollution, 20p.
- McClelland, N.I., 1977a, "Individual Onsite Wastewater Systems", Proceedings of the First National Conference, 1974, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan 166p.
- McClelland, N.I., 1977b, "Individual Onsite Wastewater Systems", Proceedings of the Second National Conference, 1975, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 218p.
- McClelland, N.I., 1977c, "Individual Onsite Wastewater Systems", Proceedings of the Third National Conference, 1976, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 319p.
- McClelland, N.I., 1978, "Individual Onsite Wastewater Systems", Proceedings of the Fourth National Conference, 1977, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 238p.
- Miner, J.R., 1971, "Farm Animal Waste Management", Iowa State University of Science and Technology, Agriculture and Home Economics Experiment Station, North Central Regional Publication 206, Special Report 67, Ames, Iowa, 44p.
- Miner, J.R., and R.J. Smith, 1975, "Livestock Waste Management with Pollution Control", North Central Regional Research Publication 222, 89p.
- Nightingale, H.I., 1975, "Lead, Zinc, and Copper in Soils of Urban Storm - Runoff Retention Basins", Journal American Water Works Association, vol 67, no 8, pp 443-446.
- Oliver, J.C., Fairbank, W.C., Meyer, J.L., and J.M. Rible, "Subfloor Monitoring of Shady Grove Dairy Liquid Manure Holding Pond", California Agriculture, vol 28, no 4, pp 6-7.
- Peterson, F.L., and D.R. Hargis, 1973, "Subsurface Disposal of Storm Runoff", Journal Water Pollution Control Federation, vol 45, no 8, pp 1663-1670.
- Pettijohn, R.A., 1977, "Nature and Extent of Ground-Water Quality Changes Resulting from Solid Waste Disposal, Marion County, Indiana", U.S. Geological Survey Water Resources Investigations 77-40, 119p.
- Rhoads, J.D., Oster, J.D., Ingvalson, R.D., Tucker, R.M., and M. Clark, 1974, "Minimizing the Salt Burdens of Irrigation Drainage Waters", Journal Environmental Quality, vol 3, no 4, pp 311-316.
- Rible, J.M., Nash, P.A., Pratt, P.A., and L.J. Lund, 1975, "Sampling the Unsaturated Zone of Irrigated Lands for Reliable Estimates of Nitrate Concentrations", in Nitrate in Effluents from Irrigated Lands, Annual Report to National Science Foundation from Kearney Foundation of Soil Science, University of California, pp 281-302.

Sartor, J.D., and G.B. Boyd, 1972, "Water Pollution Aspects of Street Surface Contaminants", U.S. Environmental Protection Agency Technology Series, Report EPA-R2-72-081, 236p.

Schmidt, K.D., 1973, "Groundwater Quality in the Cortaro Area Northwest of Tucson, Arizona", Water Resources Bulletin, vol 9, no 3, pp 598-606.

Schmidt, K.D., 1977, "Protection of Ground Water from Nonpoint Sources of Pollution", in Drinking Water Quality Enhancement through Source Protection, edited by R.B. Pojasek, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, pp 257-273.

Schmidt, K.D., 1978, "Groundwater Quality in the Major Basins of Maricopa County", prepared for Los Angeles District, U.S. Army Corps of Engineers, Phoenix Urban Study and Maricopa Association of Governments, Maricopa County 208 program.

Schneider, W.J., 1970, "Hydrologic Implications of Solid-Waste Disposal", U.S. Geological Survey Circular 601-F, 10p.

Sopper, W.E., and L.T. Kardos, 1973, "Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland", The Pennsylvania State University Press, University Park, 479p.

Stewart, B.A., and others, 1967, "Distribution of Nitrates and Other Water Pollutants Under Fields and Corrals in the Middle South Platte Valley of Colorado", U.S. Department of Agriculture, Agricultural Research Service, Report ARS 41-134, 206p.

U.S. Environmental Protection Agency, 1972, "Managing Irrigated Agriculture to Improve Water Quality", Proceedings of National Conference on Managing Irrigated Agriculture to Improve Water Quality, 306p.

U.S. Environmental Protection Agency, 1973a, "Methods for Identifying and Evaluating the Nature and Extent of Non-Point Sources of Pollutants", Office of Air and Water Programs, 261p.

U.S. Environmental Protection Agency, 1973b, "The Control of Pollution from Hydrographic Modification", 188p.

U.S. Environmental Protection Agency, 1973c, "Recycling Municipal Sludges and Effluents on Land", Proceedings of the Joint Conference, Champaign, Illinois, July 1973, 244p.

U.S. Environmental Protection Agency, 1973d, "Environmental Protecting Concepts of Beef Cattle Feedlot Wastes Management", National Environmental Research Center, Corvallis, Oregon.

U.S. Environmental Protection Agency, 1975, "Municipal Sludge Management and Disposal", Proceedings of the 1975 National Conference, Anaheim, California, August 1975, 257p.

- U.S. Environmental Protection Agency, 1977a, "Nonpoint Source Control Guidance - Hydrologic Modifications", Office of Water Planning and Standards.
- U.S. Environmental Protection Agency, 1977b, "Sludge Management, Disposal, and Utilization", Proceedings of the Third National Conference, Miami Beach, Florida, December 1976, 210p.
- U.S. Environmental Protection Agency, 1977c, "Municipal Sludge Management: Environmental Factors", U.S. Environmental Protection Agency, Office of Water Program Operations, Report EPA 430/9-77-004, 30p.
- University of Southern California, 1954, "Final Report on the Investigation of a Sanitary Landfill", prepared for California State Water Pollution Control Board, Publication No. 10, 92p.
- Whipple, W., 1975, "Urbanization and Water Quality Control", American Water Resources Association, Minneapolis, Minnesota 302p.
- Willrich, T.L., and G.E. Smith, 1970, "Agricultural Practices and Water Quality", Iowa State University Press, Ames, Iowa, 415p.
- Wilson, L.G., Herbert, R.A., and C.R. Ramsey, 1975, "Transformations in Quality of Recharging Effluent in the Santa Cruz River", Hydrology and Water Resources in Arizona and the Southwest, vol 5, Arizona Section, AWRA, pp 169-176.
- Wilson, L.G., Martin, P., and E.D. Lonergan, 1977, "Evaluation of Ground-Water Monitoring Plan (WETS)", Completion Report prepared for Arizona Department of Health Services, Bureau of Water Quality Control, Water Resources Research Center, The University of Arizona.

IV

BASIN PROBLEM EVALUATION

CHAPTER IV

BASIN PROBLEM EVALUATION

In this section of the report, both pollution sources and groundwater quality are examined in each basin. An attempt is made to analyze the impact of man's activities on groundwater quality in each basin on the basis of available data.

In order to evaluate impacts on groundwater, potential sources must be classified in a hydrogeologically meaningful manner. The simple distinction between point and nonpoint sources is not sufficient for analyzing groundwater pollution. In the following discussions, potential sources of groundwater pollution are grouped into point, line, and diffuse sources. A "point source", such as a landfill, occupies a relatively small area. A "line source" has the length dimension much greater than the width. An example is disposal of sewage effluent to a normally dry stream channel, from which infiltration occurs. A "diffuse source", such as return flow from crop irrigation, covers a large area. In this context, potential sources in Maricopa County can be grouped as follows:

Point Sources

- Storm runoff ponds and wells
- Landfills
- Industrial waste ponds and stockpiles
- Sewage effluent ponds
- PVNGS evaporation pond
- Oil refinery ponds
- Feedlots and dairies

Line Sources

- Leaking sewers
- Storm runoff disposal to stream channels
- Sewage effluent disposal to stream channels
- Drainage pumpage disposal to stream channels
- Tailwater disposal to stream channels

Diffuse Sources

- Septic tanks in urban areas
- Lawn irrigation
- Crop irrigation
- Sewage effluent disposal by irrigation

In general, point sources affect groundwater quality in only local areas. This is due to the dilution that occurs upon mixing with native groundwater. Sampling of large-capacity wells is not usually adequate for monitoring the effect of such sources, because they are not in the right location or constructed for this purpose. Instead, local small-capacity wells must be sampled or specially constructed monitor wells are necessary. Diffuse

sources and most types of hydrologic modification, on the other hand, can affect relatively large areas and influence the regional groundwater quality. Therefore, diffuse sources and hydrologic modification can often be monitored by large-capacity wells. Line sources are intermediate between the two.

In the companion report (Schmidt, 1978), chemical quality records were collected and organized for water from large-capacity wells. Thus in general, conclusions on only diffuse sources and hydrologic modification can be derived from these records. The determination of the impact of most point and many line sources on groundwater quality requires site-specific monitoring that has not been in effect.

Comprehensive monitoring of groundwater pollution involves components other than just wells. Monitoring of pollution sources and the vadose zone is necessary in many cases to precisely determine the cause and effect relationship between a source and the resulting groundwater pollution. Since there has been little or no pollution source or vadose zone monitoring for the major groundwater basins, the following evaluation should be regarded as preliminary only. Future monitoring may indicate additional sources to be considered.

POTENTIAL SOURCES OF GROUNDWATER POLLUTION IN THE SALT RIVER VALLEY

Municipal and Industrial

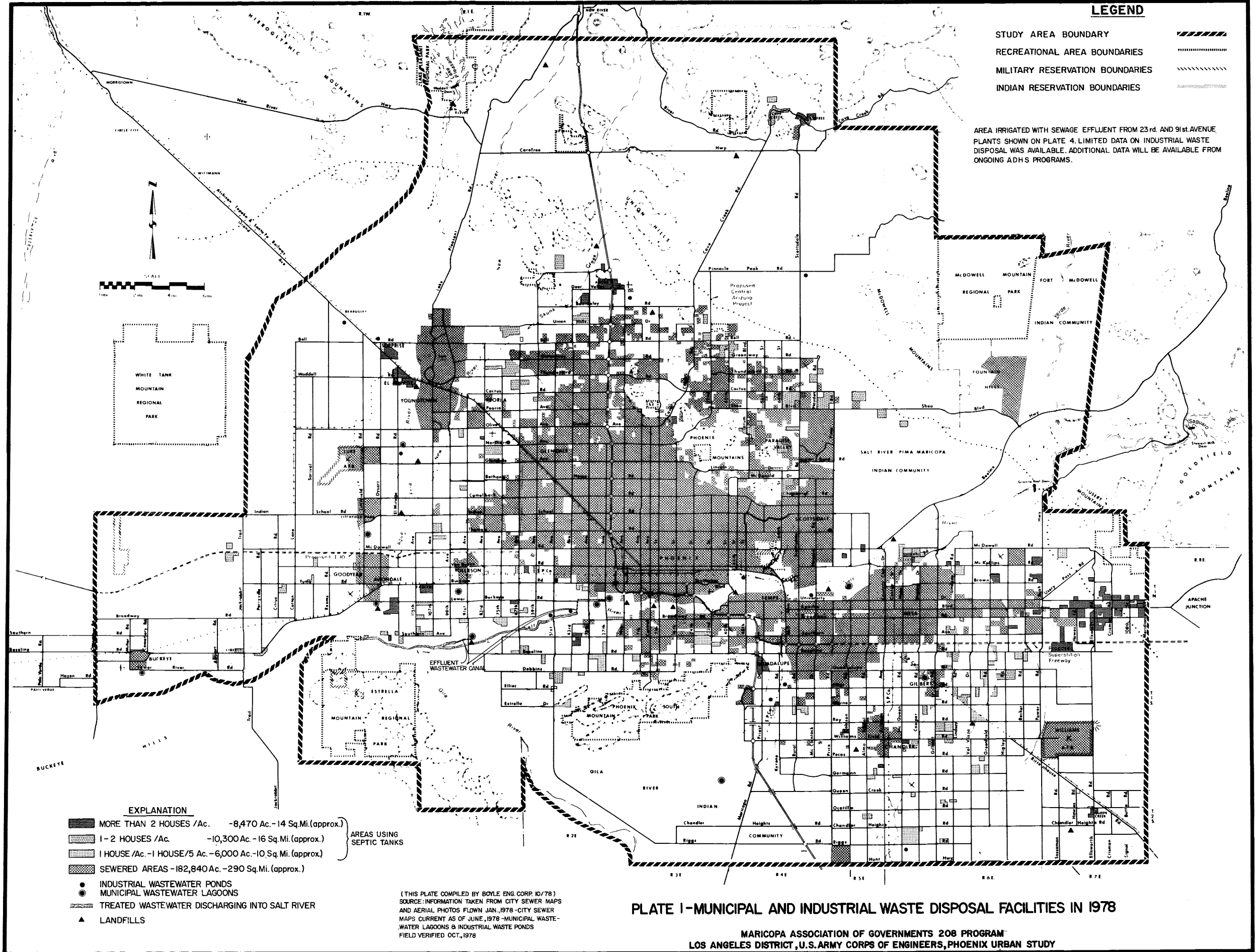
Plate 1 shows the location of municipal and industrial waste disposal facilities in 1978, as mapped by Boyle Engineering Corporation. Urban storm water disposal facilities and lawn irrigation are shown on accompanying plates.

Septic Tanks: Sewered areas and urban areas relying on septic tanks are shown in Plate 1. In general, septic tank areas are located on the fringes of sewered areas and eventually become sewered. Three classifications of septic tank density are mapped. Perhaps the largest concentration of dense septic tanks is east of Mesa near Apache Junction. There are also several areas of relatively dense septic tanks north of Scottsdale. Significant concentrations of septic tanks are present east and southeast of Gilbert. In the West Basin, the communities of Surprise and El Mirage rely on septic tanks and there are several areas of relatively dense septic tanks south of the Salt River and east of the Gila River. In 1978, there were almost 8,500 acres in the valley that contained more than two septic tanks per acre. An additional 10,300 acres had between one and two septic tanks per acre. It is estimated that about 25 percent of the septic tank areas will be sewered within the next five to ten years. However, there is a substantial possibility that there will be new areas developed that utilize septic tanks, particularly in Glendale, north of Phoenix, and Scottsdale.

LEGEND

- STUDY AREA BOUNDARY
- RECREATIONAL AREA BOUNDARIES
- MILITARY RESERVATION BOUNDARIES
- INDIAN RESERVATION BOUNDARIES

AREA IRRIGATED WITH SEWAGE EFFLUENT FROM 23rd AND 91st AVENUE PLANTS SHOWN ON PLATE 4. LIMITED DATA ON INDUSTRIAL WASTE DISPOSAL WAS AVAILABLE. ADDITIONAL DATA WILL BE AVAILABLE FROM ONGOING ADHS PROGRAMS.



EXPLANATION

- MORE THAN 2 HOUSES /Ac. -8,470 Ac.-14 Sq.Mi.(approx.)
- 1-2 HOUSES /Ac. -10,300 Ac.-16 Sq.Mi. (approx.)
- 1 HOUSE /Ac.-1 HOUSE/5 Ac.-6,000 Ac.-10 Sq.Mi. (approx.)
- SEWERED AREAS -182,840 Ac.-290 Sq.Mi. (approx.)
- INDUSTRIAL WASTEWATER PONDS
- MUNICIPAL WASTEWATER LAGOONS
- TREATED WASTEWATER DISCHARGING INTO SALT RIVER
- LANDFILLS

(THIS PLATE COMPILED BY BOYLE ENG CORP 10/78)
SOURCE: INFORMATION TAKEN FROM CITY SEWER MAPS
AND AERIAL PHOTOS FLOWN JAN, 1978 -CITY SEWER
MAPS CURRENT AS OF JUNE, 1978 -MUNICIPAL WASTE-
WATER LAGOONS & INDUSTRIAL WASTE PONDS
FIELD VERIFIED OCT., 1978

PLATE I-MUNICIPAL AND INDUSTRIAL WASTE DISPOSAL FACILITIES IN 1978

MARICOPA ASSOCIATION OF GOVERNMENTS 208 PROGRAM
LOS ANGELES DISTRICT, U.S.ARMY CORPS OF ENGINEERS, PHOENIX URBAN STUDY

Sewage Effluent: Plate 1 also shows the location of ponds for sewage effluent and reaches of stream channels where effluent is disposed. Over 180,000 acres of urban land were sewered as of 1978. Ponds were located at the Mesa, Gilbert, and Chandler sewage treatment plants in the East Basin. Ponds were located at the following plants in the West Basin: Luke Air Force Base, Litchfield Park, Tolleson, Avondale, 91st Avenue, 23rd Avenue, and Buckeye.

Sewage effluent from both the 23rd and 91st Avenue plants was discharged to the Salt River channel. According to Halpenny and Greene (1975), effluent from the 23rd Avenue plant has been discharged to the Salt River since the 1920's. Halpenny and Greene (1975) indicated that about 32,000 acre-feet, or 80% of the effluent from the 23rd Avenue plant, percolated in 1974. Effluent from the 91st Avenue plant has been discharged to the river since 1959, at which time the river was normally dry except for flood flows. By 1962, effluent from the 91st Avenue plant flowed all the way to the Buckeye Heading, a distance of six and one-half miles. Presently, all of the flow in the Gila River is diverted at the Buckeye Heading except during brief periods required for cleaning the canal and during high flood flows. Halpenny and Greene (1975) indicated that percolation losses between 91st Avenue and the Buckeye Heading amounted to about 35 percent of the effluent discharge prior to 1965 and 26 percent in 1966-67. Smaller discharges of sewage effluent to channels have also been made by Tolleson (Salt River near 91st Avenue) and Avondale (Gila River just below the confluence with the Agua Fria River).

Sewage effluent has been used for irrigation by the Buckeye Irrigation Company since 1962 and the canals distributing this effluent are shown on Plate 4. Eight hundred acre-feet were diverted in 1962, and 22,100 acre-feet in 1966. Separate records are not available for sewage effluent diversions since 1966, but by 1974 an estimated 70,000 acre-feet of effluent were diverted. There are 18,000 acres of farmland in the Buckeye Irrigation District. The effluent is mixed with groundwater and a small amount of other surface water. The effluent comprised about one-half of the irrigation water available in the district in 1974 (Halpenny and Greene, 1975). The Buckeye Irrigation Company has a long-term entitlement to 30,000 acre-feet per year of effluent. There is additional irrigation with effluent near the Mesa and Tolleson plants. Forty acres of farmland are irrigated with effluent from the Mesa STP. The Roosevelt Irrigation District may take about 20,000 acre-feet per year of reclaimed water from the 23rd Avenue STP. Effluent from this plant would receive land treatment similar to that for the Flushing Meadows Project. This effluent would be highly diluted with other water prior to its use for irrigation in the District.

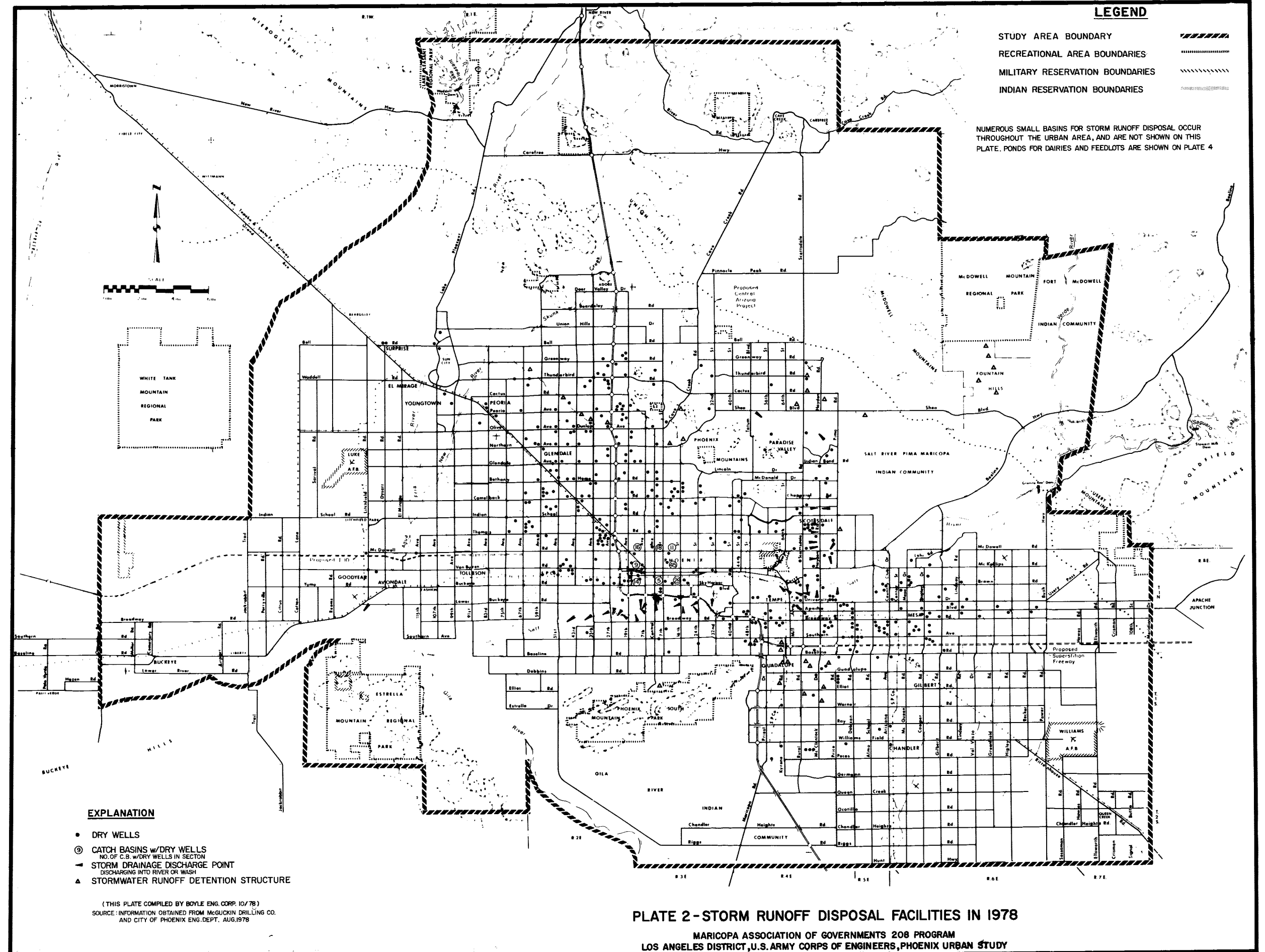
Landfills: The locations of landfills are also shown on Plate 1. There were six active landfills in the East Basin in 1978, two of which were near the Salt River channel. There were twelve active landfills in the West Basin in 1978, four of which were along the Agua Fria River and five of which were along the Salt River. Many of the landfills along stream channels are located in abandoned gravel pits. There are also numerous abandoned landfills along the Salt River between Mesa and downtown Phoenix. For landfills near stream channels, there is substantial potential for leachate formation due to contact with surface water or groundwater.

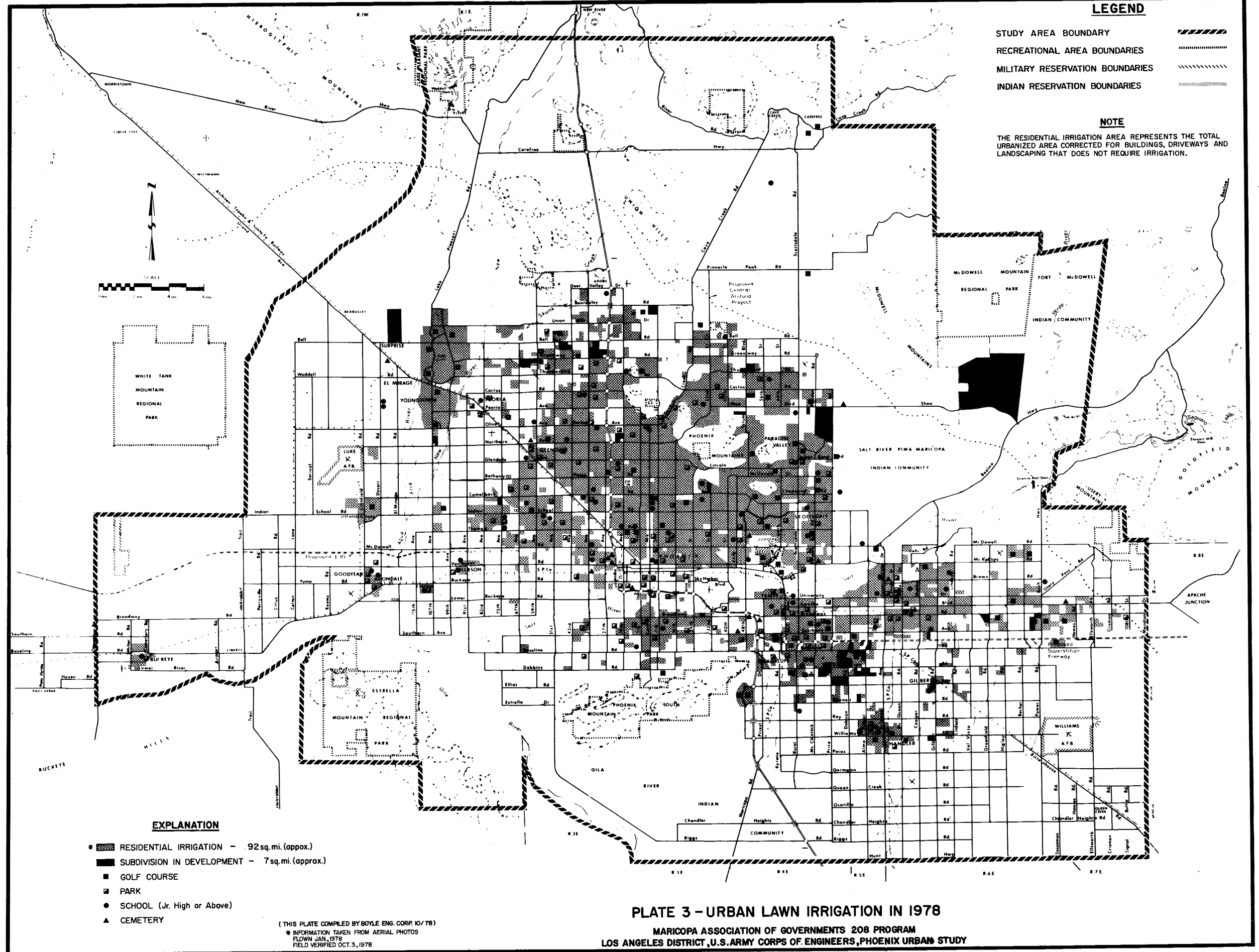
Industrial Wastes: Limited information is available on on-site disposal methods by industries in the Salt River Valley. Plate 1 shows locations where ponds or seepage pits were used for disposal of industrial wastes in 1978. This information is not complete due to lack of data. Ponds were present at power plants, a sugar beet processing facility, and several industries south and southwest of Phoenix. Halpenny and Greene (1975) noted a discharge of about 1,500 acre-feet per year of wastewater into the Salt River near 23rd Avenue. This was believed to be cooling water from downtown Phoenix. More detailed information should be available within several years from ADHS programs, especially through the surface impoundment assessment and hazardous waste program. The potential for on-site disposal of industrial wastes in the future is great because of forthcoming constraints on disposal to sewers and landfills.

Storm Runoff: Plate 2 shows the location of storm runoff facilities in 1978, as determined by Boyle Engineering Corporation. Points of discharge to stream channels, detention ponds, and dry wells are included. In addition, some urban storm runoff is disposed to canals, particularly the Arizona and Grand Canals. The average volume of urban storm runoff on an annual basis is unknown. In the East Basin there were twelve points of discharge to Indian Bend Wash and seven to the Salt River channel. In the West Basin, there were eighteen points of discharge to the Salt River channel and one to the Gila River channel. There were seventeen detention basins in the East Basin, most of which were in Scottsdale and Paradise Valley. There were also five detention basins west of the Verde River at Fountain Hills. There were eleven detention basins in the West Basin. In addition there are many small basins for storm runoff in residential areas which are not shown on Plate 2.

Dry wells are used extensively for disposal of storm runoff throughout Phoenix, Scottsdale, Tempe, Mesa, and Glendale. Such wells are commonly filled with rock placed around a four-foot diameter concrete liner. The liner is used to enable settling of suspended material. A four-inch diameter pipe extends from inside the liner to the bottom of the dry well. Suspended and floatable material remains in the liner and the four-inch pipe is perforated below the liner to allow sufficient percolation. The wells must tap a five to ten foot thickness of clay-free sand, gravel, or cobbles in order to work. Frequently these wells are used in combination with catch basins, particularly in downtown Phoenix. In 1978 there were about 150 dry wells in use in the East Basin and 250 in the West Basin.

Lawn Irrigation: Plate 3 shows the location of urban lawn irrigation in 1978, as determined by Boyle Engineering Corporation. Residential areas, parks, schools, cemeteries, and golf courses are included. The residential area exclusive of roadways and buildings was determined to be about 120,000 acres and it is estimated that about one-half of this area is not irrigated. Thus approximately 60,000 acres of residential area were irrigated in the urban area in 1978. This acreage compares with an estimated 350,000 acres of cropland irrigated in the valley in 1975. Based on data from the Arizona Water Commission (1978), it is estimated that about 250,000 acre-feet of water were used for urban irrigation in 1975. The return flow from urban





irrigation is not precisely known, but is likely less than 50,000 acre-feet per year.

Leaking Sewers: Sewers are a major potential source of groundwater pollution in the Salt River Valley. Due to the nature of the regional sewage treatment system for much of the urban area, relatively long interceptors convey sewage to the 23rd and 91st Avenue plants. Also, some of the smaller plants such as for Chandler, are some distance from the area served and thus require long interceptors. Leakage, in amounts that could adversely impact groundwater quality, is unknown for the major sewers. In the past, leakage from sewers has been considered more from the viewpoint of maintenance and operation of sewers than from the standpoint of potential adverse effects on groundwater quality. The major areas of concern would be where large interceptors overlie groundwater of excellent quality. Such areas include the northern part of Paradise Valley, the northern part of the West Basin, and the eastern part of Mesa.

Agricultural

Plate 4 shows the location of agricultural irrigation and selected feedlots and dairies, as determined by Boyle Engineering Corporation.

Irrigation: The Arizona Water Commission (1978) reported that there were about 350,000 acres of irrigated land in the Salt River Valley in 1975. This was about three-fourths of the total irrigated cropland in Maricopa County in 1975. The estimated volume of applied water for irrigation was about 2,100,000 acre-feet in 1975, or an average application rate of about 6.1 feet per acre per year. Of this applied water, an estimated 1,400,000 acre-feet were consumed by evapotranspiration and the remaining 700,000 was recharged through canal seepage and irrigation return flow. Crop acreage is projected to decline to about 270,000 acres by 2005 due primarily to urban displacement of agricultural lands.

Feedlots and Dairies: There were about one dozen feedlots in the Salt River Valley in 1978. These were generally scattered throughout the rural parts of the valley, although four were concentrated in the Palo Verde area. There were about 120 dairies in the Salt River Valley in 1978. There were numerous dairies south of the Salt River in the East Basin, particularly southeast of Chandler. In the West Basin, dairies were concentrated west of Glendale and in the Tolleson-Avondale area.

Plate 4 shows the location of feedlots and dairies where ponds were in use in 1978, as determined by Boyle Engineering Corporation. Many of these ponds are used primarily for storm runoff in the rainy seasons. Five feedlots had such ponds in the East Basin and five in the West Basin. About 35 dairies had ponds in the East Basin and nine in the West Basin.

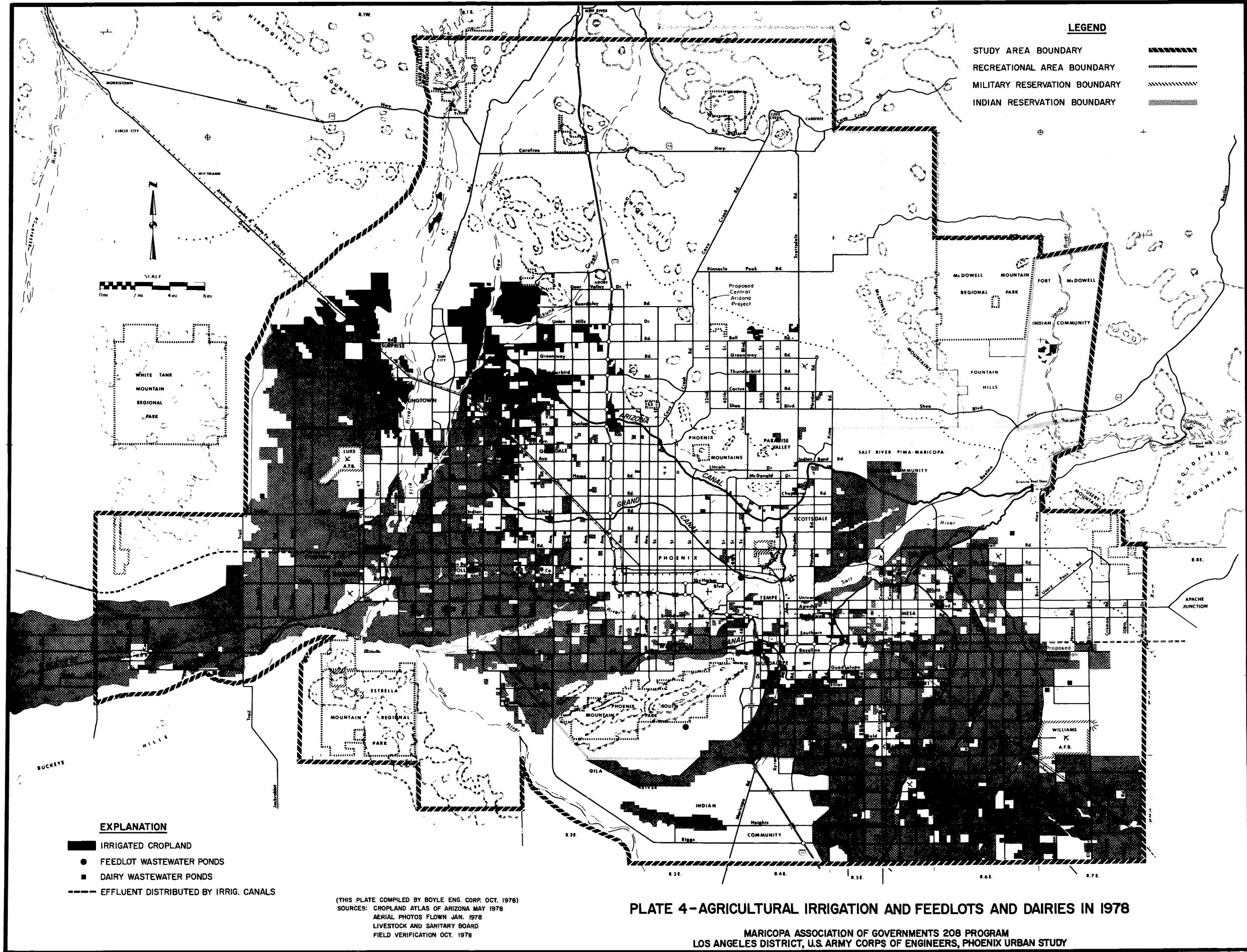
Hydrologic Modification

Substantial amounts of Central Arizona Project water will be available to the Salt River Valley. Based on the latest information, the Arizona Water Commission (1978) estimated that about 510,000 acre-feet per year would be available in 1990 and about 380,000 acre-feet in 2020. The major deliveries will apparently be for urban use and irrigation use primarily in areas outside of the Salt River Project, Buckeye Irrigation District, and Roosevelt Irrigation District. Substantial amounts of salt will be contained in this imported water. The salinity of CAP water will be approximately 90 percent greater than that of water from the Salt and Verde Rivers. At an average salinity of 735 mg/l, the annual salt import contained in 510,000 acre-feet of water is about 510,000 tons. This is roughly equivalent to the annual average salt load in the Salt and Verde Rivers at Granite Reef diversion dam.

However, salts entering the valley in imported water do not instantaneously enter the groundwater. Also, potential increases in groundwater salinity would be mitigated by precipitation of some salt in the topsoil and vadose zone. Significant amounts of salt are now exported from the valley through tailwater disposal and drainage pumpage. In the future, additional salts will leave the valley through drainage pumpage and export of sewage effluent to the Palo Verde Nuclear Generating Station.

Shallow groundwater levels have caused water-logging west of Buckeye in the past decade. As a remedial measure, drainage wells have been constructed in this area to lower water levels. Drainage wells were first placed in operation by the Buckeye Irrigation Company in 1969, and six wells were in use by 1975. Halpenny and Greene (1975) indicated that pumpage from these drainage wells was 11,500 acre-feet in 1974. The estimated total dissolved solids in drainage well pumpage is about 3,700 mg/l. The salt export in 11,500 acre-feet per year of drainage pumpage is thus about 58,000 tons per year. Halpenny and Greene (1975) estimated that about 18,000 acre-feet of tailwater and spills from the Buckeye Irrigation District were disposed to the Gila River or the Arlington Canal in 1974. The amount of tailwater and spills disposed from the Roosevelt Irrigation District into the Hassayampa River was not specified, but it is estimated to have been about 5,000 acre-feet per year. Thus the total export of tailwater and spills from the Salt River Valley was about 23,000 acre-feet in 1974. The salinity of this water is not precisely known, however about 110,000 tons per year of salt would be exported, assuming a salinity of 3,500 mg/l. Thus about 170,000 tons of salt were exported from the valley by drainage pumpage and tailwater in 1974.

Halpenny and Greene (1975) estimated that 28,000 acre-feet of drainage pumpage might be necessary by 1985. The salt export in this water, assuming the same salinity as at present, would be about 140,000 tons per year. About 107,000 acre-feet of effluent would be used for five units at the Palo Verde Nuclear Generating Station. Assuming an average salinity of 800 mg/l for the effluent, 117,000 tons of salt per year would be exported from the Salt River Valley. These two sources would thus add an additional



200,000 tons of salt export per year.

Arthur Beard Engineers, Inc. and CDM, Inc. (1977) presented estimates of salt additions from various sources in the valley. Clearly, more salt is now entering the valley in surface water inflow than is leaving the valley by surface water outflow. However, in terms of groundwater, the more important factor is the amount of salt entering and leaving the groundwater. To determine this, both mineral dissolution and salt precipitation in the soil-aquifer system must be known. Unfortunately, minimal information on these processes in the Salt River Valley is available. The magnitude of these processes likely greatly exceed relatively minor salt additions, for example, those due to the domestic use of water.

Groundwater salinity in the valley has not increased on a regional scale since the 1920's, despite the fact that large amounts of irrigation return flow are not present in the aquifer. This fact is contradictory to the projections made by some previous investigators on the basis of salt balances for surface water inflow and outflow. One of the primary reasons is likely the precipitation of calcium and magnesium carbonate and sulfate in the topsoil and vadose zone, and possibly in the aquifer. Thus the fact that more salts enter the valley in surface water than leave the valley does not necessarily imply that the groundwater salinity will increase. Furthermore, salt balances must eventually be applied to individual parts of the aquifer in the valley to be meaningful.

EFFECT OF MAN'S ACTIVITIES IN THE SALT RIVER VALLEY

East Basin

There are several areas of the East Basin where man's activities appear to have affected groundwater. The influence of irrigation with Salt River water was noted in the companion report on existing water quality. Salinity and chloride content, in particular, are noticeably higher beneath lands irrigated with Salt River water compared to adjacent areas. This is due to several factors. First, lands irrigated with Salt River water have generally been irrigated for much longer period of time than adjacent areas. Second, depth to water is generally much less beneath lands irrigated with Salt River water than beneath adjacent areas. Both factors enable the effects of irrigation return flow to be manifested earlier beneath lands irrigated with Salt River water. Lastly, the chemical composition of Salt River water is different than that of natural sources of recharge in parts of the East Basin away from the Salt River. Under natural conditions, streamflow seepage and mountain-front recharge in places such as the Queen Creek area contributed small amounts of recharge over long periods of time. This water was of much lower salinity and chloride content than Salt River water, and the chemical composition of groundwater in such areas still partly reflects recharge from these natural sources.

There is a localized plume of high nitrate content southwest of the area irrigated with City of Mesa sewage effluent. Nitrate contents exceed 45 mg/l beneath an area apparently less than 1,000 acres in size. The regional direction of groundwater movement in this area is to the southwest. This is one of the few point sources in the Salt River Valley that has affected the quality of water pumped from large-capacity wells. Potential sources associated with the sewage treatment plant include return flow from crop irrigation with effluent, seepage from effluent holding ponds, and seepage from sludge drying beds.

The salinity of well water has decreased in some areas due to pumpage and subsequent dewatering of shallow strata with a higher salinity than that of the underlying water. This trend occurred from the 1930's to the 1950's in water pumped from numerous wells near Tempe and Mesa. It is still occurring in parts of Scottsdale and Paradise Valley due to dewatering of alluvial deposits overlying deeper conglomerate layers.

Salinity has increased since about 1950 in water from wells northwest of Chandler. The average increase is about 20 mg/l per year in an area about 12,000 acres in size. This increase is due to altered groundwater flow directions caused by pumping. Groundwater of higher salinity from the southwest has moved to the north and east into areas of previously lower salinity groundwater. Also, pumping has induced downward movement of shallower groundwater of higher salinity into the producing zones of wells in this area. There have also been increases in salinity of well water in the Gilbert area since 1955. The average increase is about 20 mg/l per year in an area about 7,000 acres in size. Irrigation return flow, the presence of a regional perched groundwater zone, and numerous cascading wells are believed to be the causative factors. Wells perforated above the water table where perched water is present allow water to cascade down the well. Thus part of the vadose zone is bypassed and the effects of irrigation return flow are manifested sooner.

High contents of chromium, arsenic, and fluoride are present in groundwater beneath part of Scottsdale and Paradise Valley. In some cases, these contents exceed the Primary Drinking Water Regulations Maximum Contaminant Levels. The high contents of these constituents are due to natural factors. Groundwater southwest of Chandler is of high salinity, which is also apparently due to natural factors.

West Basin

Man's activities have noticeably affected groundwater quality in several parts of the West Basin. The influence of irrigation with Salt River water is similar to that described for the East Basin. Salinity and chloride content, in particular, are noticeably higher beneath lands irrigated with Salt River water compared to adjacent areas. Nitrate content and salinity have decreased considerably in groundwater of the Glendale and West Phoenix area since the 1930's. This is primarily due to the dewatering of shallow strata which were high in salinity and nitrate prior to large-scale pumpage.

Nitrate contents are high in water pumped from large-capacity wells near the 23rd Avenue sewage treatment plant. Sources of nitrogen include holding ponds for effluent, sludge drying beds, and nearby fields irrigated with effluent. The influence apparently extends for about one mile from the ponds. This is one of the few point sources that has impacted the quality of water pumped from large-capacity wells in the valley.

In the Buckeye Irrigation District, two predominant factors have greatly affected groundwater salinity since the 1930's. As noted by Halpenny and Greene (1975), the salinity of groundwater tapped by Buckeye Irrigation Company wells more than doubled between 1930 and 1943, from an average of 1,170 to 2,890 mg/l. This was apparently due to the deterioration in quality of the surface water supply, which was primarily irrigation tailwater from other areas. The importation of sewage effluent since 1962 has caused substantial changes in salinity and nitrate content of well water. Since the salinity of the sewage effluent is about 800 mg/l, it is of substantially lower salinity than groundwater in the area. The salinity of groundwater has decreased between Liberty and Hassayampa since 1970. Effluent provides about one-half of the present water supply to the district, and thus substantially dilutes the salinity of water pumped from wells. Nitrate contents in water from wells east of Buckeye have substantially increased since the 1960's, which is attributed to the high nitrogen content of the sewage effluent.

In the Goodyear-Liberty area, salinity has markedly increased since the early 1960's in water from a number of wells. The increase in salinity has ranged from 40 to 140 mg/l per year, in an area about 15,000 acres in size. This problem is due to altered groundwater flow directions due to pumpage. Groundwater of poor quality beneath the Gila River and in the eastern part of the Buckeye Irrigation District is now moving northerly toward Luke Air Force Base, where a large pumping depression is located.

High nitrate contents in Glendale and West Phoenix appear to be largely due to natural factors, as they were present in the 1920's prior to large-scale pumpage. However, irrigation return flow has been present for decades and is a potential source. A concentration of dairies is present west of Glendale and is also a potential source. High fluoride contents west of the Agua Fria River are also due to natural factors. Contents of both nitrate and fluoride frequently exceed the Primary Drinking Water Regulations Maximum Contaminant Levels in the West Basin. High salinity in groundwater near the Gila River is also apparently of natural origin.

THE AGUILA AREA

Plate 5 shows the location of potential sources of groundwater pollution in the Aguila area. Return flow from crop irrigation comprises the major potential source and there is one landfill near Aguila. There were approximately 105 septic tanks in use at Aguila in 1977 and they produced approximately 53,000 gallons per day of effluent (Maricopa Association of Governments, 1977).

In 1975, there were about 20,000 acres of irrigated cropland in the Aguila area (Arizona Water Commission, 1978). Water is supplied entirely by groundwater pumpage, which amounted to about 100,000 acre-feet in 1975. Of this amount, an estimated 70,000 acre-feet were consumed by evapotranspiration and 30,000 acre-feet percolated past the root zone as irrigation return flow.

Water quality records available for large-capacity wells in the area indicate no noticeable effect from irrigation. In large part, this is due to the relatively great depth to water (greater than 300 feet) and the fact that there has been large-scale irrigation for only about two decades. Significant volumes of irrigation return flow have likely not reached the water table of the main aquifer, because the alluvial deposits above the water table were moisture deficient prior to irrigation. Water samples have also not been collected and analyzed at sufficient intervals to precisely determine long-term trends in groundwater quality.

There has been no reported monitoring of groundwater near the Aguila landfill. The Aguila Water Service provides water for public supply at Aguila. The well in use is over 800 feet deep, the top of the perforations are at 660 feet and depth to water in 1969 was 470 feet. Thus proper septic-tank effluent disposal poses no threat to groundwater quality in this area.

LOWER HARQUAHALA VALLEY

Plate 6 shows the location of potential sources of groundwater pollution in the Lower Harquahala Valley. Virtually the only significant potential source of groundwater pollution is return flow from crop irrigation. About 25,000 acres of cropland were irrigated in the Lower Harquahala Valley in 1975 (Arizona Water Commission, 1978). Water is supplied entirely by groundwater pumpage, which amounted to about 125,000 acre-feet per year in 1975. Of this amount, an estimated 90,000 acre-feet were consumed by evapotranspiration and 35,000 acre-feet percolated past the root zone as irrigation return flow. Water quality records available for large-capacity wells in the valley indicate no noticeable effect from irrigation. In large part, this is due to the relatively great depth to water (greater than 300 feet) and the fact that there has been large-scale irrigation for only about two decades. As in the Aguila Area, significant volumes of irrigation return flow have likely not reached the water table of the main aquifer because the alluvial deposits above the water table were moisture deficient prior to irrigation. Much of the return flow may be present in perched zones above the main aquifer. Water samples also have not been collected and analyzed at sufficient intervals to determine long-term trends in groundwater quality.

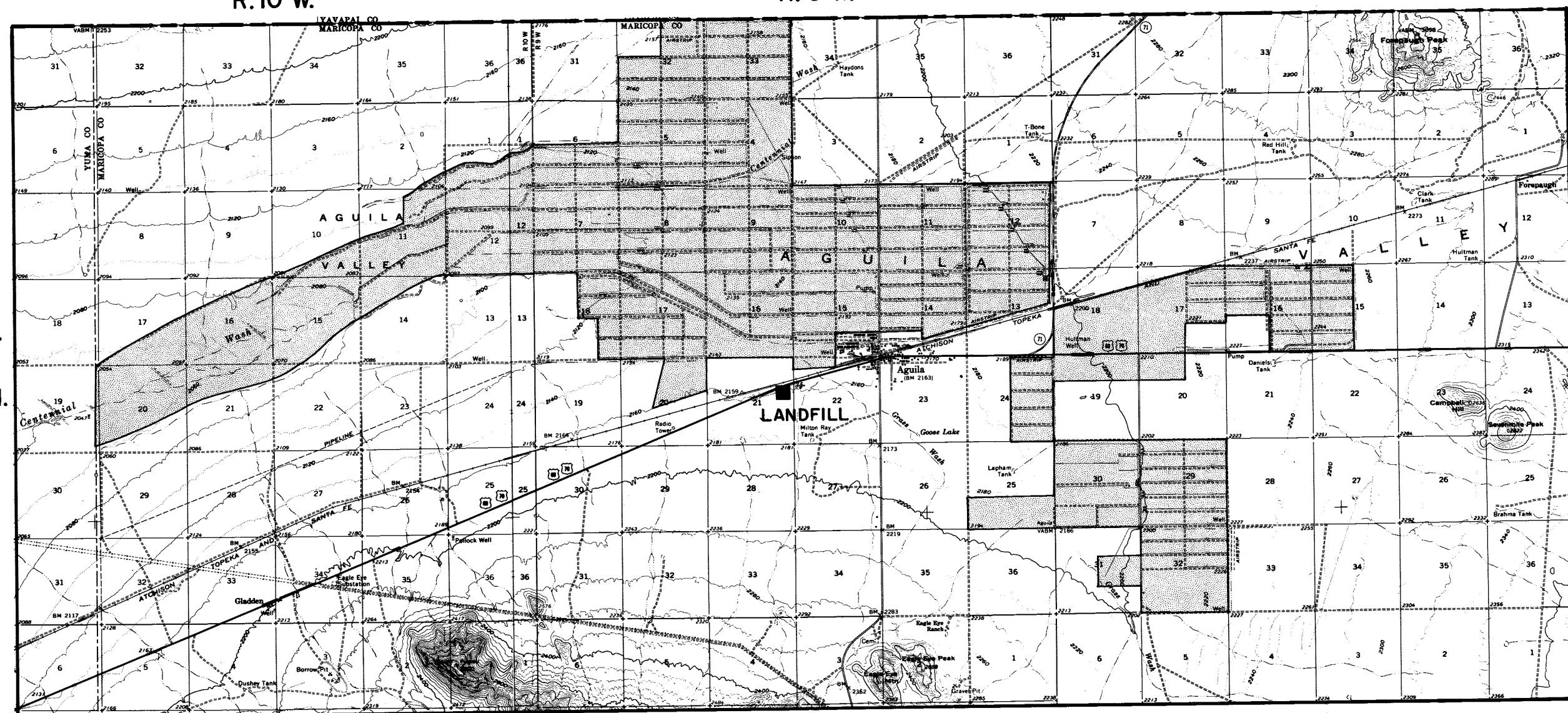
Recent unpublished work by the Arizona State Land Department, Water Rights Division, delineated the presence of a large perched zone beneath irrigated lands in the Lower Harquahala Valley. Water levels in the perched zone were hundreds of feet higher than water levels in the main aquifer in 1978. Limited water quality data for the perched zone indicate high salinity and

R. 10 W.

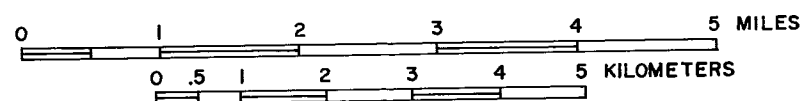
R. 9 W.

R. 8 W.

T.
7
N.



BASE FROM U.S. GEOLOGICAL SURVEY



EXPLANATION

IRRIGATED AREA IN 1972 FROM ORTHOPHOTOQUADS OF ARIZONA RESOURCES INFORMATION SYSTEM. INCLUDES FALLOW LAND.

**OTHER POTENTIAL SOURCES FROM MARICOPA
ASSOCIATION OF GOVERNMENTS (1977a).**

PLATE 5.--AGRICULTURAL IRRIGATION AND OTHER POTENTIAL
SOURCES IN THE AGUILA AREA.

MARICOPA ASSOCIATION OF
GOVERNMENTS 208 PROGRAM

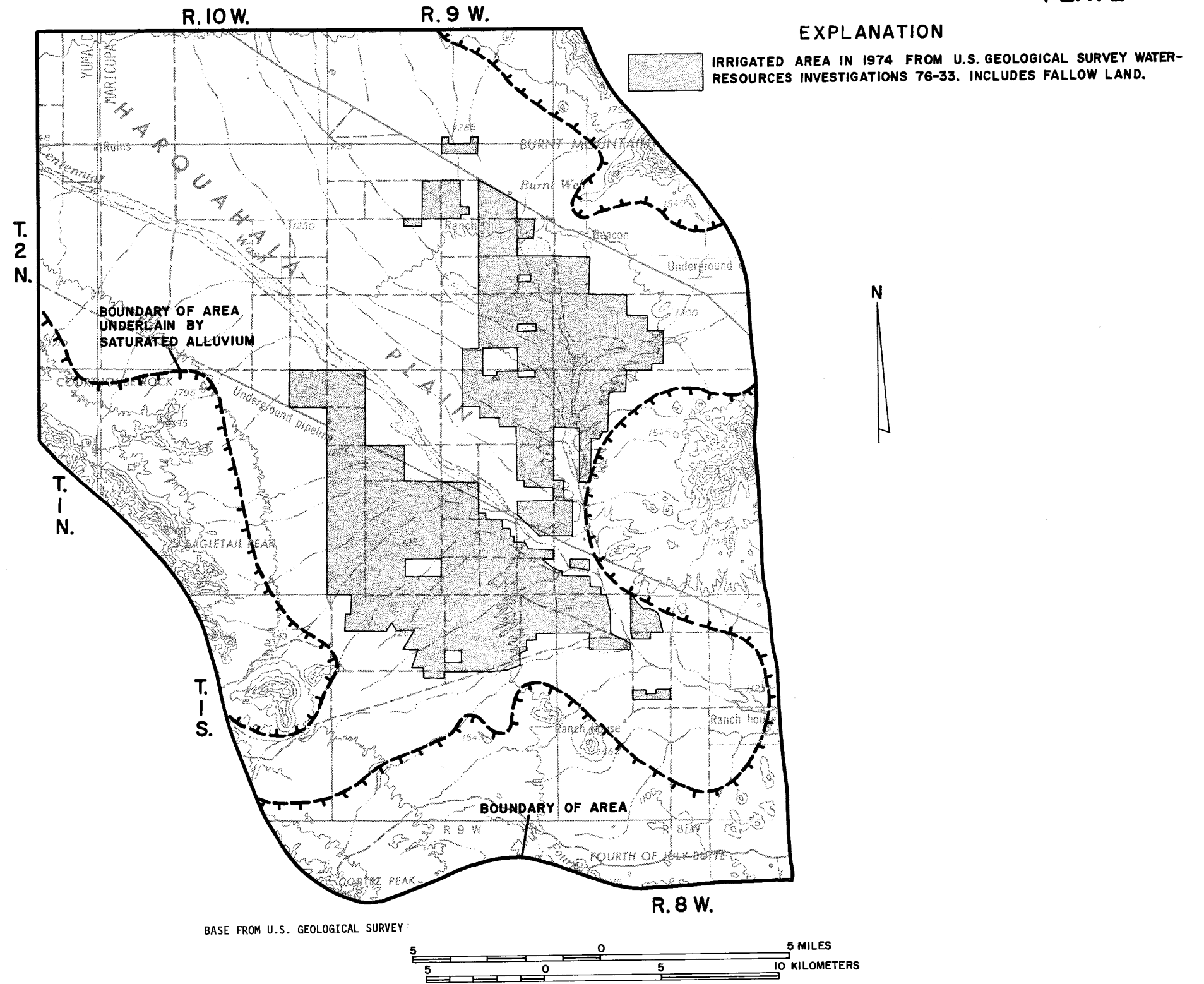


PLATE 6.--AGRICULTURAL IRRIGATION IN THE LOWER HARQUAHALA VALLEY.

MARICOPA ASSOCIATION OF
GOVERNMENTS 208 PROGRAM

nitrate content compared to that for water in the main aquifer. Water in the perched zone is believed to be largely comprised of irrigation return flow. Numerous cascading wells are present. Present data indicate that there may be substantial water quality problems due to irrigation return flow in future decades.

Substantial amounts of Central Arizona Project water will be available to the Harquahala Irrigation District in 1985. The projected volume of water to be available is about 145,000 acre-feet in 1990 and 70,000 acre-feet in 2020. This imported water contains substantial amounts of salt. At an average salinity of 735 mg/l, the annual amount of imported salt in 145,000 acre-feet of water is about 145,000 tons.

LOWER HASSAYAMPA AREA

Plate 7 shows the location of potential sources of groundwater pollution in the Lower Hassayampa Area. Return flow from crop irrigation comprises the major potential source. In 1975, there were about 19,000 acres of irrigated cropland in the Lower Hassayampa Area (Arizona Water Commission, 1978). Water supply for irrigation is primarily from groundwater, although about 15,000 acre-feet per year of surface water is imported to the area through the Arlington Canal. In 1975, groundwater pumpage supplied an additional 95,000 acre-feet per year. Of the total 110,000 acre-feet of water applied, an estimated 70,000 acre-feet was consumed by evapotranspiration and the remaining 40,000 acre-feet percolated past the root zone as irrigation return flow. A total of 140,000 acre-feet per year of sewage effluent may be imported to the area for use at the PVNGS. All of this water is to be consumed and the salt reportedly kept from entering the groundwater.

A significant amount of Central Arizona Project water will be available. In 1990, about 90,000 acre-feet per year will be available. In 2020, about 120,000 acre-feet per year will be available. This water will contain substantial amounts of salt. Assuming a salinity of about 735 mg/l, the annual amount of imported salt in 100,000 acre-feet is about 100,000 tons. In general, it will take decades or longer for this salt to affect the groundwater. Precipitation of salt in the topsoil and vadose zone would mitigate potential increases in groundwater salinity.

There is one landfill at Hassayampa, one feedlot near Gillespie Dam, and one dairy north of Hassayampa. A very important future potential source is the evaporation pond and salts at the Palo Verde Nuclear Generating Station. The Maricopa Association of Governments (1977) reported that about 2,000 acres of ponds or former ponds would ultimately be present. Another potential source is the proposed oil refinery located southwest of the PVNGS.

Water quality records for large-capacity wells away from the Gila and Hassayampa Rivers indicate no noticeable effect from irrigation, except for the perched layer at the Palo Verde Nuclear Generating Station. The perched groundwater at the PVNGS site is of poor chemical quality, and this has been attributed to irrigation return flow (Arizona Public Service

Company, 1975). Extensive irrigation away from the Gila River has been practiced for about 25 years. In this area substantial volumes of return flow have probably not reached the water table in the main aquifer. However, the quality of water in the perched zone indicates that there may be substantial water quality problems due to irrigation return flow in future decades. Water samples have not been collected and analyzed at sufficient intervals to determine long-term trends in groundwater quality.

Near the Gila River where depth to water is less than fifty feet, irrigation has been practiced for a longer period. Substantial volumes of irrigation return flow have reached the water table. However, other factors also highly influence the quality of groundwater in this area. For example, evapotranspiration by phreatophytes can increase the salinity of shallow groundwater. Other factors include disposal of sewage effluent and tailwater to the Hassayampa and Gila Rivers. A sufficient number of wells near the Gila River have not been sampled at sufficient intervals to provide information on the effect of these various factors. There has been no sampling reported for groundwater near the dairy and feedlot. Schmidt and Scott (1977) reported on sampling of groundwater near the Hassayampa landfill. They concluded that there had been no noticeable impact on the quality of water pumped from nearby wells. However, there were no on-site monitoring wells at the landfill at that time.

RAINBOW VALLEY

Plate 8 shows the location of potential sources of groundwater pollution in Rainbow Valley. Return flow from crop irrigation is the predominate potential source. Some irrigation tailwater is disposed to Waterman Wash and there is one landfill in the northeast part of the area.

There were about 11,000 acres of irrigated crops in the valley in 1975 (Arizona Water Commission, 1978). Water is supplied entirely by groundwater pumpage. In 1975 the annual pumpage was about 65,000 acre-feet. Of this amount, an estimated 40,000 acre-feet per year was consumed by evapotranspiration and the remaining 25,000 acre-feet percolated past the root zone as irrigation return flow.

Water quality records available for large-capacity wells in the area indicate no noticeable effect from irrigation. In part, this is due to the relatively great depth to water (greater than 300 feet) and the fact that there has been large-scale irrigation for only about two decades. Significant volumes of irrigation return flow have likely not reached the water table of the main aquifer, because the alluvial deposits above the water table were moisture deficient prior to irrigation. Water samples have not been collected and analyzed at sufficient intervals to determine long-term trends in groundwater quality. There has been no reported monitoring of groundwater near the landfill in Rainbow Valley.

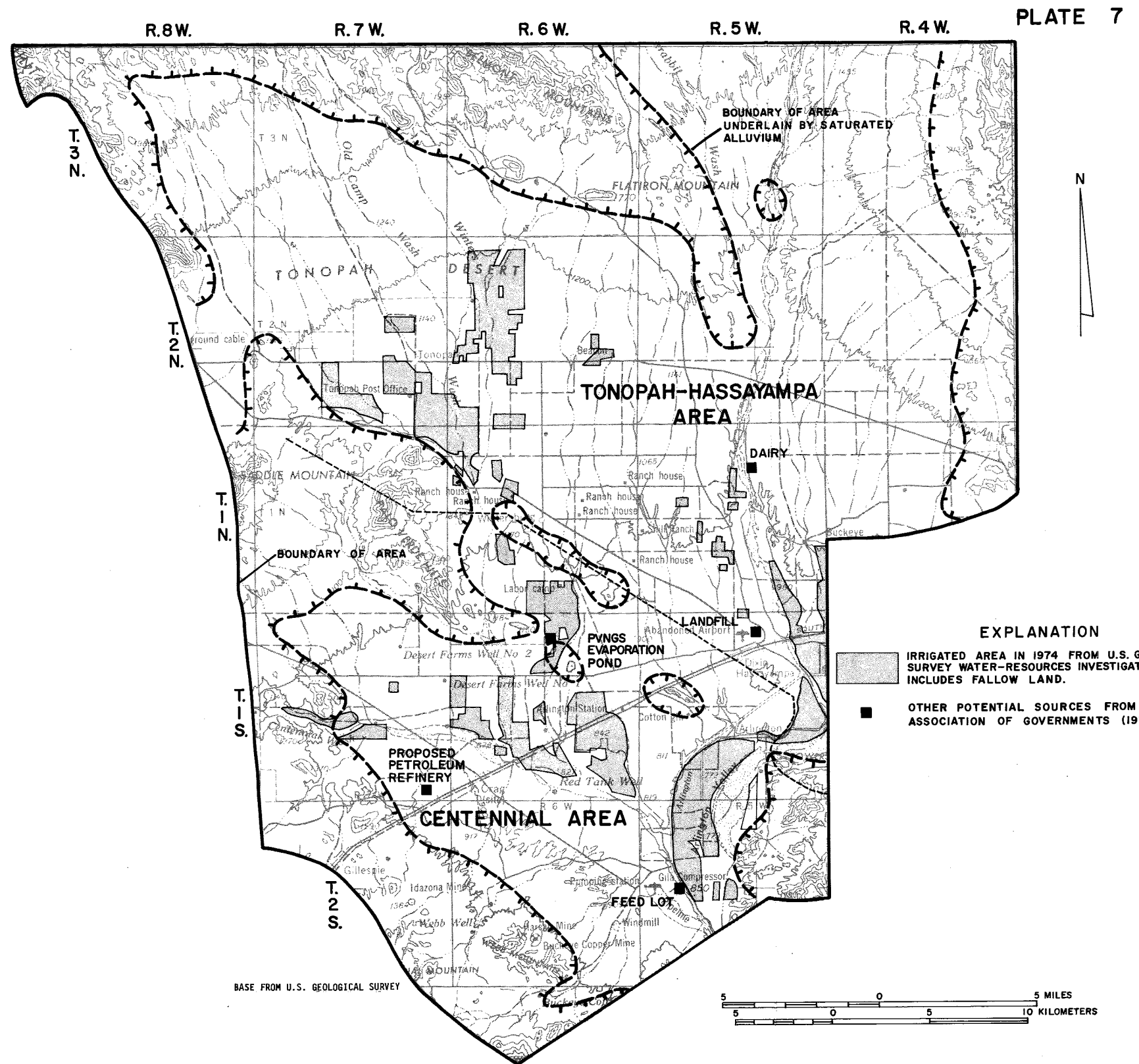


PLATE 7.--AGRICULTURAL IRRIGATION AND OTHER POTENTIAL
SOURCES IN THE LOWER HASSAYAMPA AREA.

MARICOPA ASSOCIATION OF
GOVERNMENTS 208 PROGRAM

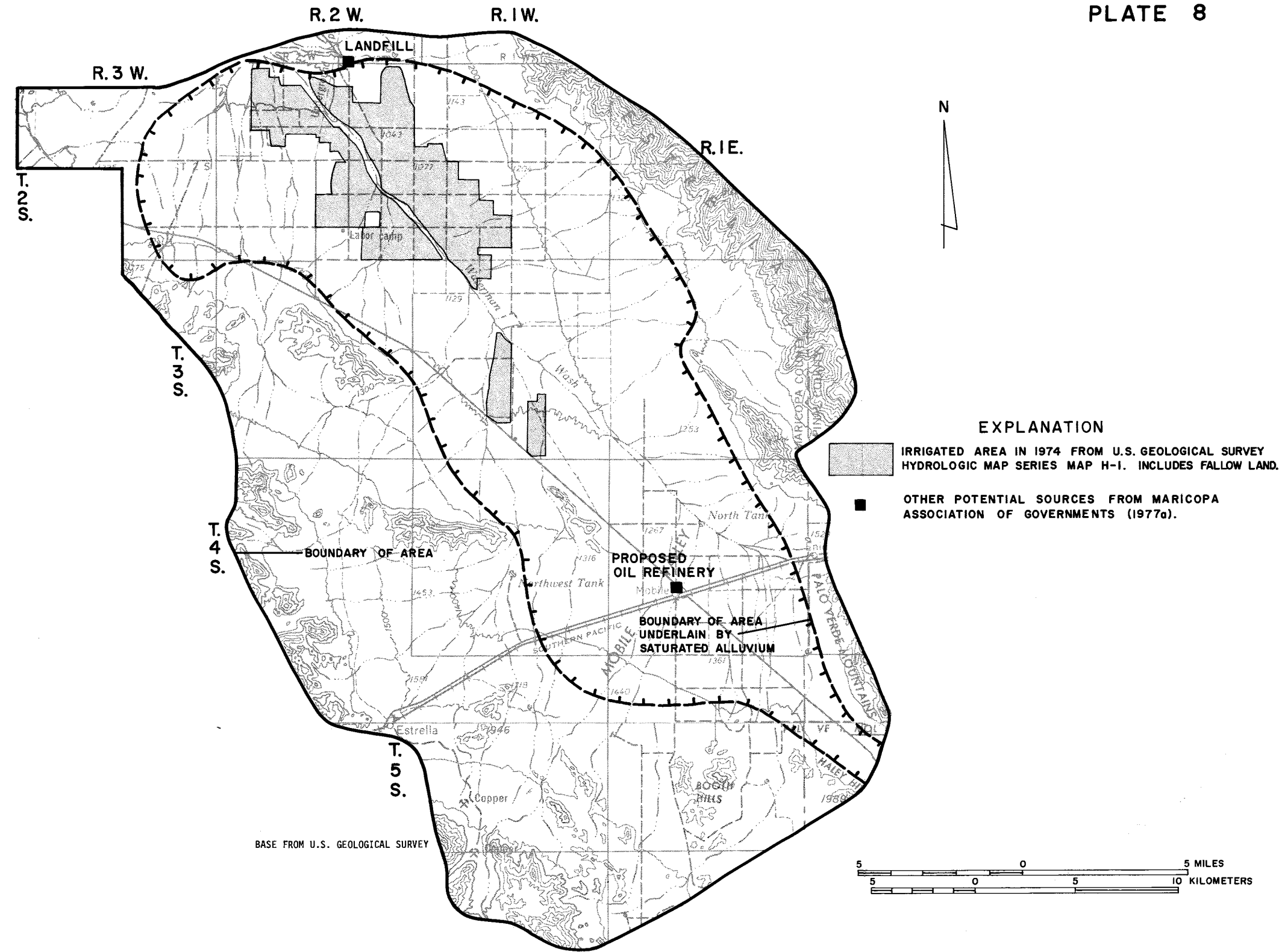


PLATE 8.--AGRICULTURAL IRRIGATION AND OTHER POTENTIAL
SOURCES IN RAINBOW VALLEY.

MARICOPA ASSOCIATION OF
GOVERNMENTS 208 PROGRAM

GILA BEND BASIN

Plate 9 shows the location of potential sources of groundwater pollution in the Gila Bend Basin. Return flow from crop irrigation is the predominant potential source. Some irrigation tailwater and spills, drainage pumpage, and sewage effluent enters the area at Gillespie Dam on the Gila River. Part of this water is diverted into the Gila Bend and Enterprise Canals and the remainder flows over the dam. In 1974, this flow totaled 28,400 acre-feet (Halpenny and Greene, 1975). The average salinity of Gila River water at Gillespie Dam is between 3,500 and 4,000 mg/l. A landfill is present northeast of Gila Bend and a feedlot near Theba. The Maricopa Association of Governments (1977) reported that about 110 septic tanks were in use at Gila Bend, with an estimated volume of effluent of 56,000 gallons per day. The sewage treatment plant at Gila Bend produced an average of about 300,000 gallons per day. Recently a water treatment plant was constructed at Gila Bend and waste materials comprise another potential source of groundwater pollution. An important hydrologic modification has been the development of a depression cone in the Gillespie Dam-Cotton Center Area, which can allow water of poor quality which flows over Gillespie Dam to percolate to groundwater.

There were about 45,000 acres of cropland irrigated in the basin in 1975. Water supply for irrigation comes primarily from groundwater, however surface water from Gillespie Dam enters the area through the Gila Bend and Enterprise Canals. In 1975, the imported surface water totaled 17,000 acre-feet. Groundwater pumpage for irrigation in 1975 was about 287,000 acre-feet. Of the 304,000 acre-feet of applied water, about 180,000 acre-feet were consumed by evapotranspiration. The remaining 124,000 acre-feet percolated past the root zone as irrigation return flow or canal seepage (Arizona Water Commission, 1978).

Water quality records available for large-capacity wells away from the Gila River indicate no noticeable effect from irrigation. Extensive irrigation has been practiced in much of the area since the 1920's, when surface water imports began. A groundwater mound had built up in the Theba area by the 1960's and is indicative of recharge from irrigation return flow and possibly the presence of a perched zone. Significant amounts of irrigation return flow have likely reached the water table beneath lands near the Gila River and lands irrigated with canal water. For lands where the underlying water table is greater than several hundred feet deep and irrigation has been practiced for only several decades, irrigation return flow may not have reached the water table of the main aquifer. Water samples have not been collected and analyzed at sufficient intervals to determine long-term trends in groundwater quality. There has been no reported monitoring to determine the effect of sewage effluent, the landfill, or the feedlot on groundwater quality.

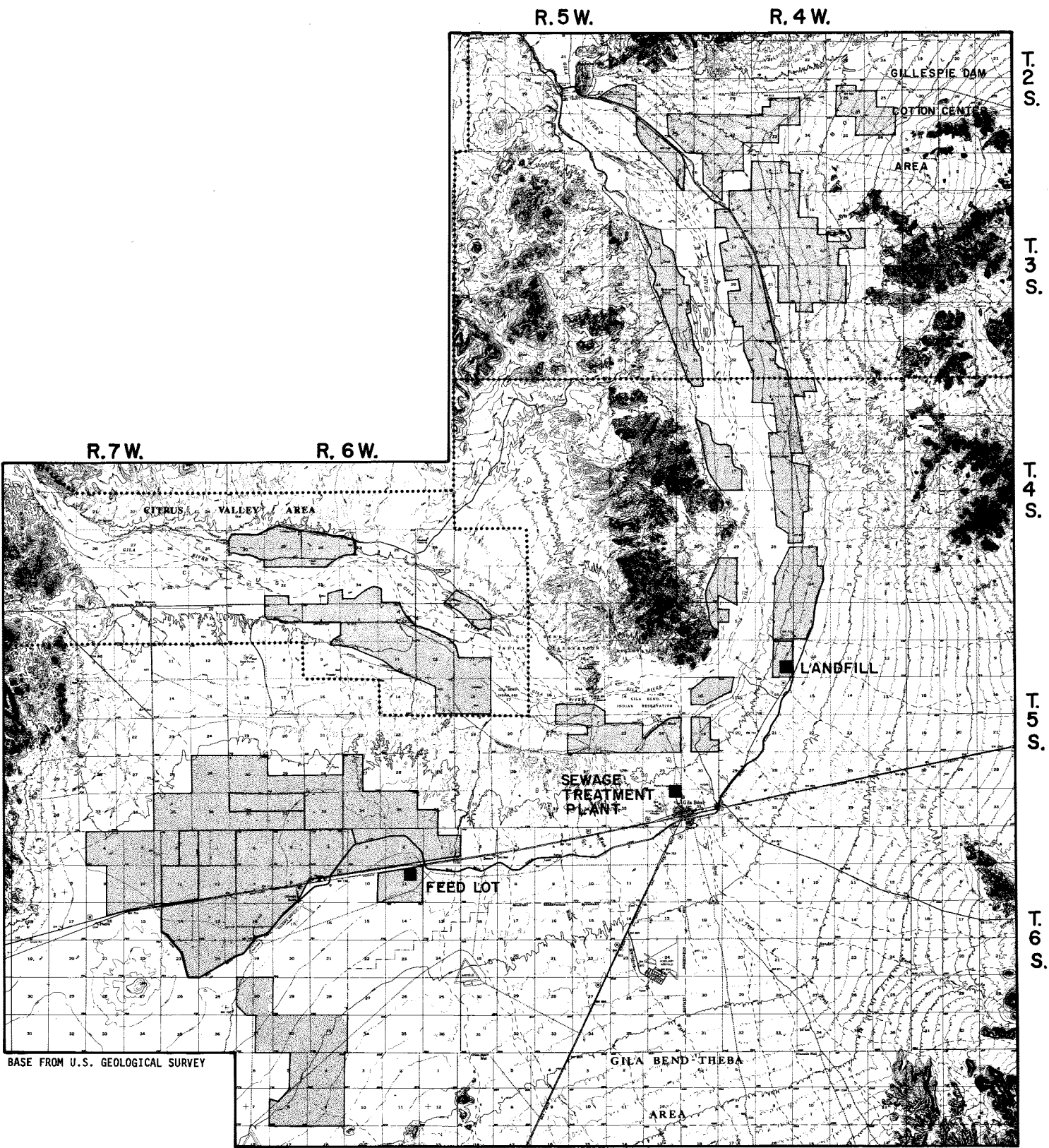
AGUA CALIENTE - HYDER AREA

Plate 10 shows the location of potential sources of groundwater pollution in the Agua Caliente - Hyder Area. Return flow from crop irrigation is the only significant potential source. There were about 10,000 acres of irrigated land below Painted Rock Reservoir in Maricopa County in 1975 (Arizona Water Commission, 1978). It is estimated that about 7,500 acres of this land were in the Agua Caliente - Hyder Area. Water is supplied entirely from groundwater. The annual pumpage in 1975 is estimated to have been about 45,000 acre-feet. Of this amount, about 30,000 acre-feet were consumed by evapotranspiration and the remaining 15,000 acre-feet percolated past the root zone as irrigation return flow.

Water quality records available for large-capacity wells in the area away from the Gila River indicate no noticeable effect from irrigation. In part this is due to the relatively great depth to water (greater than 200 feet) and the fact that there has been large-scale irrigation for only several decades. Significant volumes of irrigation return flow have likely not reached the water table of the main aquifer, because the alluvial deposits above the water table were moisture deficient prior to irrigation. However, near the Gila River, where deposits above the water table were likely at field capacity prior to irrigation and water levels are shallow, substantial volumes of irrigation return flow are present in the groundwater. Water samples have not been collected and analyzed at sufficient intervals to determine long-term trends in groundwater quality.

REFERENCES

- Arizona Public Service Company, 1975, "Preliminary Safety Analysis Report, Palo Verde Nuclear Generating Station Units 1,2, and 3", volumes II and IV.
- Arizona Water Commission, 1978, "Current and Expected Water Supplies and Demands and Groundwater Conditions in Maricopa County", prepared for Maricopa Association of Governments.
- Arthur Beard Engineers, Inc., and CDM, Inc., 1977, "Water Supply and Demand in Maricopa County, Arizona", prepared for Maricopa Association of Governments.
- Halpenny, L.C., and D.K. Greene, 1975, "Water Balance Investigation of River Bed, Salt and Gila Rivers, 23rd Avenue to Gillespie Dam, Arizona", Water Development Corporation, Tucson.
- Maricopa Association of Governments, 1977, "Working Paper, Non-Point Sources of Pollution", 35p.
- Schmidt, K.D., 1978, "Groundwater Quality in the Major Basins of Maricopa County", prepared for Los Angeles District, U.S. Army Corps of Engineers, Phoenix Urban Study and Maricopa Association of Governments, Maricopa County 208 Program.



EXPLANATION

- IRRIGATED AREA IN 1976 FROM ARIZONA STATE LAND DEPARTMENT FILES. INCLUDES FALLOW LAND.
- OTHER POTENTIAL SOURCES FROM MARICOPA ASSOCIATION OF GOVERNMENTS (1977a).

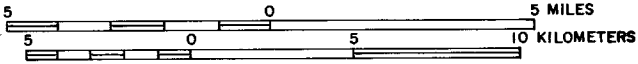
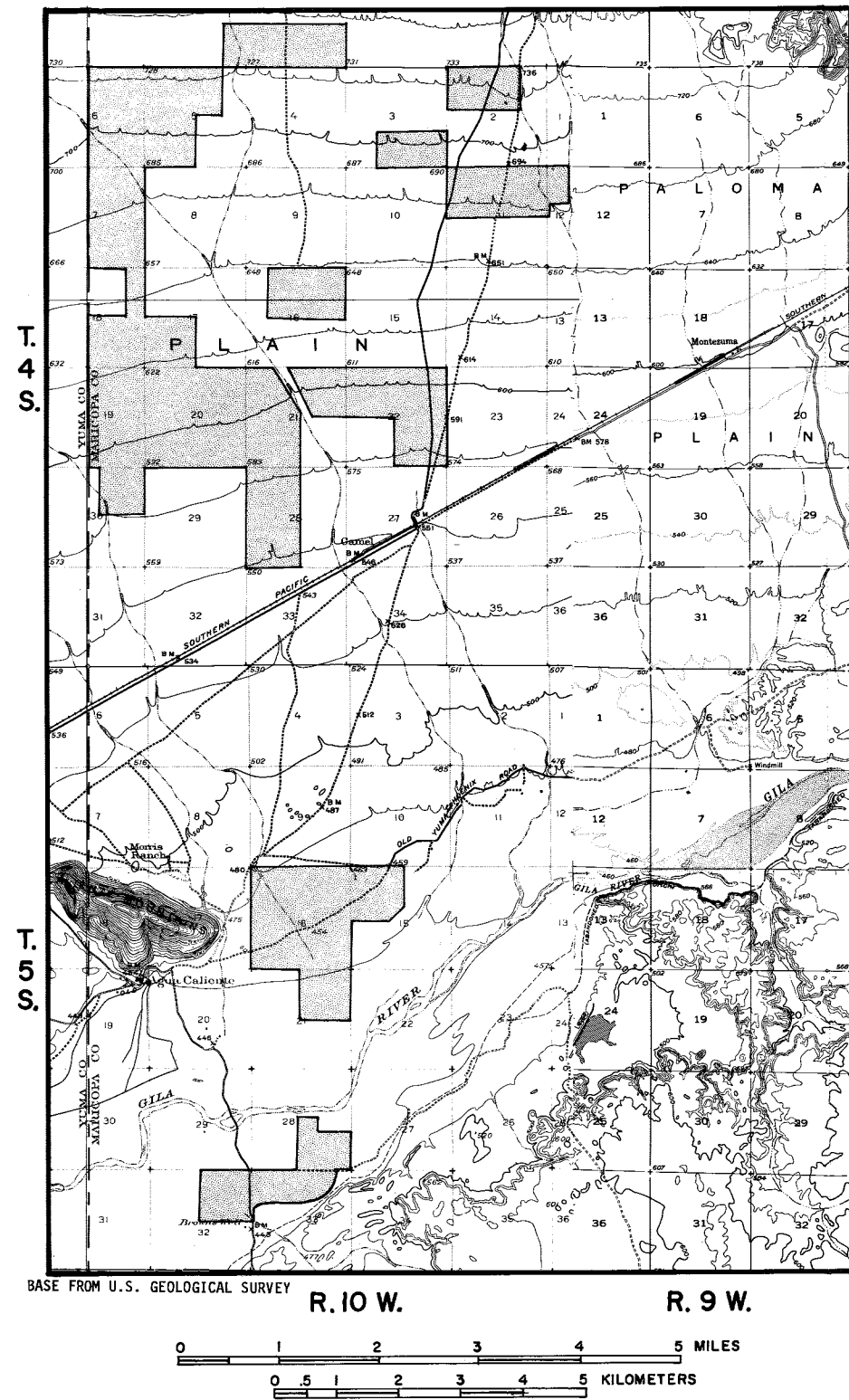


PLATE 9.--AGRICULTURAL IRRIGATION AND OTHER POTENTIAL SOURCES IN THE GILA BEND BASIN.

MARICOPA ASSOCIATION OF GOVERNMENTS 208 PROGRAM



EXPLANATION



IRRIGATED AREA IN 1972 FROM ORTHOPHOTOQUADS OF ARIZONA RESOURCES INFORMATION SYSTEM. INCLUDES FALLOW LAND.

PLATE 10.--AGRICULTURAL IRRIGATION IN THE AGUA CALIENTE-HYDER AREA.

MARICOPA ASSOCIATION OF GOVERNMENTS 208 PROGRAM

Schmidt, K.D., and R.C. Scott, 1977, "Groundwater Conditions and Waste Disposal at the Hassayampa, Casa Grande, and Somerton Landfills, Arizona", report prepared for Arizona Department of Health Services.

V

PROPOSED CONTROL MEASURES

CHAPTER V

PROPOSED CONTROL MEASURES

Section 208 of Public Law 92-500 specifies that a 208 plan shall include a number of elements. Elements specifically related to control measures include the following:

- 1) A process to identify agriculturally related nonpoint sources of pollution and to set forth procedures and methods to control, to the extent feasible, such sources.
- 2) A process to control the disposition of all residual waste generated which would affect water quality.
- 3) A process to control the disposal of pollutants on land or in subsurface excavations to protect groundwater.

In order to implement meaningful control measures to protect groundwater quality, it must first be determined if they are necessary. To make this determination, information must be available on potential sources of pollution and their impact on groundwater quality. In order to formulate control measures, if it is determined that they are necessary, the mechanism of groundwater pollution must be understood.

As explained previously in this report, there has been little or no intentional monitoring specifically to determine groundwater pollution in the major basins of Maricopa County. Present knowledge of groundwater quality is derived primarily from the results of monitoring to determine the suitability of well water for particular uses. In the companion report on groundwater quality, chemical quality data from large-capacity wells were compiled and interpreted. This knowledge pertains primarily to diffuse sources and major hydrologic modifications, and not to point and line sources. Man's activities at the land surface in arid areas frequently do not impact the quality of water pumped from large-capacity wells for decades or longer, which complicates interpretation of the results of water well sampling. The impact of point and line sources on groundwater quality can often not be determined by sampling existing large-capacity wells, but requires sampling of small-capacity wells in local areas. This is because large-capacity wells are often not located near such sources and are not constructed specifically for the purpose of monitoring these sources. Thus supplementary monitoring is usually necessary before meaningful control measures can be formulated to protect groundwater quality. This monitoring must include pollution sources and water in the vadose zone, as well as water well sampling, and must be on a long-term basis.

Boyle Engineering Corporation (1977) summarized nonpoint source control measures for crop irrigation, feedlots, landfills, and storm runoff. Control measures are also possible for the other major potential sources of

groundwater pollution in the valley, including industrial waste disposal, sewage effluent and sludge disposal, dairies, leaking sewers, septic-tank effluent, lawn irrigation, and hydrologic modification. Some control measures are already in effect in a sense, due to economic considerations and other factors. For example, over application of fertilizer is partly constrained by the price of fertilizer. However, these same factors can also create problems; for example, some methods of waste disposal may appear economical if the impact on groundwater is neglected or not known. Control measures are not discussed extensively in this report, because present information is often inadequate to determine if they are necessary. However, control measures are discussed where present information is sufficient to determine that a problem exists.

Present information indicates that several potential sources in the Salt River Valley could be addressed through implementation of control measures. They include landfills, industrial wastes, and certain types of hydrologic modification.

LANDFILLS

As indicated previously, numerous landfills in the Salt River Valley are directly exposed to contact with streamflow, groundwater, or other sources of water. As such, leachate can be generated by contact with materials in these landfills. The concentration of present and abandoned landfills near the Salt River channel (Plate 1) is a problem. Although numerous large-capacity wells for public supply are not present in much of this area, the groundwater quality should be protected. Locally, numerous small-capacity wells are used in this area. Also polluted groundwater due to landfill leachate could move toward large-capacity public-supply and irrigation wells in the future.

A hydrogeologic study should be performed before new landfills are sited. The subsurface geology, presence of any perching layers, direction of groundwater flow, location and construction of nearby wells, existing groundwater quality, and aquifer characteristics should be determined.

Presently, excavations often extend to near the water level. The depth of excavation should be limited to ten feet above the highest anticipated groundwater level. To accomplish this goal, regular measurements of depth to water must be made in shallow wells in or near areas proposed for excavation. If nearby wells are not adequate to determine on-site conditions, then monitor wells may have to be constructed. The seasonal fluctuation in water level may be significant and should be determined. Also, flood flows result in substantial rises in water level. Historical data are available that can be used to estimate water-level rises during and following flood flows in the Salt River.

Also, landfills should optimally not be sited in floodplains. If they are located in floodplains, they should be placed a minimum horizontal distance from the stream channel, or other provisions made to insure that

lateral seepage of streamflow does not enter the landfill. The hydrogeologic study would provide guidance in this regard. Suitable protection should be provided from inundation of the landfill by a 100-year flood.

All other sources of liquid should be kept from contact with organic refuse in landfills. Septic-tank pumpage should be disposed by landspreading and soil incorporation, as opposed to percolation ponds. Toxic materials should not be placed in landfills that can easily be inundated. If possible, sewage sludge should not be landfilled, but applied to large acreages of cropland. Landfills in urban areas should not be covered and irrigated, as this will almost certainly create leachate. Existing landfills should be evaluated on a hydrogeologic basis, and abandoned if necessary to protect groundwater quality. Groundwater monitoring beneath selected landfills should be required whether or not control measures are being implemented, in order to determine their effectiveness.

INDUSTRIAL WASTES

There is substantial potential for groundwater pollution in the Salt River Valley from industrial wastes, based on disposal practices reported by Behavioral Health Consultants, Inc. (1975). Ponds, seepage pits, and land spreading are used for on-site disposal of industrial wastes. Information on industrial waste disposal sufficient for formulation of control measures is not presently available. Installation of artificial liners to allow disposal by evaporation may be a feasible control measure for on-site disposal of some industrial wastes. Meaningful control measures can be implemented after completion of the state hazardous waste plan and surface impoundment assessment program.

HYDROLOGIC MODIFICATIONS

There are at least two types of hydrologic modifications that could require control measures in relation to groundwater quality. These are well construction and altered pumping patterns.

Well construction is important with respect to the vertical movement of groundwater. Both perforations and gravel packs can allow water at a specific depth to move to another depth. If groundwater quality varies with depth, then groundwater in a specific depth zone can be polluted due to mixing with water of poor quality. One example is where perforations in a well extend above the water table, allowing water to cascade down the well from shallow depths. In some cases the perched water may be of very poor quality, as documented at the PVNGS site in the Lower Hassayampa Area. Another example is where wells are drilled into deeper formations in the central parts of basins, where there is usually groundwater of poor quality at depth. Improper construction or abandonment of such wells may result in upward movement of poor quality water into the overlying strata. Such movement depends on the vertical distribution of hydraulic head.

Control measures can be implemented through well construction ordinances, such as are in effect in most counties in California. In areas of substantial variations in groundwater salinity with depth, data can be obtained during well construction to indicate the extent of the problem. An electric log can be run prior to installation of the casing in wells drilled by the rotary method. Correlation with chemical analyses of water from numerous wells tapping different depth zones allows estimation of the groundwater salinity at various depths. The well can then be completed based on this knowledge. For wells drilled by the cable-tool method, the electrical conductivity of water samples bailed from the well can be measured as drilling progresses. The vertical distribution of salinity can thus be determined.

Altered groundwater flow directions have adversely affected the quality of well water near Chandler and in the Liberty-Goodyear area. Site-specific monitoring is necessary to confirm this situation and to provide information on potential control measures. The altered flow directions in both areas have resulted primarily from large-scale pumping. The most direct control measure would be to decrease pumping downgradient from each area, which would require an alternate source of water in these areas. Present pumping patterns could possibly be altered to decrease pumping in downgradient areas. A less direct alternative would be to intentionally recharge water in downgradient areas, in order to raise water levels.

Another alternative would be to intentionally pump out the poor quality groundwater. However, present evidence indicates that the zone of poor quality groundwater is continuous from south of Chandler, along the Gila River, to Painted Rock Dam. Thus it is areally continuous over a substantial area. The total volume of this groundwater of poor quality is large and substantial amounts of pumpage would be necessary. If this alternative were selected, a number of problems could result. The energy consumption would be extremely high, numerous new wells would be necessary, and the problem of disposal of this water would arise. Lastly, selection of this alternative would likely encounter numerous institutional problems.

Implementation of any control measure may be difficult because of water quantity questions and water rights. For this reason, a prudent procedure would be to obtain precise data from a specially designed monitoring program in the two areas of concern. Such a program would enable formulation of sound control measures, if necessary. The institutional aspects of implementing control measures are not addressed in this report, but must be considered in future 208 work programs.

REFERENCES

- Behavioral Health Consultants, Inc., 1975, "A Report on Industrial and Hazardous Wastes", prepared for Arizona Department of Health Services, 110p.
- Boyle Engineering Corporation, 1977, "Compendium, Non-Point Source Control Measures", prepared for U.S. Army Corps of Engineers, Los Angeles District, 44p.

VI

PROPOSED MONITORING

CHAPTER VI

PROPOSED MONITORING

The majority of groundwater use and potential sources of groundwater pollution in Maricopa County are in the Salt River Valley. In the other major groundwater basins, agriculture is predominant and there are few potential sources. Thus the discussion of proposed monitoring is divided into 1) the Salt River Valley, and 2) the other major groundwater basins in Maricopa County. Before recommending specific monitoring activities, the status of the existing knowledge and monitoring of groundwater quality and pollution is reviewed.

EXISTING KNOWLEDGE AND MONITORING

Existing knowledge and monitoring are discussed in terms of three categories: 1) hydrogeologic framework, 2) regional groundwater quality, and 3) site-specific monitoring.

Salt River Valley

Hydrogeologic Framework: In order to fully understand groundwater quality in the valley, the quantitative aspects of the groundwater system must be fairly well known. Both the quantity and quality aspects vary throughout the valley and are complex. Quantity factors include recharge, aquifer characteristics, subsurface geology, groundwater flow patterns, and discharge. A number of efforts are in progress to obtain information on the quantitative aspects of groundwater in the valley. These are being undertaken primarily from the viewpoint of future water supplies and management.

A thorough understanding of the subsurface geology is necessary in order to properly interpret groundwater quality. Regional data are available from previous studies of the U.S. Geological Survey and references such as the U.S. Bureau of Reclamation (1977). However, more detailed regional studies and site-specific evaluations are necessary. Dr. Robert Laney's study of the subsurface geology of the East Basin has furnished extremely valuable data for groundwater quality considerations. Maps illustrating areal variations and cross sections indicating vertical variations in subsurface geology are important for interpretations of groundwater quality. For example, the distribution of chromium in groundwater of Scottsdale and Paradise Valley has been directly related to the particle-size distribution of the alluvium. However, Dr. Laney's study in the East Basin has not been completed and a comparable study in the West Basin has not begun. These investigations are necessary to more fully explain the occurrence and distribution of constituents in groundwater that are of natural origin. In addition, more information needs to be obtained on the vadose zone, particularly for perching layers.

Both the horizontal and vertical direction of groundwater movement must be known in local areas in order to determine the impact of point and line sources of groundwater pollution. Many water-level measurements are not referenced to precise elevations, and thus available water-level maps are often not of adequate detail to use for investigations in local areas. The vertical distribution of hydraulic head is poorly known in much of the valley. Aquifer characteristics, such as transmissivity and storage coefficient, must be known in order to evaluate rates of groundwater flow, dilution, and other factors. There is a paucity of recent aquifer tests in the valley, and thus knowledge of aquifer characteristics is limited.

The volume of pumpage is generally well known in urban areas and where irrigation districts operate wells. In other irrigated areas, the pumpage is often poorly known. In order to determine volumes of irrigation return flow, for example, the volume of applied water (some or all of which may be from pumpage) and the evapotranspiration must be known. Evapotranspiration rates for various crops in the valley are generally well known. One of the largest unknowns is the relative magnitudes of canal seepage and irrigation return flow. Commonly used methods of measuring water volumes often do not distinguish between seepage in the canal system and on-farm percolation.

The U.S. Geological Survey previously completed an electrical analog model of the Salt River Valley. At least two groundwater modeling efforts are in progress in the valley. One covers the Salt River Project and the other covers much of the rest of the valley. Such models, when calibrated, can provide substantial information on the physical aspects of the groundwater system.

Regional Groundwater Quality Monitoring: Substantial data are available on the inorganic chemical quality of water from large-capacity public-supply and irrigation wells in the valley, as documented by the companion report on existing groundwater quality (Schmidt, 1978). These data have contributed significantly to an understanding of the impacts of some diffuse sources and some types of hydrologic modification. However such data have been largely collected to determine the quality of the water supply, as opposed to determining the extent of groundwater pollution. Thus in agricultural areas, available chemical analyses are primarily of value for irrigation use of the water. Similarly, in urban areas, chemical analyses are primarily of value for drinking water supply.

Irrigation and domestic wells owned and operated by individuals or small farming concerns have generally rarely been sampled. Thus there are gaps in the present regional monitoring of large-capacity wells, for example on the Salt River Indian Reservation, in the McMicken Irrigation District, and in the Roosevelt Water Conservation District. Intensive sampling surveys for well water, such as that done by the U.S. Geological Survey in 1966 for electrical conductivity determinations, have been infrequent. Although there has been extensive sampling of water wells since the 1920's and tens of thousands of chemical analyses are available, there was no procedure to collect, organize, and integrate these analyses prior to the 208 program. The U.S. Geological Survey has collected some of the

analyses, which are available on a computer printout. The organic chemical composition of groundwater in the valley on a regional basis is virtually unknown. Limited data on the radiological composition of groundwater are available.

Site-Specific Monitoring: Site-specific monitoring often involves a combination of several components: 1) pollution source, 2) infiltration potential, 3) vadose zone, and 4) aquifer. This approach is particularly applicable to diffuse sources and arid areas in general. Pollution source monitoring includes inventorying types and amounts of waste and documenting the method of waste disposal. Both solid and liquid wastes may be sampled and analyzed for specific pollutants. Monitoring of infiltration potential involves determination of the amount of wastewater that moves downward past the root zone or topsoil. In the case of solid wastes, it is the amount of leachate which can percolate down to the water table. A water budget approach can be used if the volume of wastewater, evaporation rates, and other factors are known.

Monitoring in the vadose zone (above the main water table) is often necessary in arid areas because of the long travel time of percolating water in the vadose zone. Such monitoring can detect potential problems before large volumes of groundwater are polluted, so that remedial measures can be initiated. Monitoring of water quality in the aquifer is primarily accomplished through sampling of pumping wells. Site-specific monitoring often involves selection of shallow wells near a source or construction of special monitor wells for sampling. In general, there is little or no site-specific groundwater quality monitoring in progress in the valley other than that by Herman Bouwer and colleagues near the 23rd Avenue and 91st Avenue sewage treatment plants, as part of effluent reclamation projects. Monitoring programs have recently been established at some landfills.

Other Groundwater Basins in Maricopa County

Hydrogeologic Framework: Groundwater conditions in all of the six basins have been studied by the U.S. Geological Survey and recent open-file map reports have been prepared for the Lower Harquahala Valley, the Lower Hassayampa Area, and Rainbow Valley. In addition, the Lower Harquahala Valley and Lower Hassayampa Area were included in investigations by the U.S. Bureau of Reclamation for the Central Arizona Project. Detailed groundwater studies have been conducted in the Lower Hassayampa Area for the PVNGS. Lastly, the Arizona State Land Department has recently conducted investigations in the Gila Bend Basin and the Lower Harquahala Valley related to possible designation of parts of these basins as critical groundwater areas. In general, this information is adequate for regional groundwater quality interpretations. However, knowledge of the vadose zone is fragmentary throughout the basins, except at the PVNGS site.

Regional Groundwater Quality Monitoring: In contrast to the situation in the Salt River Valley, few wells in the other major groundwater basins of Maricopa County have been sampled on a regular basis. Thus data on long-term time trends in the quality of well water are fragmentary. Recent

intensive sampling surveys for determination of electrical conductivity and fluoride content have been completed in all of the basins by the U.S. Geological Survey. Complete analyses for the major inorganic chemical constituents are available for water sampled from wells in the Lower Harquahala Valley, the Lower Hassayampa Area, and Rainbow Valley between 1974 and the present. Recent complete chemical analyses for well water are generally not available in the Aguila Area and Gila Bend Basin. Complete chemical analyses are available for water from numerous wells in the Agua Caliente - Hyder Area in 1972. Trace element determinations, such as chromium and arsenic, have been limited to samples from only a few public-supply wells and several monitor wells near the PVNGS site. The organic chemical composition of groundwater in the six basins is virtually unknown, other than near the PVNGS site. Limited data on the radiological composition of groundwater are available.

Site-Specific Monitoring: There is no known site-specific monitoring in progress in the basins, except that near the PVNGS. When the first unit of the PVNGS becomes operational, detailed monitoring of groundwater quality is to be done near the evaporation pond.

RELATED ON-GOING PROGRAMS

There are two on-going investigations which provide an opportunity to avoid duplication with the 208 program, through a cooperative effort. The U.S. Geological Survey is conducting the Southwest Alluvial Basin Study, as part of a nationwide program for the major aquifers in the U.S. The study area includes all of southern Arizona, including Maricopa County. The final objective is to develop and make available groundwater models which can be used to evaluate various management alternatives. The project began in October 1978 and will be of four years in duration. An important component of the study involves groundwater quality and irrigation return flow.

The Arizona Water Commission, in cooperation with the Municipal Water User's Association and the Salt River Project, is conducting a groundwater resources study of the Salt River Valley. A groundwater model of the valley is to be developed as part of the study. Important parts of this study include collection, organization, and computerization of substantial hydrologic data. Water quality records obtained since the completion of the 208 data collection program in 1977 have been collected. The data collection phase will be completed in July 1979 and the groundwater modeling phase completed in June 1980.

RECOMMENDED MONITORING

Proposed monitoring is based on a prioritization of potential sources of pollution and an evaluation of potential problems. Thus not all of the potential sources are recommended for monitoring at this time. Important factors include volumes of waste, pollutant loads, method of waste disposal, and groundwater quality and use. These factors have been thoroughly discussed

in a recent report on a state-wide groundwater monitoring plan prepared for the Arizona Department of Health Services (Wilson, Martin, and Lonergan, 1977). This report provided substantial background information for purposes of formulating a proposed monitoring program for the major groundwater basins of Maricopa County.

Approximately three-fourths of the irrigated cropland and much of the animal wastes in Maricopa County are in the Salt River Valley. The great majority of municipal and industrial wastes are also generated in the valley. An estimated 1,700,000 acre-feet of groundwater were pumped in the Salt River Valley and about 700,000 acre-feet in the other basins of Maricopa County in 1975 (Arizona Water Commission, 1978). The predominance of groundwater pumpage for urban use is in the Salt River Valley. However, groundwater is the sole source of water supply in the Aguila Area, Lower Harquahala Valley, Rainbow Valley, Agua Caliente - Hyder Area, and much of the Lower Hassayampa Area. Much less monitoring has been done and is being done in the other basins than in the Salt River Valley. On the basis of all of these factors, it is recommended that about eighty percent of the monitoring effort in Maricopa County be undertaken in the Salt River Valley.

Salt River Valley

Proposed monitoring in the Salt River Valley is divided into 1) hydrogeologic, 2) regional groundwater quality, and 3) site-specific.

Hydrogeologic: Approximately twenty percent of the monitoring effort in the Salt River Valley would be directed toward hydrogeologic factors. The U.S. Geological Survey would be encouraged to complete the subsurface geologic studies by Dr. Robert Laney in the East Basin and to undertake similar studies in the West Basin. Rock cuttings should be collected at 10-foot depth intervals when new wells are drilled or wells deepened. These samples should be subjected to particle-size analysis. Also, electric logs should be run where possible on new wells, in order to provide information on subsurface geology and vertical variations in salinity. A detailed up-to-date water-level elevation contour map would be prepared for the valley. Water levels in numerous wells would be measured during minimum pumping periods to supplement other measurements routinely made by the Salt River Project and other agencies.

Perhaps the most important gap in knowledge of the hydrogeologic conditions necessary for evaluation of groundwater pollution in the valley is the character of the vadose zone. In the future, every opportunity should be used to collect information on the geologic materials above the water table, through a cooperative effort with local water-supply agencies and drillers. A procedure would be established to insure that such information is obtained during the construction of new wells, when feasible. Specifically, this includes the extent and development of caliche zones, presence of perched water bodies, and the delineation of perching layers.

Regional Groundwater Quality Monitoring: About thirty percent of the monitoring effort in the Salt River Valley would be to supplement the existing sampling and analyses of water from large-capacity wells. The existing monitoring of water quality for large-capacity wells is highly beneficial and should be fully utilized. Upon this base, supplementary monitoring can be superimposed to produce an optimal monitoring program. Also, tabulations of chemical analyses prepared as part of the 208 program would be annually updated. Intensive sampling of water from large-capacity wells during heavy pumping periods should be undertaken every five years, starting in 1980. An estimated 1,200 of the approximately 1,400 large-capacity wells in the valley would be sampled. Temperature, electrical conductivity, and pH would be measured at the well discharge and selected samples (an estimated 250) collected and treated for laboratory analysis.

Specific constituents in selected samples would be analyzed in the laboratory. Hexavalent chromium content would be determined in water samples collected from wells in the area of high chromium content in Paradise Valley and Scottsdale. Similarly, fluoride and chromium content would be determined in samples from wells west of the Agua Fria River. Nitrate content would be determined in samples from wells in the high nitrate area east of the Agua Fria River in the West Basin. Because of a general lack of recent data on the distribution of boron in groundwater of the valley, boron content would be determined on about 300 samples collected during the first intensive survey.

The gross organic chemical content of water pumped from large-capacity wells should be determined. Dissolved organic carbon content should be determined. Dissolved organic carbon content would be determined on about 300 water samples selected from those collected during the first intensive survey. Numerous wells would be chosen that are located in areas where sources of organic chemicals are present, such as areas of sewage effluent disposal, urban storm water disposal, and areas with high septic-tank densities.

A procedure would be developed to obtain information, during the drilling of future wells, on the vertical distribution of selected constituents in groundwater. For wells drilled by the cable-tool method, samples of water can be bailed from specific depths and analyzed. This procedure would be especially valuable for chromium and arsenic in parts of Paradise Valley and Scottsdale, for nitrate in Glendale and West Phoenix, for fluoride west of the Agua Fria River, and for salinity in many parts of the valley. Samples of solid materials should also be collected in some cases. For example, in the high nitrate area of the West Basin, samples of geologic materials could be collected from various depths for determination of organic matter content, total nitrogen content, and nitrate minerals. It is estimated that samples would be collected during drilling of approximately fifty new wells each year, in cooperation with local water-supply agencies, other well owners, and drillers.

Recent experience by the City of Glendale with nitrate and previous experiences of the U.S. Geological Survey with salinity in the Beardsley area indicate that there are substantial differences in chemical quality with the

pumping rate of some large-capacity wells. The well discharge could be sampled frequently during pump testing of newly constructed wells, or during pumping of existing wells. This approach would be especially important in areas of high salinity, nitrate, chromium, or fluoride content. It is estimated that about twenty such tests would be made each year, for durations averaging about twenty-four hours.

All of the regional groundwater quality monitoring should make full use of on-going efforts of the various water-supply agencies, regulatory agencies, and research projects. A cooperative program should be developed to insure that on-going monitoring associated with the 208 program is of maximum benefit to the local users.

Site-Specific Monitoring: Site-specific monitoring is recommended for about fifty percent of the monitoring effort in the valley. This type of monitoring is specifically recommended for: 1) areas of altered groundwater flow direction and subsequent increasing salinity, 2) irrigation return flow, 3) storm runoff, and 4) point sources, such as landfills, animal waste ponds, and industrial waste disposal. Furthermore, irrigation return flow should account for at least half of the effort in this category, due to its large volume and long-term impact on groundwater quality. Before proceeding to the details of site-specific monitoring, three items are discussed. These include monitor well construction, sampling procedures, and chemical analyses of water samples.

First, monitor wells are to be equipped with 8-inch diameter PVC casings. This allows for installation of portable submersible pumps for collection of water samples. PVC casing is also superior material to minimize the adsorption of trace metals and organic chemicals. The hole diameter would be about 14 inches to allow gravel packing. Monitor wells would generally extend about fifty feet below the water table, with the casing perforated opposite the lower thirty feet. In areas where substantial water-level declines are projected, modifications in well construction would be necessary. A minimum twenty-foot annular seal would be installed to prevent entrance of water from the land surface. A protective cap with a lock would be placed over the top of the well. All monitor wells would be carefully logged by a geologist during construction and thoroughly developed upon completion. The well discharge would be sampled for about eight-hour periods of continuous pumping to determine optimal pumping rates and times for periodic water sample collection.

Water samples from monitor wells would be collected through installation of portable submersible pumps. Depth to water would be measured prior to installation of the pump and the pumping rate would be accurately measured during each sampling. The pumping period prior to sample collection would generally range from one to eight hours and the sampling frequency would generally be quarterly.

The major inorganic chemical constituents should be analyzed for most water samples collected. A complete analysis is preferable for several reasons. First, it allows checking of the accuracy of the chemical analysis. Second,

it provides valuable information for water quality interpretations, such as preparation of a trilinear diagram. A "complete analysis" includes:

calcium	bicarbonate	boron
magnesium	sulfate	fluoride
sodium	chloride	total dissolved solids @ 180°C
potassium	nitrate	electrical conductivity
carbonate	silica	pH

Proper sampling and analytical techniques and quality control are mandatory.

The two areas of increasing salinity are near Chandler and in the Liberty-Goodyear Area. For these areas, intensive semi-annual water-level measurement programs would be undertaken to supplement other measurements. Also, intensive annual water sampling programs would be conducted during heavy pumping periods. Temperature and electrical conductivity of the well discharge would be measured. Approximately fifty wells would be selected in each area. As much information as possible would be collected on well construction, subsurface geology, and historic water levels. Additional hydrogeologic work would be done in each area, primarily developing cross sections to characterize the subsurface geology and preparing detailed water-level elevation contour maps.

For irrigation return flow, monitoring would be undertaken where depth to groundwater is relatively shallow and irrigation has been practiced for many decades. The area recommended is near Gilbert, because of the presence of a regional perched groundwater zone and the increasing salinity in well water. Water samples would be collected annually from existing shallow wells that tap this zone. An estimated thirty wells would be sampled and temperature, electrical conductivity, and pH would be measured in the field, when possible. Complete chemical analyses would be performed in the laboratory on all samples. Water levels in wells tapping the perched zone would also be measured semiannually.

A complementary program in the same area would be the sampling of cascading water. Abandoned or unused wells with access would be located, and samples of cascading water collected by lowering a device on a cable into the well. Also a cooperative program with individual farmers and districts would be developed whereby samples of cascading water would be collected when the pumps in active wells are temporarily removed. Selected wells would be chosen for down-the-hole gamma ray logging to provide accurate information on the subsurface geology. Additional hydrogeologic work would define the extent, thickness, and character of the perching layer. Also, historical cropping and irrigation practice in the area would be reviewed. Results of these programs would be compared to the results of the regional groundwater quality monitoring program.

Irrigation return flow should also be monitored in an area where the water table is very deep, irrigation has only been practiced for several decades, and groundwater is the sole source of water supply. Irrigation return flow in such an area is likely still primarily in the vadose zone, and not yet

in the main aquifer. Such monitoring is proposed in a later section of this report for a basin in Maricopa County other than the Salt River Valley.

Urban storm runoff can potentially pollute the groundwater. The methods of disposal and location of disposal sites are known at present, but the volumes disposed are not precisely known. A first step in monitoring would be to determine the average annual volumes of runoff disposed. For example, measuring devices would be installed at sites of discharge to stream channels. Secondly, grab samples would be collected of storm runoff for both winter and summer storms. Care would be taken to include storms early in the season when maximum pollutant loads are present. Four different drainage sites would be chosen, including two residential, one industrial, and one commercial site. Samples would be collected at discharge points into ponds and stream channels. Complete chemical analyses would be performed on the samples, and lead, copper, zinc, the nitrogen forms, and total organic carbon would also be determined. If significant amounts of organic carbon are found, then fractionation analyses could be made on selected samples. It is estimated that about forty samples would be collected and analyzed during the first year of monitoring.

As a supplement to the source monitoring, monitor wells would be installed. Two sites would be selected near the Salt River, where large amounts of urban storm runoff are disposed. Two additional sites would be selected near large concentrations of disposal wells, such as in the downtown Phoenix area. Approximately four wells at an average depth of 200 feet would be installed at each site. Water samples would be collected on a quarterly basis. The same constituents would be determined as for the samples of storm runoff, except dissolved organic carbon would be substituted for total organic carbon.

A similar procedure to the foregoing would be followed for point sources. Candidate sources include animal waste ponds, industrial waste ponds, and landfills subject to contact with water. It is recommended that two landfills, two animal waste ponds, and two industrial waste ponds be monitored. Samples of wastewater would be periodically collected, including landfill leachate. Any wells within one-quarter mile of the source would also be routinely sampled, and construction details on such wells obtained. Additional hydrogeologic work would include preparation of cross sections to illustrate the subsurface geologic conditions. Water-level elevation contour maps and flownets would also be prepared for the vicinity. These would aid the siting and construction of monitor wells and delineate areas that could be impacted. Three or four monitor wells would be installed at each site, unless existing wells are adequate. The constituents to be determined in water samples depend on the specific type of waste and pollutants contained therein. In general, a complete chemical analysis would be performed and additional constituents determined, such as trace elements. Vadose zone monitoring may be advisable after results are obtained from pollution source and aquifer monitoring.

Other Groundwater Basins in Maricopa County

Recommended monitoring in the basins other than the Salt River Valley is grouped into: 1) hydrogeologic, 2) regional groundwater quality, and 3) site-specific.

Hydrogeologic: Approximately twenty percent of the monitoring effort in the other basins should be directed toward hydrogeologic factors. The most important gap in knowledge of hydrogeologic conditions necessary for evaluation of groundwater pollution is the character of the vadose zone. As for the Salt River Valley, every opportunity should be used to collect information on the geologic materials above the water table, through a cooperative effort with local water-supply agencies, farmers, and drillers. A procedure would be established to insure that such information is obtained during the construction of new wells. Specifically, this includes the extent and development of caliche zones, the delineation of perching layers, and the characteristics of perched groundwater bodies.

Regional Groundwater Quality Monitoring: Approximately forty percent of the monitoring effort in the basins other than the Salt River Valley should be utilized for enhancing the existing regional groundwater quality monitoring. The U.S. Geological Survey may make annual intensive sampling surveys for large-capacity wells at regular intervals for the major groundwater basins of Maricopa County. It is recommended that cooperation be extended to that agency to insure that intensive surveys are conducted at approximately five-year intervals. Electrical conductivity, fluoride, and temperature would be measured at the well discharge and water samples collected for selected laboratory determinations. Upon this base, supplementary monitoring can be superimposed to produce an optimal monitoring program.

Recent intensive surveys are summarized below:

<u>Groundwater Basin</u>	<u>Year</u>	<u>Number of Wells Sampled</u>
Aguila Area	1976	26
Lower Harquahala Valley	1974	54
Lower Hassayampa Area	1974	56
Rainbow Valley	1974	38
Gila Bend Basin	1977	65
Agua Caliente-Hyder Area	1973	12

About 250 large-capacity wells in the basins other than the Salt River Valley were sampled during these intensive surveys. Approximately this same number of wells would be sampled at five-year intervals. Wells in the Lower Harquahala Valley, Lower Hassayampa Area, and Rainbow Valley would be sampled during an intensive survey in summer 1979. Wells in the Aguila Area, Gila Bend Basin, and Agua Caliente - Hyder Area would be sampled during an intensive survey in 1981.

Hexavalent chromium content should be determined in all water samples collected during the first intensive survey in each basin. This is because of 1) the lack of data on the regional distribution of chromium in groundwater

of these basins, and 2) the likelihood of chromium being present in some areas at contents exceeding the maximum contaminant level for drinking water.

As proposed for the Salt River Valley, a procedure would be developed to obtain information, during the drilling of new wells, on the vertical distribution of selected constituents in groundwater. This procedure would be especially valuable for salinity, fluoride, and possibly chromium in all of the basins. In problem areas, such as near the Gila River where groundwater is of high salinity, frequent sampling could be done during pump testing of newly constructed wells, or during pumping of existing wells.

In addition to the periodic intensive surveys, key irrigation wells would be selected in each area for annual sampling during the heavy pumping period. These wells would be chosen on the basis of cooperation of owner and operator, access, well construction, subsurface geology, chemical quality, and geographic location. The following numbers of wells are recommended for each basin:

<u>Groundwater Basin</u>	<u>Number of Wells</u>
Aguila Area	10
Lower Harquahala Valley	15
Lower Hassayampa Area	10
Rainbow Valley	10
Gila Bend Basin	20
Agua Caliente-Hyder Area	5

An effort should be made to select wells which have been previously sampled for complete chemical analyses, such as those sampled during the recent intensive surveys. Temperature, electrical conductivity, and pH would be measured at the well discharge. Complete chemical analyses would be performed on water samples collected from these wells, as a framework for establishing long-term time trends in groundwater quality. This would supplement the historical chemical analyses for water from public-supply wells at Gila Bend and wells monitored as part of the PVNGS operation.

Site-Specific Monitoring: Approximately forty percent of the monitoring effort for the basins other than the Salt River Valley would be for site-specific monitoring. Most of the effort would be directed toward irrigation return flow. It is assumed that detailed groundwater quality monitoring will be undertaken at the PVNGS under review of the Nuclear Regulatory Commission. The only other significant point sources recommended for monitoring are the Hassayampa landfill and the oil refinery, if it is constructed. Construction of monitor wells, sampling procedures, and analytical determinations were discussed under "Site-Specific Monitoring" proposed for the Salt River Valley and the reader is referred to that section of the report for additional information.

The Hassayampa landfill presently receives hazardous wastes. A hydrogeologic investigation has been completed and a monitoring program recommended (Schmidt and Scott, 1977). This program should be implemented and would

consist of more precise source monitoring and installation of several on-site monitor wells. Source monitoring includes inventorying the types and amounts of hazardous wastes and location of disposal. Wells would be approximately 150 feet in depth and of similar construction to those previously proposed for aquifer monitoring in the Salt River Valley. Portable submersible pumps would be used to collect water samples on a quarterly basis. Temperature, electrical conductivity, and pH would be measured in the field. Laboratory determinations would include complete chemical analyses, selected trace elements, dissolved organic carbon, and selected pesticides.

Plans for the oil refinery southwest of the PVNGS site or near Mobile are not sufficiently known to enable detailed recommendations for groundwater monitoring. However, some ponds for wastewater will likely be used. Volumes of wastewater should be measured and the wastewater sampled and analyzed on a regular basis. Monitor wells should be installed at the site, whether or not liners are in use for liquid wastes in ponds. Portable submersible pumps should be used for quarterly sampling.

The monitoring effort directed toward irrigation return flow would be undertaken to complement that proposed for the Salt River Valley. In this case, however, the effort would focus on an area relying solely on groundwater for irrigation and where water tables are deep. Candidate basins include the Aguila Area, Lower Harquahala Valley, and Rainbow Valley. Recent water-level measurements in irrigated parts of these basins indicate that depth to water exceeds 350 feet. The Aguila Area is recommended for monitoring of irrigation return flow.

Monitoring would include determination of past cropping and irrigation practice. Volumes of pumpage and evapotranspiration rates would be determined. Numerous existing wells would be selected for down-the-hole gamma ray logging, in order to provide much better information on the subsurface geology than is now available. Approximately one dozen access tubes for neutron probes would be installed beneath the oldest irrigated fields to determine the vertical distribution of moisture in the vadose zone. They would be installed to at least 200 feet in depth and deeper if possible. Neutron probe surveys would be run quarterly for the first year and annually thereafter. The access holes should be carefully logged by a geologist during drilling. Texture, degree of cementation, and development of caliche should be given special attention. Subsurface materials would be sampled during drilling of the access holes. Electrical conductivity and nitrate content could be measured on saturation extracts of samples from specific depths.

Wells selected for annual sampling, as part of the regional groundwater quality monitoring program, would be chosen so that many would be in the vicinity of the irrigation return flow monitoring site. If any perched zones are identified, monitor wells would be constructed into these zones to allow collection of water samples by means of a portable submersible pump.

IMPLEMENTATION ASPECTS

In order to implement the proposed monitoring activities, several items are of paramount importance. First monitoring generally requires access to specific sites. In order to gain access, close cooperation is necessary with local entities and individuals. Through the 208 advisory committee structure, local input can be obtained on suggested monitoring and assistance with potential problems such as access.

In the case of monitoring irrigation return flow or animal wastes, the cooperation of the agricultural community is necessary. This includes Natural Resources Conservation Districts, irrigation districts, and individual farmers. For example, water sampling rounds for pumping wells must be coordinated to insure optimal sampling during heavy pumping periods. Also, sampling of cascading water, in part, requires access to wells when pumps are temporarily pulled for repair.

For monitoring potential sources in the urban area, there should be close cooperation with the various cities. In some cases, cities may have existing monitor wells that could be sampled; for example, near landfills. On-going investigations by the Arizona Department of Health Services, the U.S. Geological Survey, the Arizona Water Commission, and others should have a direct influence on the 208 program. If monitoring can be conducted in cooperation with these agencies, there can be substantial economic savings, by avoiding duplication. In terms of solid wastes, industrial wastes, and hazardous wastes, there should be close cooperation with the relevant Bureau of Sanitation programs. Monitoring in all of the basins should be coordinated with the on-going Southwest Alluvial Basin Study of the U.S. Geological Survey. Monitoring in the Salt River Valley should be coordinated with the on-going Arizona Water Commission investigation. Lastly, monitoring of groundwater quality in Maricopa County should be coordinated with that done for the Pima County 208 program to avoid duplication; for example, in the case of urban storm runoff.

A number of potential sources were discussed in Chapter III of this report, but not specifically covered under control measures and monitoring. Implementation of the proposed monitoring program and close cooperation with on-going related programs will allow consideration of all potential sources. For example, sampling of well water for dissolved organic carbon may indicate sources of groundwater pollution not previously considered. The 208 program should be sufficiently flexible to allow changes each year in priorities. As some potential problems are shown to be minimal, less attention can be given to these and more attention given to others. In this manner, more attention is gradually focused on the most significant problems. Control measures can then be enacted, where necessary.

REFERENCES

Arizona Water Commission, 1978, "Current and Expected Water Supplies and Demands and Groundwater Conditions in Maricopa County", prepared for Maricopa Association of Governments.

Schmidt, K.D., 1978, "Groundwater Quality in the Major Basins of Maricopa County", prepared for Los Angeles District, U.S. Army Corps of Engineers, Phoenix Urban Study and Maricopa Association of Governments, Maricopa County 208 program.

Schmidt, K.D., and R.C. Scott, 1977, "Groundwater Conditions and Waste Disposal at the Hassayampa, Casa Grande, and Somerton Landfills, Arizona", report prepared for Arizona Department of Health Services.

U.S. Bureau of Reclamation, 1977, "Geology and Groundwater Resources Report, Central Arizona Project, Maricopa and Pinal Counties, Arizona", volumes 1 and 2.

Wilson, L.G., Martin, P., and E.D. Lonergan, 1977, "Evaluation of Groundwater Monitoring Plan (WETS)", Completion Report prepared for Arizona Department of Health Services, Bureau of Water Quality Control, Water Resources Research Center, The University of Arizona.