

RESULTS OF THE INITIAL
GROUNDWATER QUALITY MONITORING PHASE
(NOVEMBER 1979 - JANUARY 1981)

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Phoenix, Arizona

by

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CONCLUSIONS

1. Monitoring of storm runoff in the Phoenix urban area indicated that cadmium is usually present in the dissolved form at contents exceeding the drinking water limit. However, sampling of groundwater along the Salt River in the vicinity of storm drains indicated no adverse impact on groundwater quality due to disposal of urban storm runoff.
2. New information was collected on changes in chemical quality of groundwater with depth in the Salt River Valley. Such information is important when new wells are to be drilled and for consideration in formulating water well standards to protect groundwater quality.
3. Groundwater of high salinity in shallow strata is moving downward into producing zones of wells near Chandler. This has caused an increase in salinity of well water in recent decades in this area. In the Goodyear-Liberty Area, groundwater of high salinity near the Gila River is moving northerly. This has caused an increase in salinity of well water in recent decades in this area.
4. The chemical quality of perched groundwater has been determined in the Lower Maricopa Valley, the Lower Hassayampa Area, and in part of the Salt River Valley. High salinity and nitrate content are typical where the major source of recharge is from irrigation return flow. On the other hand, water in perched zones is often of excellent chemical quality where canal seepage is an important source of recharge.
5. Monitor wells have been installed at four landfills along the Salt River. Leachate has been detected at two of these landfills and the influence of disposal of industrial wastes has been found at one of these.
6. Sampling of many wells in the Multi-Source Area indicated only localized groundwater pollution near point sources. However, more site-specific monitoring is needed near most of these sources to identify the extent of the problem.
7. Future monitoring has been recommended, particularly for perched groundwater in the Salt River Valley and industrial wastes in the Multi-Source Area.

INTRODUCTION

This report describes the results of the third phase of the MAG 208 groundwater quality program. This program 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 designated the Maricopa Association of Governments (MAG) as the agency responsible for 208 planning in Maricopa County. Since 1977, major consideration has been given to the impact of nonpoint sources on groundwater in the Maricopa County 208 program. Because of the normal lack of surface water flow in most of the area, except for short periods following heavy precipitation, nonpoint source contributions are primarily to groundwater. The Salt River Valley is emphasized for several reasons. First, most of the groundwater pumpage in Maricopa County is in the valley. Second, a substantial percentage of the total groundwater pumpage for public supply in Arizona is centered in the Phoenix urban area. Finally, most of the potential nonpoint sources of groundwater pollution in Maricopa County are concentrated in the valley.

Background

The first phase began in fall 1977 and was completed in December 1978. Results were presented in the report "Groundwater Quality in the Major Basins of Maricopa County" (Schmidt, 1978). This phase dealt primarily with the distribution of

inorganic chemical constituents in groundwater in the major basins of Maricopa County. Included were the East and West Basins of the Salt River Valley, the Aguila Area, Lower Harquahala Valley, the Lower Hassayampa Area, Rainbow Valley, the Gila Bend Basin, and the Agua Caliente-Hyder Area. Historical trends in groundwater quality were examined in the Salt River Valley, where extensive water-quality records are available since the 1920's. The abundant information was used to aid in determining the impact of man's activities and natural factors on groundwater quality. Such information is necessary before control measures can be undertaken for specific sources of groundwater pollution.

The second phase focused on identifying the major potential sources of pollution and was completed in June 1979. Results were presented in the MAG 208 report "Nonpoint Sources of Groundwater Pollution" (Schmidt, 1979). Amounts and composition of liquid and solid wastes were determined to the extent possible based on the available data. Impacts of specific sources on groundwater quality were evaluated. The impact of some major diffuse sources, such as irrigation return flow, altered groundwater flow directions, and irrigation with sewage effluent, was obvious from existing data. Because there was virtually no site-specific or source-specific monitoring in effect (except for the perched groundwater zone at the Palo Verde Nuclear Generating Station in the Lower Hassayampa Area), the impact of most point and line sources on groundwater quality could not be determined based on

available data. Because of the lack of data on which control measures for specific sources could be based, an extensive monitoring program was recommended at the end of the second phase.

The third phase, which is described in this report, commenced in November 1979 and involved site-specific and source-specific monitoring in the Salt River Valley. This program was outlined in a final working paper by MAG 208 in November 1979. EPA, Region IX decided that activities involving test hole and well drilling were not grant eligible. The proposed evaluation of irrigation return flow, the most important nonpoint source, was greatly limited in scope because of this decision.

The major topics addressed in this phase were:

- Urban Storm Runoff
- Vertical Distribution of Groundwater Quality
- Altered Groundwater Flow
- Perched Groundwater
- Landfills
- Numerous Sources along the Salt River near Phoenix

Monitoring during this phase continued through January 1981, for a duration of more than one year.

This program was enhanced by a review of other on-going studies. Substantial information was gathered on perched groundwater in the Lower Harquahala Valley as part of a study began by the Arizona State Land Department and completed by the Arizona Department of Water Resources. Also, substantial information became available from the extensive groundwater quality monitoring program at the PVNGS in the Lower Hassayampa

Area. This latter information comprises the results of the most extensive monitoring program of perched groundwater known to be in existence in Arizona.

Because of problems with leachate at some landfills due to the flood releases during 1978 through 1980, a total of fourteen monitor wells were installed at four landfills near the Salt River. Agreements were made whereby the MAG 208 program provided manpower to sample water from these wells and funds for chemical analyses. In exchange, valuable information on the impact of landfill leachate on groundwater was obtained.

Substantial information on pollution sources became available through the ADHS Surface Impoundment Assessment program. Also, the U.S. Environmental Protection Agency (1980) mapped numerous existing disposal sites for municipal and industrial solid and liquid waste in the Salt River Valley.

A number of new wells were drilled, deepened, or rehabilitated during the course of this program, and this enabled collection of some data in certain areas. Also, the U.S. Geological Survey began implementation of the Southwest Alluvial Basin Study. Through coordination of efforts, a substantial groundwater quality sampling program was undertaken in Maricopa County. This program provided important new information on the quality of well water in the county, particularly field pH and alkalinity, dissolved organic carbon, and numerous trace constituents.

Sampling and Analysis

An important aspect of a groundwater quality monitoring program is the methodology for sample collection and preservation and laboratory analyses. Wood (1976) discussed guidelines for collection and analysis of groundwater samples for selected unstable constituents. This reference is based on the extensive experience of the U.S. Geological Survey in groundwater quality sampling over many decades. Such information was used to determine which constituents should be determined in the field. In general, temperature, electrical conductivity, pH, and alkalinity were measured in the field at the time of water sample collection. Taylor pocket thermometers were used to measure temperature. A Hach portable conductivity meter, equipped with an automatic temperature compensator, was used to measure electrical conductivity. The meter was periodically calibrated with a standard solution. A Hach portable digital pH meter, equipped with an automatic temperature compensator, was used to measure pH. This meter was calibrated between every measurement with standard solutions of pH 4 and 9. Alkalinity was measured in the field, utilizing standard titration methods. The water sample preservation procedures were generally those of the U.S. Environmental Protection Agency (1979).

Water samples collected for determination of trace metal content were filtered through Millipore 0.45 or 0.10 micron membrane filters. Water samples collected for determination of total trace metal content were not filtered. These samples were either collected in pre-treated polyethylene bottles or

treated in the field with nitric acid. Water samples collected for determination of dissolved organic carbon were filtered through silver membrane filters, to be consistent with the procedure of the U.S. Geological Survey, and placed in glass bottles treated with sulfuric acid. Water samples collected for determination of nitrogen forms were placed in polyethylene containers treated with sulfuric acid. Water samples collected for determination of cyanide were placed in polyethylene containers treated with sodium hydroxide. Water samples collected for determination of phenolics were placed in glass containers treated with phosphoric acid and copper sulfate. Water samples collected for dissolved organic carbon, nitrogen forms, cyanide, and phenolics were kept cool and shipped within several hours to the laboratory for analysis. Water samples collected for determination of the major inorganic chemical constituents were placed in untreated polyethylene containers. Analyses of inorganic chemical constituents and organic carbon were performed by BC Laboratories, Inc. of Bakersfield, California.

Determination of radiological constituents was limited to water from monitor wells at the 19th Avenue landfill, where previous sampling indicated the presence of tritium. Water samples for radiological analysis were collected in untreated polyethylene containers and shipped to LFE Environmental, Analysis Laboratories Division, in Richmond, California. Determination of specific organics was limited to monitor wells at the three City of Phoenix landfills along the Salt River. Water samples collected for analysis of trace organic consti-

tuents were placed in glass containers and the top covered with aluminum foil prior to sealing. The samples were cooled and shipped within several hours to LFE Environmental or Stoner Laboratories in Santa Clara, California.

A number of duplicate samples were collected and analyzed by the U.S. Geological Survey Central Lab in Denver, Colorado, as part of the Southwest Alluvial Basin Study. Duplicate sampling, cation-anion balances, comparison of calculated total dissolved solids vs. residue, repetitive sampling, and rigorous scrutiny provided quality control during this program.

Water Quality Criteria

Drinking Water

The U.S. Environmental Protection Agency (1976) promulgated the National Interim Primary Drinking Water Regulations. Primary regulations concern constituents affecting the health of consumers and are applicable to all public water systems. Maximum contaminant levels were established for inorganic, organic, micro-biologic, and radiologic constituents. Maximum contaminant levels for inorganic chemical constituents are as follows:

<u>Constituent</u>	<u>Level (mg/l)</u>
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Fluoride (Phoenix area)	1.4
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.0
Selenium	0.01
Silver	0.05

The maximum contaminant level for nitrate is applicable to both community and non-community water systems. The levels for the other inorganic chemicals apply only to community water systems. Primary drinking water regulations are federally enforceable.

The U.S. Environmental Protection Agency (1977) proposed National Secondary Drinking Water Regulations. Secondary regulations concern the aesthetic qualities of drinking water. The constituents for which secondary maximum contaminant levels are proposed in these regulations may not have a significant direct impact on the health of the consumers, but their presence in excessive quantities may discourage the utilization of a drinking water supply by the public. Maximum contaminant levels are as follows:

<u>Constituent</u>	<u>Level (mg/l)</u>
Chloride	250
Copper	1.0
Foaming Agents	0.5
Hydrogen Sulfide	0.05
Iron	0.3
Manganese	0.05
pH	6.5-8.5
Sulfate	250
Total Dissolved Solids	500
Zinc	5.0

Secondary regulations are not federally enforceable, but are intended as guidelines. Although hardness is not included in the regulations, it is a commonly used measure of water quality for domestic use. Smith, et al (1963) indicated that hardness as calcium carbonate should not exceed 170 mg/l for good quality water. Water temperature is also important for domestic use, but is not included in the regulations.

The Arizona Department of Health Services (1978) issued drinking water regulations for the state of Arizona. The primary maximum contaminant levels for inorganic chemicals are identical to those of EPA.

Irrigation

Ayers (1977) summarized water quality criteria for irrigation. These criteria are based on problems with 1) salinity, 2) permeability, 3) toxicity, and 4) other factors. Permeability problems are normally associated with irrigation water of very low salt content or a high sodium content relative to calcium and magnesium. Boron, chloride, and sodium, can exert a direct toxic effect on certain sensitive crops. Following are recommended guidelines of importance in Maricopa County.

<u>Constituent</u>	<u>Extent of Problem</u>		
	<u>None</u>	<u>Increasing</u>	<u>Severe</u>
Salinity (Electrical Conductivity in micromhos)	<750	750-3,000	>3,000
Chloride (mg/l)	<140	140-350	>350
Boron (mg/l)	<0.5	0.5-2.0	>2.0
Ammonia-N and Nitrate-N for Sensitive Crops (mg/l)	<5	5-30	>30

The guidelines are flexible and intended for use in estimating potential hazards to crop production associated with long-term use of the particular water being evaluated.

CHAPTER I URBAN STORM RUNOFF

The MAG 208 Water Quality Management Program report on nonpoint sources of groundwater pollution (June 1979) recommended site-specific monitoring for storm runoff in the Phoenix urban area. Much of this storm runoff is disposed to normally dry stream channels. Plate 2 of that report showed the location of the major storm drain outfalls in the Phoenix urban area. Prior to this program there had been no known monitoring of the quality of urban storm runoff in the Phoenix urban area. After consultation with City of Phoenix personnel familiar with the storm drains, two major storm drains with outfalls on the north side of the Salt River were selected for monitoring. The 15th Avenue storm drain was selected because design features and land use in the drainage area are especially well documented. Three distinct types of land use are present along this drain: 1) residential, 2) commercial, and 3) light industrial. The 43rd Avenue storm drain was selected because the lower part drains a heavy industrial area.

The storm runoff monitoring undertaken during this program was of a reconnaissance nature. More exhaustive studies may be undertaken in the future as part of the U.S. Geological Survey Urban Study Program. The MAG 208 monitoring is concerned primarily with groundwater impacts. Although some characteristics of the composition of urban storm runoff

could be estimated based on sampling from other areas, site-specific data are necessary to evaluate the pollution potential in the Phoenix urban area. Of particular concern are dissolved contents of certain trace elements and the dissolved organic carbon content in the urban storm runoff. The major inorganic chemical constituents were also determined because these can control the content of many trace elements. For example, lead can be precipitated by high contents of bicarbonate or sulfate. Also, analyses of these constituents can provide information on the source of specific constituents in urban storm runoff. For example, runoff from irrigated areas could be influenced by the composition of irrigation water, such as Salt River Project canal water, which has a distinct chemical composition.

Quantity

Volumes of urban storm runoff have not been measured in the Phoenix urban area. However, the University of Arizona Water Resources Research Center has measured rainfall and runoff for several small urban watersheds in Tucson since 1968. DeCook and Wilson (1980) stated that the average annual volume of storm runoff from the Tucson urban area is about 65 acre feet per square mile. Storm runoff averages about ten percent of the average annual precipitation of 12 inches. The average annual precipitation in the Phoenix urban area is about seven inches. There were an estimated 325 square miles of urbanized land in this area in 1979. Applying a

similar percentage runoff as for Tucson, the average annual volume of urban storm runoff is thus about 12,000 acre-feet in the Phoenix urban area. Of this amount, some is recharged through wells and ponds and some is diverted into canals. However, the majority is discharged through storm drains to the Salt River and its tributaries. There is a high density of large drains along the Salt River between Price Road and 51st Avenue, and this is probably where much of the recharge occurs.

Rainfall records were obtained from the City of Phoenix Engineering Department, the U.S. National Weather Service, and the Arizona State University Laboratory of Climatology. Records of daily rainfall maintained by the City of Phoenix are usually for fire stations. Although these records are not as precise as those maintained by professional meteorologists, they were found to be closely correlated to precise measurements at Sky Harbor Airport. The locations of the City of Phoenix stations are as follows:

- 14th Street and Thomas Road
- 27th Avenue and Northern Road
- 16th Street and Missouri
- 2nd Street and Roeser
- 59th Avenue and Indian School Road
- 2nd Avenue and Washington
- 43rd Avenue and Glendale

Originally it was planned to sample runoff during several winter and summer storms. Six successive winter storms were sampled between December 1979 and February 1980. However, only small amounts of runoff were present after the few summer storms at the selected outfalls in 1980. Samples were collected

from only one storm in the summer and the results were in close agreement with the results of winter sampling.

Table 1 contains data on the estimated rainfall in the drainage areas for the two outfalls and the number of samples collected per storm at the two outfalls. Prior to the first storm, there had been no substantial rainfall since summer 1979. A traverse was made along the 15th Avenue drain at selected manholes during the fifth storm and along the lower part of the 43rd Avenue drain during the sixth storm. The December 21, 1979 storm was the first one of the winter 1979-80 period. Runoff during every significant storm through February 14 was sampled. Substantial rain fell during a storm on February 19-21 and later; however, flood releases down the Salt River channel at this time precluded sampling at the outfalls. Access to the outfalls was hampered due to road closings and water in the channel covered both outfalls at this time. Because runoff from six storms had already been sampled, the winter sampling program was ended as of February 14, 1980.

Quality

Grab samples were collected at the 15th and 43rd Avenue outfalls during high flows for each storm period. This was done to minimize the effect of other small flows in the storm drains, such as runoff from lawn irrigation. Previous storm runoff studies have shown a flushing effect in some areas. That is, where rains do not occur uniformly throughout the

TABLE 1-SUMMARY OF STORMS SAMPLED DURING WINTER 1979-80

<u>Storm No.</u>	<u>Date</u>	Average Rainfall (inches)	<u>No. of Outfall Samples Collected</u>	
			<u>15th Ave.</u>	<u>43rd Ave.</u>
1	12/21/79 pm	0.08	1	2
2	01/09/80 pm	0.36	3	3
3	01/11	0.30	1	1
4	01/18 pm	0.25	1	1
5	01/29-30	0.25	1	1
6	02/13-14	0.46	1	2

year, but only during specific times of the year, pollutants on streets, yards, and other surfaces build up between rains. The first rains of the season can result in high pollutant levels in the storm runoff. Subsequent runoff often has lower pollutant levels due to this flushing effect; that is, the previous storms have removed much of the pollutants. The flushing effect was noticeable in the sampling during winter 1979-80.

15th Avenue Outfall

The 15th Avenue storm drain outfall is 96 inches in diameter and is designed to handle a flow of over 400 cfs. The drainage area tributary to the outfall includes about 4,600 acres south of the Arizona canal, between 7th Avenue and 19th Avenue (Figure 1). Based on this drainage area and the previous estimates of runoff in the Phoenix urban area, the average annual volume of storm runoff from this drain is estimated to be about 300 acre-feet. Land use is primarily light industrial between the outfall and Jackson, commercial between Jackson and McDowell Road, and residential north of McDowell Road.

Table 2 contains the results of chemical analyses for the major inorganic chemical constituents in selected samples of storm runoff at the 15th Avenue outfall. Total dissolved solids generally decreased to less than 250 mg/l after the first part of the second storm. A significant storm had not occurred before the first storm since summer 1979. Runoff

TABLE 2 - MAJOR INORGANIC CHEMICAL CONSTITUENTS
IN STORM RUNOFF AT 15TH AVENUE OUTFALL

Constituent (mg/l)	STORM NO.				
	1	2	2	4	5
Calcium	72	68	17	17	16
Magnesium	35	44	3	3	8
Sodium	770	280	7	16	49
Potassium	14	5	3	3	3
Carbonate	0	0	0	0	0
Bicarbonate	327	326	70	71	87
Sulfate	176	150	<5	12	11
Chloride	1132	371	10	18	68
Nitrate	3	30	<1	1	5
Fluoride	0.7	0.8	0.1	0.1	0.2
Boron	0.6	0.6	<0.1	<0.1	0.1
pH	7.0	7.8	6.5	7.1	6.9
Electrical Conductivity (micromhos/cm @ 25°C)	3250	1510	140	180	340
Total Dissolved Solids @ 180°C	2350	1073	117	127	230
Date	12/21/79	1/9/80	1/9/80	1/18/80	1/30/80

from the first storm was of the sodium chloride type and appears to be primarily affected by the composition of water used for lawn irrigation. Nitrate content was 30 mg/l for one sample during the first part of the second storm. Fluoride contents exceeded 0.7 mg/l and boron contents exceeded 0.5 mg/l during the first storm and part of the second storm. The high constituent levels during the first storm and first part of the second storm thus were primarily due to the long time since rainfall had occurred. Runoff from the last four storms was generally of the calcium sodium bicarbonate type with low total dissolved solids content. Nitrate, boron, and fluoride contents were low at this time. Runoff during these storms thus reflects previous flushing of constituents.

Total metal content (suspended plus dissolved fractions) was determined once during each of four storms (Table 3). Chromium and zinc contents were far below the drinking water limits of 0.05 mg/l and 5.0 mg/l, respectively. Cadmium contents were usually about 0.02 mg/l, which exceeds the drinking water limit of 0.01 mg/l. Lead contents ranged from 0.02 to 0.24 mg/l, whereas the drinking water limit is 0.05 mg/l. The pH ranged from 6.5 to 7.0 and the runoff was thus slightly acidic.

Dissolved contents of trace metals are more meaningful than total contents in terms of the impact on groundwater. Dissolved metal content (the fraction passing through 0.45 micron filter) was determined on a total of eight samples for the six storms. Chromium contents were less than 0.01 mg/l

TABLE 3 - TRACE ELEMENTS IN STORM
RUNOFF AT 15TH AVENUE OUTFALL

<u>Storm No.</u>	<u>Date</u>	<u>Cd</u>	<u>Cr</u>	<u>Pb</u>	<u>Zn</u>	<u>pH</u>	<u>EC</u> (<u>micromhos</u>)
<u>TOTAL METAL CONTENT (MG/L)</u>							
1	12/21/79	.02	<.01	.02	.15	7.0	3250
2	1/9/80	.02	<.01	.24	-	6.5	140
5	1/30	.02	-	.02	.06	6.9	340
6	2/13	<.01	<.01	.13	.12	6.9	170
<u>DISSOLVED METAL CONTENT (MG/L)</u>							
1	12/21/79	.01	<.01	<.01	.07	7.0	3250
2	1/9/80	.01	<.01	<.01	.02	7.8	1510
2	1/9	.01	<.01	.06	.04	6.5	140
2	1/10	.02	<.01	<.01	.03	6.6	150
3	1/11	<.01	<.01	<.01	.01	6.6	280
4	1/18	.01	<.01	<.01	.02	7.1	180
5	1/30	.01	-	<.01	.03	6.9	340
6	2/13	.01	<.01	<.01	.03	6.9	170
Drinking Limit		.01	.05	.05	5.0		

for all samples. Lead contents were less than 0.01 mg/l, except for one sample which contained 0.06 mg/l. Zinc contents ranged from 0.01 to 0.07 mg/l. All of these three metals thus appear to pose no threat to groundwater quality. Cadmium contents were usually near the drinking water limit of 0.01 mg/l. Apparently, a significant part of the total cadmium is present in the dissolved fraction. Although the dissolved cadmium levels are relatively low, they still warrant attention because of the low drinking water limit.

Table 4 contains the results of determinations of dissolved organic carbon (DOC). Except for the first storm, when the DOC content exceeded 100 mg/l, values for DOC ranged from 7 to 17 mg/l. This decrease is similar to that for the major inorganic chemical constituents. High levels were apparently flushed during the early storms. Future studies are advisable to identify the specific organic constituents present.

The results of storm runoff sampling at the 15th Avenue storm drain outfall are generally similar to those reported by Ellis and Alley (1979) for the Denver, Colorado urban area during periods of no snowmelt runoff. Rainfall averages about 11 inches per year in the Denver urban area. Average electrical conductivities ranged from 140 to 180 micromhos and average pH ranged from 7.5 to 8.3. Average dissolved organic carbon content ranged from 12 to 22 mg/l. Total lead content averaged about 0.40 mg/l. Total cadmium levels and dissolved contents of trace metals were not reported for storm runoff at Denver.

TABLE 4 - DISSOLVED ORGANIC CARBON
IN STORM RUNOFF AT 15TH AVENUE OUTFALL

<u>Storm No.</u>	<u>Date</u>	<u>DOC (mg/l)</u>	<u>pH</u>	<u>EC (micromhos)</u>
1	12/21/79	101	7.0	3250
2	1/9/80	7	7.8	1510
2	1/9	17	6.5	140
2	1/10	15	6.6	150
3	1/11	17	6.6	280
4	1/18	11	7.1	180
5	1/30	8	6.9	340
6	2/13	15	6.9	170

15th Avenue Storm Drain Traverse

During the January 29-30 storm, a traverse was made of the part of the 15th Avenue storm drain below the Grand Canal. A total of 14 samples were collected from manholes along the drain (Figure 1). The sampling was conducted in the upstream direction. Field measurements of electrical conductivity and pH were made on all samples and selected samples were analyzed for the major inorganic chemical constituents, suspended solids, and dissolved organic carbon. Samples 1 through 5 were from the light industrial area, 6 through 9 were from a predominantly commercial area, and 10 through 14 were from a predominantly residential area. Samples collected from the industrial and commercial areas are affected by upstream land uses also. Table 5 summarizes the results. There is a distinct correlation between the results of the field measurements and the predominant land use in the area drained. In the residential area, pH ranged from 6.9 to 7.3 and electrical conductivity ranged from 130 to 180 micromhos. In the commercial area, pH ranged from 7.3 to 7.8 and electrical conductivity ranged from 500 to 920 micromhos. Flows in the "commercial" area appear to be highly influenced by Encanto Park. The higher salinity in runoff downstream from the park is likely due to irrigation at the park. In the light industrial area, pH ranged from 6.9 to 7.4 and electrical conductivity ranged from 280 to 350 micromhos. This suggests that runoff from the industrial area has a similar salinity to that from the residential area.

TABLE 5 - FIELD MEASUREMENTS DURING SAMPLING
TRAVERSE OF 15TH AVENUE STORM DRAIN

JANUARY 30, 1980

<u>Sample No.</u>	<u>pH</u>	<u>EC (micromhos)</u>
1	6.91	320
2	7.24	280
3	7.26	320
4	7.15	340
5	7.41	350
6	7.29	500
7	7.35	590
8	7.61	790
9	7.75	920
10	7.05	130
11	7.01	140
12	6.93	145
13	7.29	160
14	7.23	180
Outfall	7.18	340

Sampling locations are shown in Figure 1. Sampling points are numbered in the upstream direction.

The results of analyses for the major inorganic chemical constituents are presented in Table 6. Runoff from the "commercial" area contained significant contents of sodium, chloride, and nitrate compared to the other two areas. This is attributed largely to irrigation at Encanto Park, and not to commercial activities. Many commercial areas are now drained by dry wells as opposed to storm drains.

43rd Avenue Outfall

The 43rd Avenue storm drain outfall is 90 inches in diameter. The drainage area tributary to the outfall is estimated to contain about 2,300 acres between 39th Avenue and 45th Avenue, south of the Arizona Canal (Figure 1). Based on runoff estimates for the Phoenix urban area and the size of the drainage area, the average annual volume of storm runoff is estimated to be about 150 acre-feet. Land use is primarily residential north of Van Buren Street and heavy industrial to the south.

Table 7 contains the results of chemical analyses for the major inorganic chemical constituents in selected samples of storm runoff at the 43rd Avenue outfall. Total dissolved solids ranged from about 100 to 300 mg/l, but were less than 250 mg/l after the first part of the second storm. The decreases in salinity are due to flushing of materials by the earlier storms. Storm runoff was generally of the calcium or calcium-sodium bicarbonate type. Nitrate contents were usually less than 10 mg/l, and boron and fluoride contents

TABLE 6 - CHEMICAL ANALYSES OF STORM RUNOFF
SAMPLED DURING TRAVERSE OF 15TH AVENUE DRAIN

Constituent (mg/l)	SAMPLE NO.					
	1	6	8	9	11	13
Calcium	13	22	33	37	15	12
Magnesium	5	14	23	26	4	3
Sodium	39	80	139	173	10	7
Potassium	3	4	4	4	3	3
Carbonate	0	0	0	0	0	0
Bicarbonate	71	115	168	198	74	58
Sulfate	<5	40	65	86	<5	<5
Chloride	55	106	189	225	12	8
Nitrate	5	8	13	17	5	4
Fluoride	0.2	0.3	0.4	0.6	0.1	0.1
Boron	0.1	0.2	0.3	0.4	<0.1	<0.1
pH	7.1	6.9	7.2	7.3	7.0	7.2
Electrical Conductivity (micromhos/cm @ 25°C)	320	500	790	920	170	140
Total Dissolved Solids	203	357	557	637	120	90
Dissolved Organic Carbon	10	7.8	-	5.6	5.8	6.5
Suspended Solids	48	25	-	16	30	94

Sampling locations are shown in Figure 1.

TABLE 7 - MAJOR INORGANIC CHEMICAL CONSTITUENTS
IN STORM RUNOFF AT 43RD AVENUE OUTFALL

Constituent (mg/l)	STORM NO.				
	1	2	2	4	5
Calcium	50	47	16	27	13
Magnesium	9	10	5	13	5
Sodium	37	36	9	32	16
Potassium	8	9	5	4	1
Carbonate	0	0	0	0	0
Bicarbonate	146	140	67	147	64
Sulfate	72	62	8	38	20
Chloride	40	45	10	26	11
Nitrate	6	<1	10	3	3
Fluoride	0.5	0.4	0.2	0.4	0.6
Boron	0.2	0.3	0.1	<0.1	0.1
pH	6.3	6.8	6.5	7.3	6.7
Electrical Conductivity (micromhos/cm @ 25°C)	390	390	170	320	180
Total Dissolved Solids @ 180°C	295	280	120	240	107
Date	12/21/79	1/9/80	1/10/80	1/18/80	1/30/80

were relatively low.

Total metal content was determined on a total of four samples from three of the storms (Table 8). Chromium and zinc contents were far below the drinking water limits of 0.05 mg/l and 5.0 mg/l, respectively. Cadmium contents were usually about 0.01 mg/l, which is the drinking water limit. Lead contents ranged from 0.01 to 0.11, and commonly exceeded the drinking water limit of 0.05 mg/l. The pH ranged from 6.6 to 6.9 and the runoff was thus slightly acidic.

Dissolved metal content was determined on a total of ten samples for the six storms. Chromium contents were usually less than 0.01 mg/l. Lead contents were less than 0.03 mg/l except for two samples, one of which contained 0.29 mg/l. Lead contents were less than 0.02 mg/l after the first part of the second storm. This is attributed to wash-off by the earlier storms. Zinc contents ranged from 0.01 to 0.43 mg/l and were less than 0.08 mg/l after the first part of the second storm. All of these trace metals thus appear to pose no threat to groundwater quality. Cadmium contents ranged from less than 0.01 mg/l to 0.02 mg/l, and often exceeded the drinking water limit of 0.01 mg/l. Although these dissolved cadmium levels are relatively low, they still warrant attention.

Table 9 contains the results of determination of dissolved organic carbon. Except during the first storm and the first part of the second storm, when the DOC contents ranged from 66 to 98 mg/l, values for DOC ranged from 8 to 25 mg/l. These

TABLE 8 - TRACE ELEMENTS IN STORM
RUNOFF AT 43RD AVENUE OUTFALL

<u>Storm No.</u>	<u>Date</u>	<u>Cd</u>	<u>Cr</u>	<u>Pb</u>	<u>Zn</u>	<u>pH</u>	EC (<u>micromhos</u>)
<u>TOTAL METAL CONTENT (MG/L)</u>							
2	1/10/80	.01	<.01	.11	.09	6.9	370
5	1/30	.01	-	.01	.07	6.7	180
6	2/13	<.01	<.01	.06	.09	6.6	120
6	2/14	.02	<.01	.01	.08	6.9	170
<u>DISSOLVED METAL CONTENT (MG/L)</u>							
1	12/21/79	<.01	<.01	.08	.10	6.3	390
1	12/22	.02	<.01	.02	.02	7.9	-
2	1/9/80	.01	.02	.29	.43	6.8	390
2	1/10	.01	<.01	.01	.03	6.9	370
2	1/10	.02	<.01	<.01	.07	6.5	170
3	1/11	<.01	<.01	<.01	.02	6.4	210
4	1/18	.02	<.01	<.01	.03	7.3	320
5	1/30	.01	<.01	<.01	.03	6.7	180
6	2/13	<.01	<.01	.01	.01	6.6	120
6	2/14	.02	<.01	<.01	.02	6.9	170

TABLE 9 - DISSOLVED ORGANIC CARBON
IN STORM RUNOFF AT 43RD AVENUE OUTFALL

<u>Storm No.</u>	<u>Date</u>	DOC (<u>mg/l</u>)	<u>pH</u>	EC (<u>micromhos</u>)
1	12/21/79	82	6.3	390
1	12/22	66	7.9	-
2	1/9/80	98	6.8	390
2	1/10	10	6.9	370
2	1/10	21	6.5	170
3	1/11	25	6.4	210
4	1/18	21	7.3	320
5	1/30	8	6.7	180
6	2/13	12	6.6	120
6	2/14	8	6.9	170

results are slightly higher than those obtained from the 15th Avenue outfall sampling.

43rd Avenue Storm Drain Traverse

Rather than an extensive traverse as was done for the 15th Avenue storm drain, sampling was limited to the vicinity of the heavily industrialized area. Samples were collected during the storm of February 13-14, 1980. A sample was collected from the 43rd Avenue storm drain upstream of the industrialized area and additional samples from several drains tributary to the 43rd Avenue drain (Figure 1). Determinations of electrical conductivity, trace metals, and organic carbon showed no differences from the outfall sampling. However, oil and grease contents were relatively high (2.6 to 6.0 mg/l) in the industrialized area compared to upstream (less than 1.0 mg/l). More detailed sampling of storm runoff from industrialized areas should be undertaken in the future.

Multi-Source Area Groundwater Sampling

Besides the sampling of urban storm runoff reported previously, an intensive well sampling program was conducted along the Salt River in the Phoenix urban area in summer 1980. The area sampled extended from the Tempe Bridge on the east to 91st Avenue on the west. This sampling was conducted because there are numerous potential sources of groundwater pollution in this area, including urban storm runoff. The results of this sampling are discussed in more detail in the chapter "Multi-Source Area" in this report. Basically, the

groundwater sampling indicated that lead and cadmium contents were less than 0.01 mg/l in the groundwater along the Salt River, except near some point sources, such as landfills. Thus there was no indication of groundwater pollution from urban storm runoff. However, the large flood releases prior to this sampling resulted in substantial recharge of excellent quality water from the Salt and Verde Rivers. This recharge could effectively dilute pollutant levels from some sources, such as urban storm runoff. Different results may have been obtained if the well sampling had been conducted in a drought period, when flood releases had not been made for many years. In this case, dilution by streamflow recharge would be minimal.

Conclusions

Contents of lead and other trace elements besides cadmium in urban storm runoff at Phoenix do not appear to be a concern for groundwater pollution. Cadmium is a concern because it is present in the dissolved form in contents exceeding the drinking water limit of 0.01 mg/l. Groundwater in the area most likely to be impacted by urban storm runoff showed no pollution from this source in summer 1980. However, unusual conditions were present at that time, due to prior large releases of flood flows down the Salt River and the associated recharge of excellent quality water. Specific determinations of hydrocarbons were not made as part of this investigation, but recent studies (Whipple and Hunter, 1979) indicate that they may be important pollutants in urban storm runoff.

Both cadmium and hydrocarbons in groundwater should be studied in the future in the Multi-Source Area. Sampling of storm runoff in dry wells was scheduled for summer 1980, but was not accomplished due to a lack of runoff at wells selected for monitoring. Dry well disposal is commonly used for commercial development in the Phoenix urban area. Both dry well disposal and storm runoff from industrial areas should be monitored in the future in the Multi-Source Area, possibly as part of the U.S. Geological Survey Urban Studies Program.

CHAPTER II VERTICAL DISTRIBUTION OF GROUNDWATER QUALITY IN THE SALT RIVER VALLEY

Vertical trends in groundwater quality are important for several reasons. First, knowledge of the vertical distribution of constituents important for a specific use of the water can provide the necessary information for improved well construction techniques. Such techniques can allow pumpage of water of suitable quality, compared to what may have been obtained otherwise. Second, because there are substantial differences in chemical quality with depth, there is a potential for groundwater pollution from both well drilling and abandonment. Both test holes and wells can penetrate zones of vastly differing quality in the Salt River Valley. Vertical head gradients can provide the driving force for movement of poor quality water from one depth zone into another. Both test holes and wells can contribute to groundwater pollution by providing continuity between different depth zones. This problem can be minimized through use of sufficient knowledge of the variation of chemical quality with depth. The discussion in this chapter deals with water in the aquifer, as opposed to water in perched zones above the main water level, which is discussed in a separate section.

Past Studies

The MAG 208 report "Groundwater Quality in the Major Basins of Maricopa County" (Schmidt, 1978) indicated that

there were substantial lateral and vertical differences in groundwater quality in the Salt River Valley. Contour maps showing the geographic distribution of many constituents were presented in that report. The geographic distribution of chemical constituents in groundwater of the valley can often be explained by factors such as subsurface geologic conditions and recharge. The report also discussed the vertical distribution of some constituents. Information was available from water samples collected during drilling, from sampling of wells before and after deepening or replacement, and by evaluating well construction data and chemical analyses of water from wells in specific areas.

In terms of the first category, most available analyses were for water samples bailed from wells at different depths during drilling by the cable-tool method. The main parameters evaluated were salinity and fluoride content. Numerous Salt River Project wells have been deepened or replaced by deeper wells. Chemical analyses of water from the shallower well can be compared with those of water for the deeper well. Inferences can then be drawn on the variation of chemical quality with depth. This information is generally available for only salinity and the major inorganic chemical constituents. A comparison of nitrate levels and well construction data for City of Glendale wells provides substantial information on vertical patterns. Similarly, a comparison of salinity and well construction data for City of Mesa wells and several

wells west of Chandler provides substantial information on these patterns.

Past studies have shown that several patterns of a regional nature are evident. For example, nitrate content usually decreases with increasing depth. Near the edges of the East and West Basins, salinity decreases with depth, particularly when conglomerate layers are tapped. Near the centers of basins, where evaporite deposits are often present, salinity increases dramatically with depth. Fluoride contents usually increase with depth, particularly when conglomerate layers or certain clay strata are tapped. In Paradise Valley, chromium contents below a depth of 700 feet also usually increase with depth.

New Studies

Substantial new information has been obtained for specific testing programs conducted as part of the MAG 208 program and other programs. As part of the MAG 208 program, water samples were collected from several wells during drilling by the cable-tool method. Electrical conductivity and nitrate and fluoride content were determined on the collected samples. In recent years, other drilling methods have been used to collect water samples with depth. These include the reverse rotary method, which was used in test holes for the City of Scottsdale. This method is described in detail in the next section of this chapter. The dual-tube reverse rotary method has also been used in the Salt River Valley. Once

a production well is completed, a step drawdown test is normally conducted. Water samples can be collected at various pumping rates during such a test. Often, these samples reflect differences in chemical quality with depth.

Figure 2 shows the location of wells where information on the distribution of chemical quality with depth is available. Maps for specific depth zones have not been prepared because there are inadequate data at present. More information on subsurface geology must first be developed before meaningful maps can be prepared on the vertical distribution of selected constituents for the West Basin. Once the various subsurface geologic units are adequately mapped, then the results of depth sampling can be used to define chemical quality in such units. There is sufficient information on subsurface geology in the East Basin; however, additional water sampling with depth is necessary. Chemical analyses of water pumped from existing wells are of limited value in this regard. The extent of the annular well seal and gravel pack, location of the perforated interval, pumping water level, and other factors influence the quality of water pumped from a well.

City of Scottsdale Sampling

During 1979 and 1980, test holes were drilled by the reverse rotary method in Paradise Valley for the City of Scottsdale (Montgomery Engineers, Inc., 1979, and W.S. Gookin & Associates, 1980). The results for several of the test holes are discussed here because of the valuable information

that was obtained. In this case, a test hole was drilled to total depth and several geophysical logs run. The intervals for water sampling were then selected and a five-inch diameter perforated pipe was lowered to the depth zone to be sampled. Gravel was placed around the perforated pipe and a seal emplaced above the gravel. Water was then airlifted from the drill pipe for a sufficient time prior to water sample collection. In some cases more than 24 hours was necessary. Water samples were analyzed for the major inorganic chemical constituents and the constituents listed in the primary drinking water regulations, including chromium, arsenic, and fluoride. This information was utilized in determining the depths, perforated intervals, gravel pack, and well seals for production wells that were subsequently drilled.

Tables 10, 11, and 12 contain the results of depth sampling for three City of Scottsdale test holes. Test Hole No. 15 was drilled in December 1979 to a depth of 1,855 feet. Water samples were collected at five different depths (Table 10). Sodium, bicarbonate, fluoride, and arsenic contents, total dissolved solids and pH increased with depth, whereas calcium and magnesium content decreased with depth. Because of the high chromium contents encountered at the depths sampled, this hole was subsequently plugged and abandoned.

Test Hole No. 32 was drilled to a depth of 1,724 feet in Spring 1980. Water samples were collected at seven different depths (Table 11). There was little variation in chemical quality with depth at this site. A production well was sub-

TABLE 10 - CITY OF SCOTTSDALE TEST HOLE NO. 15
(A-3-4) 22aca

<u>Constituent (mg/l)</u>	<u>990</u>	<u>Depth (Feet)</u>			<u>1325</u>	<u>1403</u>
		<u>1090</u>	<u>1249</u>			
Calcium	10	10	7		4	3
Magnesium	10	9	5		1	1
Sodium	70	63	89		100	102
Carbonate	0	0	0		2	4
Bicarbonate	203	181	220		232	244
Sulfate	12	12	8		3	10
Chloride	20	16	20		14	20
Nitrate	6	6	4		8	5
pH	8.3	8.3	8.3		9.0	9.4
Total Dissolved Solids	210	200	250		230	300
Fluoride	0.5	0.6	0.6		1.0	1.1
Arsenic	0.02	0.02	0.02		0.05	0.0
Chromium	0.10	0.15	0.05		0.11	0.1

Water airlifted from 16.5 to 37 hours at each depth prior to sample collection. Analyses by Arizona Testing Labs. Data reported by W.S. Gookin & Associates (1980).

TABLE 11 - CITY OF SCOTTSDALE TEST HOLE NO. 32
(A-3-4) 21aad

<u>Constituent (mg/l)</u>	<u>Depth (Feet)</u>						
	<u>690</u>	<u>895</u>	<u>1100</u>	<u>1220</u>	<u>1375</u>	<u>1550</u>	<u>1700</u>
Calcium	25	24	22	27	22	23	17
Magnesium	13	18	25	18	24	25	25
Sodium	64	65	50	63	54	44	50
Carbonate	2	0	0	0	0	0	1
Bicarbonate	234	222	234	232	220	227	244
Sulfate	11	14	11	12	10	11	13
Chloride	40	44	34	36	36	26	26
Nitrate	4	4	3	2	3	4	4
pH	8.5	8.3	8.3	7.8	8.1	8.2	8.5
Total Dissolved Solids	260	260	240	280	250	250	270
Fluoride	0.7	0.4	0.5	0.6	0.6	0.4	0.5
Arsenic	<0.01	<0.01	<0.01	0.01	0.01	0.03	<0.01
Chromium	0.01	0.01	0.01	0.01	0.02	0.05	0.02

Water airlifted from 24 to 30 hours at each depth prior to sample collection. Analyses by Arizona Testing Labs. Data reported by W.S. Gookin & Associates (1980).

TABLE 12 - CITY OF SCOTTSDALE TEST HOLE NO. 33
(A-4-3) 26bbc

<u>Constituent (mg/l)</u>	<u>800</u>	<u>Depth (Feet)</u>		<u>1500</u>
		<u>960</u>	<u>1275</u>	
Calcium	33	36	36	52
Magnesium	21	15	37	37
Sodium	49	53	179	280
Carbonate	0	1	1	0
Bicarbonate	205	234	195	173
Sulfate	15	18	70	92
Chloride	46	36	280	460
Nitrate	4	3	1	1
pH	7.9	8.5	8.5	8.2
Total Dissolved Solids	260	280	710	1040
Fluoride	0.7	0.5	1.5	2.2
Arsenic	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01

Water airlifted for 24 hours at each depth prior to sample collection. Analyses by Arizona Testing Labs. Data reported by W.S. Gookin & Associates (1980). Data below 1000 feet in depth may not be representative due to sampling problems.

sequently completed, with perforations extending from 840 to 1,725 feet in depth. Analysis of a water sample collected near the end of a 24-hour pump test indicated suitable chemical quality for public supply.

Test Hole No. 33 was drilled to a depth of 1,508 feet in April 1980. Water samples were collected at four different depths after airlifting for 24 hours (Table 12). Below a depth of 1,000 feet, sodium, magnesium, sulfate, chloride, fluoride, and total dissolved solids increased with depth. However, data below 1,000 feet were not believed to be representative due to sampling problems. A production well was subsequently completed, perforated from 781 to 1,509 feet. A water sample collected at the end of a 24-hour pump test indicated suitable chemical quality for public supply.

Step Test Sampling

Previous experience in the Salt River Valley has shown that there can be substantial differences in the chemical quality of water at the well discharge, depending upon the pumping rate. This is particularly true in areas where there are substantial differences in chemical quality with depth. The locations of wells where information is available on the variation in chemical quality with pumping rate are shown in Figure 2. Ordinarily, after a permanent pump is installed in a well, a constant discharge is maintained when the well is pumping. On the other hand, when new wells are drilled or existing wells are redeveloped, a step test is often

performed. This usually involves pumping for a duration of several hours at each of from three to five different rates. Prior to this program, information on this phenomenon was available for one well in the Luke area, where salinity was the major concern, and two wells near Glendale, where nitrate was the major concern. The results obtained during drilling and testing of Glendale Well No. 29, (A-3-2) 6aaa, were discussed in the previous MAG 208 report "Existing Groundwater Quality in the Major Basins of Maricopa County" (December 1978).

Table 13 contains the results of step test sampling of a well north of Glendale (Manera & Associates, Inc., 1979). High nitrate contents are present in the shallow groundwater. Because urbanization is occurring in this area, a well was drilled to determine if low nitrate well water could be obtained by tapping deep strata and sealing off the shallower strata. No depth sampling was performed; instead the results of sampling existing wells of known construction data were used. The well was perforated from 675 to 1,440 feet and the annular space above the perforations was filled with a seal. Results of the step test indicate that low nitrate contents were present in discharged water at pumping rates of 1,800 gpm or less. However, at a pumping rate of 2,500 gpm, nitrate content in discharged water increased about five fold. The drawdown at this high pumping rate was almost 170

TABLE 13-NITRATE CONTENTS IN WATER PUMPED
DURING STEP TEST OF WELL NEAR GLENDALE, ARIZONA

(A-4-1) 25cad

<u>Discharge</u> <u>(gpm)</u>	<u>Pumping Level</u> <u>(feet)</u>	<u>Nitrate-N</u> <u>(mg/l)</u>
500	473	1.0
1000	503	1.0
1500	536	0.6
1800	560	1.0
2500	607	5.2

Well perforated and gravel packed from 675-1440 feet. Static water level 439 feet. Steps were run about six hours in duration in April 1979. From Manera & Associates, Inc. (1979).

feet. Apparently at this pumping rate, sufficient downward flow of shallow high nitrate groundwater was induced near the well to produce higher nitrate content in the discharged water.

As part of this program, water samples were collected during step tests on ten wells. These wells included four at the City of Scottsdale, two on the Salt River Indian Reservation, two on the Salt River Project, and two at the City of Chandler. The major inorganic chemical constituents were determined on the collected samples, except for the City of Scottsdale wells, where fluoride, arsenic, chromium, pH, and electrical conductivity were determined. There was little variation in chemical quality with pumping rate for the City of Scottsdale wells. This is attributed to the selective sealing of zones of abnormal quality. That is, the wells were intentionally constructed to tap groundwater of rather uniform chemical quality with depth.

Some of the most significant changes in chemical quality occur for relatively deep wells that are perforated over large depth intervals and have continuous gravel packs from the bottom of the well to the land surface. Table 14 contains the results of sampling a Salt River Project well near Gilbert. Regional information on chemical quality indicates that salinity and nitrate content decrease with depth in this area, whereas fluoride content increases with depth. The well was perforated from 318 to 1,000 feet in depth and gravel packed from the bottom to the land surface. Table 14 indicates that

TABLE 14-CHANGES IN SELECTED CONSTITUENTS
WITH PUMPING RATE FOR WELL NEAR GILBERT, ARIZONA

SRP Well 31.1E - 4.5S

<u>Discharge (gpm)</u>	<u>Pumping Level (feet)</u>	<u>Electrical Cond. (micromhos @ 25°C)</u>	<u>Nitrate (mg/l)</u>	<u>Fluoride (mg/l)</u>
1500	293	2150	78	0.18
2000	312	1990	70	0.24
2500	331	1870	61	0.52

Static water level was 242 feet. Well pumped at each rate for eight hours in January 1980. Well perforated from 318 to 1000 feet.

deeper water was being pumped from the well at higher pumping rates. Whereas salinity and nitrate content were lowest at the highest pumping rate, fluoride content and temperature were highest at this rate.

The results of step-test sampling can provide an indication of vertical changes in chemical quality. Also, useful information for pump design can be gathered, because water of suitable quality may be pumped from a well at certain rates, whereas water of unsuitable quality may be pumped at other rates. Results of such sampling in some cases can provide an indication of future changes in chemical quality to be expected due to substantial declines in water levels.

Conclusions

There are pronounced vertical differences in chemical quality of the groundwater in much of the Salt River Valley. These differences are important from two standpoints. First, when future wells are drilled, knowledge of vertical differences in chemical quality can enable a well to be constructed that will pump better quality water. Second, groundwater can be degraded by movement of poor quality water into other depth zones. This degradation can be enhanced by test holes and wells that penetrate several strata of varying chemical quality. Degradation due to this process can be controlled with knowledge of the vertical distribution of specific constituents in the aquifer.

Substantial information is available on some constituents

in specific areas. Salinity and fluoride have been investigated for several decades. In recent years, nitrate and chromium have received attention. The cable-tool, reverse rotary, and dual-tube reverse rotary methods have been used for collection of water samples at specific depths. Each method can be successfully used; however, care must be taken in the sampling procedure. For example, in the cable-tool method, if samples are bailed the casing should ideally be landed in a clay strata above the point of sample collection. Several hours of bailing may be necessary to obtain a representative sample. For the reverse rotary method, it may be necessary to air-lift for more than 24 hours to obtain a representative sample. This depends on the constituent to be determined, the depth of sampling, and the volume of water produced. Depth sampling has proved to be invaluable when new wells are being drilled in some problem areas of the Salt River Valley.

State well construction regulations are now being developed by the Arizona Department of Water Resources. Adoption of suitable well construction and abandonment procedures in areas of significant differences in chemical quality with depth is a significant control measure. There is a need to develop specific well standards for the Salt River Valley. This is because of the substantial differences in water quality with depth and the importance of protecting the quality of groundwater for municipal use in the valley. Depth sampling in the future throughout the valley and better definition of the subsurface geologic conditions in the West Basin

would greatly enhance knowledge of groundwater quality in the Salt River Valley.

CHAPTER III ALTERED GROUNDWATER FLOW

There are at least two areas in the Salt River Valley where hydrologic modifications have apparently resulted in significant changes in groundwater quality. These are near Chandler and Goodyear.

Chandler Area

As noted in the MAG 208 report "Nonpoint Sources of Groundwater Pollution" (June 1979), the salinity of water in a number of wells northwest of Chandler has increased since about 1950. The average increase in total dissolved solids has been about 20 mg/l per year beneath an area of about 12,000 acres. Groundwater of high salinity has been present for many decades west and southwest of Chandler, toward the Gila River. Schmidt (1979) attributed the increasing salinity to altered groundwater flow directions caused by pumping. Regional groundwater-level elevation contour maps indicate a northerly and easterly direction of flow in this area. Thus groundwater of higher salinity could have moved to the north and east as water levels have been lowered beneath adjacent areas. Regional data also suggest that the salinity is highest in the shallow part of the aquifer, and decreases with depth, particularly near Interstate 10 and Williams Field Road. Pumping has also likely induced downward movement of shallow groundwater of

higher salinity into the producing zones of deeper wells in this area.

Groundwater quality in the area near Chandler is of particular concern because the sole source of public water supply at present is groundwater. The planning area for the City of Chandler extends westward to Interstate 10 and overlies some areas of high groundwater salinity. The purpose of the MAG 208 study in this area (Figure 3) was to delineate flow directions and chemical quality of the groundwater in more detail than was previously available. This will enable a better understanding of the causative factors for the increasing salinity and provide other useful information for future water-supply planning in the area.

Water Levels

Water levels in about 50 large-capacity wells were measured during January 28 - February 1, 1980. A review of construction records and drillers logs for wells in this area indicates that most of these wells are less than 500 feet deep. This time period was selected so that it could be coordinated with the water-level measurement program of the Salt River Project. Water levels in about one dozen SRP wells in the area were measured by SRP personnel in January 1980. Measurements at this time show the effects of minimal pumping. Substantial amounts of canal water were available at that time due to recent years of above average runoff. Except for several isolated irrigation wells that were pumping at this time, the only large-capacity wells that were pumping were

for public supply, primarily at the City of Chandler. The elevations of the measuring points for SRP wells have been precisely determined, and thus water-level elevations can be calculated to at least the nearest foot. However, precise elevations of the measuring point have not been determined for the other wells measured. Land surface elevations were determined from U.S. Geological Survey 7.5-minute quadrangle maps, which show 10-foot elevation contour intervals in the area. The elevation of the measuring point was estimated within several feet from these maps and field data. Based on these data, a water-level elevation contour map was prepared.

Figure 3 shows the location of wells measured and water-level contours for January 1980. Three cones of depression are shown on the map. The most significant one was near Chandler, where water levels were as much as 50 feet lower than beneath the surrounding agricultural land. This cone of depression is attributed to pumpage for public supply at Chandler. The second cone of depression was less pronounced and was located several miles south of Chandler. There was also a less pronounced cone of depression about six miles west of Chandler, near the Gila River Indian Reservation boundary. The latter two cones of depression may be highly influenced by subsurface geologic conditions.

There appeared to be a recharge mound near Ocotillo, about six miles south-southwest of Chandler. This may be due to substantial irrigation return flow in this area. North of Williams Field Road, the direction of groundwater flow

was primarily to the north. Groundwater levels were relatively flat immediately southwest of Chandler. Anomalous deep water levels were present in a few wells compared to those in surrounding wells. The deeper water levels were often from 20 to 30 feet lower than the water levels in nearby wells. An examination of well construction records indicates that the anomalous water levels are generally for deep wells. Thus there appears to be a regional pattern of decreasing hydraulic head with depth. Such a pattern is to be expected if the vertical permeability of the subsurface geologic materials impedes the downward flow of groundwater. Stratification of the alluvial deposits at depth likely causes partial confinement of the aquifer. Recharge originating at the land surface cannot easily reach the deeper strata, because of the low vertical permeability of the confining strata.

Chemical Quality

In contrast to the water-level measurements, the water samples were intentionally collected at a time of heavy pumping in order to obtain representative samples. About 55 large capacity wells were sampled between July 7 and August 7, 1980. An effort was made to insure that the wells had been pumping several days before the water samples were collected. Temperature, electrical conductivity, alkalinity and pH of the discharged water were determined in the field. The major inorganic chemical constituents were determined on all samples. Dissolved organic carbon and numerous trace elements were also

determined in about one-fourth of the samples. Salt River Project wells were generally not pumping during this time, because of the abundance of canal water. However, SRP personnel conducted 24-hour pump tests on these wells sometime during the summer and water samples were collected near the end of each test. Temperature and electrical conductivity of the discharged water were measured. There were about one dozen SRP wells in the Chandler area for which this information was available.

Figure 4 shows the locations of sampled wells and electrical conductivity contours for the study area. The overall pattern is similar to that shown on Plate 3 of the MAG 208 report "Existing Groundwater Quality in the Major Basins of Maricopa County" (December 1978). Electrical conductivity of well water was highest southwest of Chandler near I-10, where values exceeded 6,000 micromhos per centimeter at 25°C. Salinity decreased in a northeasterly direction, and the electrical conductivity was less than 1,500 micromhos near Chandler.

Chemical analysis and temperature of the discharged water can be compared to well construction records to evaluate vertical differences in salinity. In general, water from deeper wells in the area was of lower salinity than water from shallow wells. For example, near Ocotillo, water pumped from deep wells was about 10°F warmer than water from shallow wells. The electrical conductivity of water from shallow wells in

this area ranged from 3,100 to over 4,200 micromhos. On the other hand, the electrical conductivity of deeper water ranged from about 900 to 1,900 micromhos. Wells with a discharge temperature greater than 85°F in the study area usually pumped water with an electrical conductivity less than 2,000 micromhos regardless of the location. The relatively low salinity of well water at Chandler is due to the relatively great depths of public supply wells compared to those of surrounding irrigation wells.

Conclusions

The information gathered as part of this program indicates that downward flow of high salinity shallow groundwater is a major factor in the increasing salinity of well water in most of the Chandler area, where the water table is relatively flat. However, in the area west of Chandler and north of Ray Road, the direction of groundwater movement is to the north. In this part of the study area, the horizontal component of groundwater flow may also be important in the increasing salinity of well water.

Of particular concern to the City of Chandler is the future quality of well water on a long-term basis. Largely this depends on both vertical differences in chemical quality and subsurface geologic conditions. For future water-supply planning purposes, additional information on these phenomena is necessary in the area west of Chandler. Test holes could be drilled by the cable-tool method and drill cuttings logged

by a geologist. Upon completion of each hole, a gamma neutron log could be run. This method would allow collection of water samples at different depths for chemical analyses. Variation in hydraulic head with depth could also be determined. Subsurface geologic cross sections could be prepared and the vertical distribution of chemical quality mapped. With this and other information, an estimate of the amount of potable groundwater in storage beneath the Chandler planning area could be made. Such information could be used to determine if groundwater is a viable long-term supply in the Chandler planning area.

Goodyear-Liberty Area

The MAG 208 report "Groundwater Quality in the Major Basins of Maricopa County" (December 1978) noted that salinity had markedly increased since the early 1960's in water from a number of wells in the Goodyear-Liberty area. The increase in salinity ranged from 40 to 140 mg/l per year, in an area of about 15,000 acres (shown in Plate 2 of that report). Schmidt (1979) attributed this to altered groundwater flow directions due to pumpage. As shown in Plate 3 of that report, high salinity groundwater was present beneath the south part of the area. Regional water-level elevation contour maps suggested that groundwater of poor quality had been moving to the north in the Goodyear-Liberty area since the 1950's. An intensive water-level measurement program was undertaken as part of this program to allow a more precise determination of the direction of groundwater flow

in the Goodyear-Liberty area. An intensive well water sampling program was also undertaken to provide up-to-date information on chemical quality in the area. The overall objective was similar to that for the Chandler Area. Halpenny and Green (1980) completed an investigation of groundwater conditions in the planning area of the town of Goodyear. This report provides substantial recent data.

Water Levels

Figure 5 shows the location of wells where water levels were measured and water-level elevation contours for January-February, 1980. Water levels in about 55 large-capacity wells in the area were measured during February 4-8, 1980. These wells included private irrigation wells, Roosevelt Irrigation District wells, and Goodyear and Avondale public-supply wells. Construction records and drillers logs for wells in the area indicate that well depths generally increase to the north, corresponding with the increasing depth to water. In addition, water-level measurements for January 1980 were available for 20 Buckeye Irrigation District wells and two Salt River Project wells in or near the area. The water levels were intentionally measured during a period of minimal pumping. Other than the pumpage for public supply at Goodyear and Avondale, the only significant pumpage was for several isolated irrigation wells and several wells near the Roosevelt Canal in the western part of the area. Except for the SRP wells, precise elevations of the measuring points are unknown. Land surface elevations were determined from U.S. Geological Survey 7.5-minute quadrangle

maps, which show five-foot contour intervals in the area. The elevations of the measuring point can be estimated within several feet from these maps and field data. Depth to water measurements were thus converted to water-level elevations and a water-level elevation contour map was prepared.

The water-level contours indicate that the regional direction of flow was westerly south of Avondale and Goodyear, and northwesterly beneath most of the remainder of the area. There was no indication of inflow of groundwater from the west, as had been suggested by some previous water-level elevation contour maps. There appeared to be little difference in hydraulic head with depth throughout most of the area, based on water-level measurements in completed wells.

Chemical Quality

Water samples were collected from about 50 large-capacity wells in the Goodyear-Liberty area between August 8 and September 3, 1980. The sampling was intentionally conducted during a period of maximum pumping. All wells sampled were generally pumping for several days prior to collection of the water samples, except for public-supply wells which were pumped frequently, although not continuously. Electrical conductivity, temperature, alkalinity, and pH of the discharged water were measured in the field and water samples collected for laboratory analyses. The major inorganic chemical constituents were determined for all samples. Contents of numerous trace elements and dissolved organic carbon were determined in about one-fourth of the samples.

Figure 6 shows the locations of sampled wells and contours for electrical conductivity. There was a distinct regional pattern north of Broadway Road, with groundwater salinity decreasing to the north. The historical increases in salinity have been observed mostly in wells north of Broadway Road. The lowest salinity well water was present in and to the north of Avondale, where the electrical conductivity was often less than 1,500 micromhos. Recharge from the Agua Fria River is apparently responsible for the low salinity groundwater in this area (Halpenny and Greene, 1980). South of Broadway Road, salinity decreased to the south. This is primarily attributed to recharge of relatively low salinity water by seepage from the Buckeye Canal. The area of highest salinity (electrical conductivity exceeding 5,000 micromhos) may be related to the presence of finer-grained deposits in the subsurface (Halpenny and Greene, 1980).

Water samples were collected at four different depths during drilling of Goodyear Well No. 6, (B-1-1) 3ddb. This sampling showed higher total dissolved solids and nitrate contents in the groundwater at a depth of 200 feet compared to contents between 300 and 500 feet. In most of the Goodyear-Liberty area, both salinity and nitrate content generally decrease with depth, whereas fluoride content increases with depth.

Except south of Avondale, there was a northern component to the regional groundwater flow pattern in the Goodyear-Liberty area in February 1980. A comparison of the electrical

conductivity and the water-level elevation contours indicates that northerly flow of high salinity water from the south explains the historical increases in salinity. An exception is near Avondale and Goodyear, where the historical increase in salinity is likely due to downward flow of high salinity water from shallow depths. Sufficient differences in hydraulic head with depth to produce such flow are apparently not present beneath the rest of the Goodyear-Liberty Area. If the regional direction of groundwater flow remains the same in the future, the salinity of groundwater can be expected to continue to increase in the area north of Broadway Road and west of Bullard Road.

Conclusions

Except near the Town of Goodyear, the increasing groundwater salinities that have been observed since the early 1960's are due to the northerly flow of poor quality groundwater to the south. Beneath most of the Goodyear-Liberty Area, significant differences in hydraulic head with depth are not present. Thus the horizontal component of groundwater flow is the most significant factor in the increasing salinity. Groundwater beneath Goodyear and Avondale apparently comes primarily from the east. There have been only limited historical increases in salinity near Goodyear and Avondale. The absence of a northern component of the groundwater flow in this vicinity has thus been beneficial from the standpoint of groundwater quality. The increases in salinity of water from several

public supply wells in this vicinity may be due to downward flow of shallow groundwater of high salinity. Lower hydraulic heads with depth are likely near Goodyear and Avondale due to pumpage from selective strata for public supply.

CHAPTER IV PERCHED GROUNDWATER

Deep percolation of irrigation return flow is believed to be the major source of recharge to groundwater beneath many of the basins in Maricopa County. Recently, it has been realized that sampling of groundwater from saturated regions above the main water table can be of substantial value in understanding the impact of irrigation return flow on groundwater quality. The chemical quality of water in these perched zones can provide an indication of the impact of deep percolation of irrigation return flow on groundwater quality before the water in the main aquifer is affected. Changes in chemical quality that occur below the root zone and above the water table can be evaluated. This is of crucial importance in considering future groundwater quality. This approach is particularly applicable to alluvial groundwater systems where water levels in the main aquifers are deep. Differences in texture and permeability of various strata result in conditions favorable for the formation of saturated zones perched above the main water table. Information from central and southern Arizona indicates that perched groundwater is usually present beneath irrigated lands. This approach is simplest to use in basins where irrigation return flow is virtually the sole source of recharge. It is more difficult to use in basins where multiple sources of recharge are present,

because impacts of other sources must also be evaluated in this case.

There are several methods by which samples of perched groundwater can be collected. First, cascading water can be bailed from wells where perforations or other openings in the casing extend above the water table. Second, water samples can be collected during drilling of new wells, particularly where the cable-tool method is used. Lastly, special monitor wells can be drilled to tap the perched groundwater.

There are three basins in Maricopa County for which substantial information on perched groundwater is available. Graf (1980 a and b) reported on an investigation of perched groundwater beneath the Lower Harquahala Valley. Controls for Environmental Pollution, Inc. (1979 a and b) reported on the monitoring of perched groundwater at the Palo Verde Nuclear Generating Station in the Lower Hassayampa Area. Samples of perched groundwater have been collected as part of the MAG 208 program in the Salt River Valley, and the extent and nature of perching layers in the valley have been evaluated in a preliminary sense.

Lower Harquahala Valley

Graf (1980 a) reported on studies of perched groundwater in the Lower Harquahala Valley. Groundwater is the sole source of irrigation water in the area. Depth to water in the main aquifer ranges from about 440 to 580 feet below land surface in the area where perched water occurs (Graf, 1980 b).

Thick clay strata in this part of the Lower Harquahala Valley appear to comprise the perching layer. Graf (1980 a) observed 27 wells which had either cascading water or anomalously shallow water levels that were indicative of perched water. Because water levels in the main aquifer have declined about 300 feet in recent decades, many wells now have perforations extending far above the water level in the main aquifer. Water levels in wells penetrating the perched zone range from about 30 to over 200 feet below land surface. The perched zone (Figure 7) is overlain by irrigated land, and evidence indicates that the major source of recharge to the perched zone is irrigation return flow.

Table 15 contains the results of chemical analyses of water from both the perched zone and the main aquifer. One problem in interpreting the sampling results is that different agencies collected the water samples and different laboratories analyzed the water samples for the two sets of data. In general, groundwater in the perched zone has a higher salinity than groundwater in the main aquifer. Contents of most major inorganic chemical constituents are generally substantially higher in the perched groundwater than in water in the main aquifer. Average values for specific parameters in water in the perched zone (Table 15) were calculated and compared to average values in water in the main aquifer.

Electrical conductivity is one of the simplest measurements in the chemical analyses, and values for this parameter may be the most meaningful. Assuming that groundwater in the

TABLE 15 - CHEMICAL ANALYSES OF GROUNDWATER IN
THE LOWER HARQUAHALA VALLEY

Constituent (mg/l)	PERCHED WATER			MAIN AQUIFER			
	(B-1-9) 17abb	(B-1-9) 2lbcc	(B-2-9) 14bbb	(B-1-9) 11bbb	(B-1-9) 20ccc	(B-2-9) 14bbb	(B-2-9) 26adc
Calcium	134	66	189	12	16	32	17
Magnesium	88	40	20	2	9	14	7
Sodium	760	680	710	235	204	144	143
Carbonate	0	0	0	0	0	0	0
Bicarbonate	173	198	102	165	267	140	134
Sulfate	660	440	1050	250	110	150	110
Chloride	796	524	630	81	120	120	92
Nitrate	944	522	86	15	15	21	21
Fluoride	3.2	4.2	4.4	1.8	2.9	1.6	2.4
pH	7.8	7.8	7.7	8.0	7.9	7.8	7.9
Electrical Conductivity (micromhos/cm @ 25°C)	4000	2780	3700	1170	1190	1005	850
Total Dissolved Solids	3567	2423	3126	738	641	589	486
Date	9/26/79	9/26/79	12/11/79	8/13/74	8/7/74	8/7/74	8/8/74
Lab	ADHS	ADHS	ADHS	USGS	USGS	USGS	USGS

Modified from Graf (1980 a). Samples of perched water were taken by bailing except for well (B-2-9) 14bbb, which was pumped. Samples from main aquifer were taken during pumping.

perched zone represents irrigation return flow, then the electrical conductivity measurements indicate an average concentration in salinity in the perched zone by a factor of 3.3 over that in the main aquifer. This would be expected with an irrigation efficiency of about 70 percent, if there was no dissolution or precipitation of salt in the soil-aquifer system. Irrigation efficiency, as used in this report, refers to the crop evapotranspiration divided by the applied water, which in this case is from pumpage. The Arizona Water Commission (1978) estimated the consumptive use of water and pumpage in the Lower Harquahala Valley for 1975. On the basis of these estimates, the irrigation efficiency would be about 72 percent, which is in excellent agreement with that based on salinity. These results thus suggest that concentration by evapotranspiration is the predominant factor in producing the differences in chemical quality between the perched zone and main aquifer.

Additional inferences can be made based on concentrations of individual constituents. Chloride contents in the perched groundwater average about 6.3 times as high as those in the main aquifer. If chloride was not being dissolved or precipitated in the soil-aquifer system, then an irrigation efficiency of about 84 percent would explain this relationship. Calcium, magnesium, sodium, chloride, and sulfate contents on an average basis in the perched groundwater range from 4 to 8 times as high as those in the main aquifer. However, bicarbonate contents in the perched groundwater are generally not

greatly different than those in water in the main aquifer. This suggests that there may be some precipitation of carbonate in the topsoil or vadose zone during downward percolation. Precipitation of carbonate in the topsoil is likely between irrigations. Thus salts in the irrigation return flow are concentrated due to evapotranspiration, but this factor is partly counter-balanced by precipitation of carbonate in the topsoil and vadose zone.

Nitrate contents in water in the perched zone average about 29 times as high as those in the main aquifer. The source of nitrate is probably nitrogen fertilizers. Nitrate contents in water from the perched zone are about two to twenty times as high as the EPA maximum contaminant level for drinking water of 45 mg/l.

Lower Hassayampa Area

Extensive hydrogeologic investigations have been completed near the Palo Verde Nuclear Generating Station (PVNGS) (Arizona Public Service Company, 1975 and 1980). The station is located in an area (Figure 8) that was formerly irrigated, and a perched zone was found during test drilling prior to the start of construction of the station. The exact extent of the perched zone is unknown because of a lack of data points in other parts of the area. The zone is present above a fine-grained unit, which includes the Palo Verde clay, a widespread silty clay unit in the Lower Hassayampa Area. Water levels in the perched zone have been measured at least

bi-monthly since late 1973. Water levels in the perched zone ranged from about 10 to 80 feet below the land surface in 1975, whereas water levels in the main aquifer were about 300 feet deep. A mound was delineated by water-level measurements for the perched zone. This mound coincided with the location of formerly irrigated lands. During the last two years of irrigation, water levels in the perched zone remained relatively constant, indicating that a steady-state had been reached. Since irrigation at the site ceased in 1975, water levels in the perched zone have generally declined at an average rate of about three feet per year. This is likely due to downward flow through the perching layer. The source of water in the perched zone was thus primarily from irrigation return flow. Irrigation in most of the Lower Hassayampa Area has only been practiced for several decades and groundwater has been the sole source of water supply. Direct recharge from local precipitation is considered negligible due to the low rainfall in the area (an average of less than seven inches per year).

Controls for Environmental Pollution, Inc. (1979 a and b) reported on the groundwater quality monitoring program for the perched zone and regional aquifer. A quarterly water sampling program was commenced in 1976, and the sampling interval was changed to semi-annual at the end of 1978. Twelve monitor wells tapping the perched zone have been sampled. In addition, six wells tapping the regional aquifer have been sampled. Figure 8 shows the location of monitor wells tapping

perched groundwater at the PVNGS. All wells tapping the perched zone and two of the wells tapping the regional aquifer have been sampled by bailing. The remaining wells are equipped with permanent pumps and have been pumped for fifteen minutes prior to water sample collection. The results of sampling for the perched zone have been somewhat erratic, probably because of the small diameter of the well casing, which prohibits installation of a pump for water sample collection. Many of the major inorganic chemical constituents, pH, electrical conductivity, boron, fluoride, selected trace elements and gross alpha and gross beta activities have been determined.

The electrical conductivity of well water previously used for irrigation at the PVNGS averaged about 1,200 micromhos per centimeter at 25°C. Extreme or unusual values reported from the monitoring program have been disregarded in this report for interpretative purposes. Monitor wells tapping the perched zone can be divided on the basis of salinity of sampled water into four categories:

<u>Well Number</u>	<u>Typical Electrical Conductivity (Micromhos)</u>
14H, 28H, 31H & Q-1	14,700 - 19,700
22H, 30H & 33H	6,700 - 11,800
21H, 29H, 34H & Q-5	3,600 - 5,200
PVR-2A	1,000 - 1,200

Comparing this information to that in Table 15 for the perched zone in the Lower Harquahala Valley (where the salinity of groundwater in the main aquifer is similar to that

beneath the PVNGS), it is apparent that the third group of wells (21H, 29H, 34H and Q-5) produce water with a salinity that could easily be explained by evapotranspiration effects alone. If the average electrical conductivity of water from these wells was 4,400 micromhos, then an average concentration in salinity of 3.7 has occurred. This would be expected with an irrigation efficiency of about 73 percent. The Arizona Water Commission (1978) estimated the consumptive use of water and pumpage in the Lower Hassayampa Area for 1975. On the basis of these estimates, the irrigation efficiency would be about 70 percent, which is in excellent agreement with that estimated based on salinity.

The higher salinities in water from most of the other monitor wells are due to factors other than crop evapotranspiration alone. There are two primary factors that could result in these higher salinities. First, there could be dissolution of salts in the topsoil and vadose zone. The application of irrigation water on newly developed farmland can result in a considerable leaching of salt in an arid area. This is because of the presence of soluble salts in the topsoil and vadose zone which were not leached by the low rainfall prior to the development of irrigation. Such a phenomenon was evaluated prior to deliveries of California Aqueduct water on the west side of the San Joaquin Valley by Doneen (1968). Second, because of the relatively shallow depth to water in the perched zone (sometimes only several tens of feet or less), direct evaporation of shallow

groundwater may play an important part. In general, if this factor is important, there should be a correlation between depth to water and salinity, with shallowest water containing the most salt. An examination of depth to water and salinity of water in the perched zone indicates no apparent relation. Thus the first factor is probably the most important at the PVNGS. The substantial differences in salinity between the groups of wells are likely due to the distribution of soluble salts in the topsoil and vadose zone prior to development of irrigation. The salinity of water in PVR-2A is similar to that of groundwater in the main aquifer. Water in this well is likely not from irrigation return flow, but from local streamflow recharge.

The nitrate content in well water used for irrigation at the PVNGS is estimated to have averaged about 9 mg/l. Monitor wells tapping the perched zone can be divided on the basis of nitrate content of sampled water into four categories:

<u>Well Number</u>	<u>Typical Nitrate Content (mg/l)</u>
14H, 28H, 31H & Q1	490-750
22H, 30H, 33H & Q5	90-180
21H, 29H, & 34H	35-66
PVR-2A	<9

The pattern of nitrate content in the perched zone is thus similar to that of salinity; that is, high salinity is usually accompanied by high nitrate content. Nitrogen fertilizers are a likely source of high nitrate contents in the perched zone. These nitrate contents are at levels similar to those

in perched groundwater beneath the Lower Harquahala Valley.

Arsenic has been found at significant levels in water from two wells tapping the perched zone:

<u>Well Number</u>	<u>Typical Arsenic Content (mg/l)</u>
29H	0.32 - 0.65
Q-5	0.16 - 0.38

Both of these wells have relatively low salinity and nitrate content compared to water from other wells tapping the perched zone. Cyanide has been found at significant levels in water from three wells tapping the perched zone:

<u>Well Number</u>	<u>Typical Cyanide Content (mg/l)</u>
29H	0.2 - 0.8
31H	0.1 - 0.9
34H	0.4 - 1.5

Both arsenic and cyanide are used in some pesticides and Controls for Environmental Pollution, Inc. (1979a) stated that this could be the explanation for the high contents of these constituents in water from selected wells. The reason why high arsenic and cyanide contents have been found only in certain wells is unknown.

Salt River Valley

Modern irrigation has been practiced for at least 80 years in many parts of the Salt River Valley. Perched groundwater is common beneath much of the Salt River Valley where water levels are more than 100 feet deep. The U.S. Geological Survey and U.S. Bureau of Reclamation measured the level that cascading water entered wells in much of the valley in 1972.

Figure 9 shows the location of two regional perched groundwater zones delineated by these measurements. Many wells (particularly for public supply) do not directly show the influence of perched groundwater because the perforations do not extend above the water table. Most cascading wells are irrigation wells that were drilled several decades ago. As water levels have declined, they have fallen below the shallow well perforations, which can allow perched water to enter and cascade down the well.

The extent of the regional perched zone in the East Basin (Figure 9) is based on water-level measurements in more than 30 cascading wells in 1972. The regional zone shown in Figure 9 does not include shallow perched zones tapped by dry wells in Phoenix and near Chandler. Water-level elevation contours for this regional perched zone in 1972 indicate that the perching layer coincides with a change in subsurface geology delineated by Robert Laney of the U.S. Geological Survey. Laney's unpublished work on subsurface geologic units in the East Basin indicates the location and thickness of an upper alluvial unit. This Recent alluvium is coarse-grained, highly permeable, and up to 250 feet thick in some places. The underlying alluvium is generally finer-grained and of lower permeability. Thus conditions are favorable for formation of a perched zone above the contact between these two units. The primary sources of water in the perched zone are believed to be deep percolation of irrigation return flow and

canal seepage. Water levels in the perched zone were often about 20 to 80 feet above this contact in 1972. The direction of flow in the part of the perched zone south of the Salt River appears to be toward a structural depression near Gilbert. This coincides with an area of increasing salinity in the main aquifer delineated by Schmidt (1978) in studies for the MAG 208 program. This increase in salinity was attributed to irrigation return flow. Because of the configuration of the perching layer and groundwater flow directions in the perched zone, the impact of irrigation return flow could be obvious in the area near Gilbert.

Water-level measurements for 1972 indicate that a regional perched zone is also present west of the Agua Fria River in the West Basin (Figure 9). In this case, the top of a thick clay sequence may comprise the perching layer. This layer has been termed the "Middle Fine-Grained Unit" by the U.S. Bureau of Reclamation (1977). The extent of the regional perched groundwater zone in the West Basin is based on water-level measurements in about 40 cascading wells. The direction of groundwater flow in this perched zone appears to follow that in the main aquifer, i.e., toward a depression near Luke Air Force Base. The primary source of water in the perched zone is believed to be deep percolation of irrigation return flow. Water levels in the perched zone in 1972 were generally from 20 to over 150 feet higher than water levels in the main aquifer. The greatest differences in water level between the perched zone and the main aquifer were generally present

beneath the northern part of the area.

The extent of the regional perched groundwater zones in the Salt River Valley has not been completely determined. Perched groundwater is also believed to be present beneath a substantial part of the West Basin east of the Agua Fria River. Apparently, water levels in cascading wells in this part of the valley were not measured in 1972. In addition to these regional zones, there are several localized areas of shallow perched water. One of these shallow zones is in central Phoenix and the other is near Chandler. The extent of these local zones is not shown on Figure 9 because there are an insufficient number of data points. These perched zones have been penetrated at depths ranging from about 30 to 60 feet by dry wells.

North of Mesa

Table 16 contains chemical analyses for five samples of perched groundwater near the Salt River north of Mesa. All of these samples were collected from sites believed to be within the regional perched groundwater zone (Figure 9). Two monitor wells were drilled by the cable tool method during summer of 1980 at the Tri-Cities landfill. Water samples were bailed from the wells during drilling. An additional sample of perched water was obtained from a cascading well west of the landfill.

The Tri-Cities landfill is located on the north side of the Salt River, southeast of Beeline Highway, east of Arizona

TABLE 16 - CHEMICAL ANALYSES OF PERCHED GROUNDWATER
AND WATER IN THE MAIN AQUIFER NORTH OF MESA

Constituent (mg/l)	Monitor Well No. 1		Monitor Well No. 2		(A-1-5) Saaa Cascading Water
	Perched Water	Main Aquifer	Perched Water	Main Aquifer	
Calcium	59	78	41	36	142
Magnesium	56	56	19	43	42
Sodium	154	148	172	89	301
Potassium	13	9	6	7	8
Carbonate	0	0	0	0	0
Bicarbonate	623	670	400	445	407
Sulfate	34	44	43	12	144
Chloride	125	113	127	64	440
Nitrate	3	<1	8	2	46
Fluoride	0.2	0.2	0.3	0.2	0.3
Boron	-	-	0.2	0.2	-
Iron	<0.05	<0.05	0.05	-	-
Manganese	0.02	1.6	<0.01	-	<0.01
Arsenic	<0.01	0.01	<0.01	-	<0.01
pH	7.8	8.1	8.0	7.8	7.4
Electrical Conductivity (micromhos/cm @ 25°C)	1300	1330	1050	900	1820
Total Dissolved Solids	660	703	630	437	1187
Date	6/80	6/80	1/81	8/80	3/7/80
Depth (feet)	65	135	180	85	212-232
					140

Avenue, and north of the extension of McDowell Road. The water level in the main aquifer was at a depth of about 190 feet in this area in summer 1980. Perched groundwater was sampled at three different zones above the water level in the main aquifer at Monitor Well No. 1. For Monitor Well No. 2, a sample of perched groundwater was collected at only one depth for analysis. Water samples were pumped from the completed monitor wells in January 1981. Monitor Well No. 2 samples shallower water than Monitor Well No. 1. The depth to water in January 1981 was about 205 feet. Because of the proximity of these wells to the Salt River (less than 200 feet) and the prevalence of flood releases during the previous several years, the most likely source of water in the perched zones at this site is seepage of water from the Salt River.

At Monitor Well No. 1, total dissolved solids contents in water from the perched zones ranged from 660 to 710 mg/l. Water in the perched zones was of the sodium bicarbonate type. Groundwater in the main aquifer had a total dissolved solids content of 630 mg/l. Groundwater in the main aquifer had slightly higher contents of sodium, chloride, and nitrate, but lower contents of calcium, magnesium, potassium, bicarbonate, and manganese than groundwater in the perched zones. Water in the main aquifer is of slightly lower salinity than that of water in the perched zones. Analyses for manganese in water at Monitor Well No. 1 suggest that the dissolved oxygen content decreases with depth as recharged water percolates downward toward the water table. If there is a decrease

in carbon dioxide content at the water table, then this could cause precipitation of calcium and magnesium carbonate. Potassium would be expected to be partially removed during recharge due to adsorption. The increase in sodium and decrease in calcium and magnesium could also be due to ion exchange processes.

Results for Monitor Well No. 2 show a somewhat similar pattern. Total dissolved solids content of water in the perched zone was about 440 mg/l, compared to about 750 mg/l in the uppermost part of the main aquifer. Calcium, sodium, sulfate, chloride, and nitrate contents were higher in the main aquifer. Magnesium and bicarbonate contents were slightly lower in the main aquifer. The chemical quality of all water samples collected at these two wells is highly indicative of Salt and Verde River water.

A sample of cascading water was bailed from Well (A-1-5) 5aaa in March 1980. This well is near the intersection of Alma School and McDowell Roads. The cascading water entered the well at a depth of 140 feet, about 80 feet above the water level in the main aquifer at that time. Water-level elevation contour maps indicate that the regional direction of groundwater flow in the main aquifer was to the southeast. The salinity of water in the perched zone is about twice that of groundwater in the underlying aquifer. Nitrate content in water from the perched zone exceeds 45 mg/l. Chemical quality data indicate that water in the perched zone at this site is derived primarily from irrigation return flow and not seepage

from the Salt River. Both groundwater and surface water are used for irrigation on lands upgradient from Well (A-1-5) 5aaa.

Chandler Area

Table 17 contains chemical analyses of perched water from four wells near Chandler. Wells (D-1-4) 33aba, 33bba, and 36add are dry wells that encountered water at a depth ranging from 40 to 55 feet below ground surface. Two of these wells are along Williams Field Road, between 59th Street and Kyrene Road. The third is near Fry and Price Roads. Water samples were collected by bailing. The perching layer in this case appears to be clay strata above a depth of 70 feet. Well (D-2-5) 5dbb is an irrigation well 350 feet deep, which was sampled at the well discharge by the U.S. Geological Survey in March 1972. This well is located south of Pecos Road and near Interstate 10. Later, when the pump was pulled from this well, a sample of cascading water at a depth of 130 feet was bailed from the well. In this case the perching layer appears to be the top of the finer-grained geologic unit that is present beneath the Recent alluvium.

The primary source of water in the perched zone at Well 33aba appears to be seepage from the Gila Drain, which is adjacent to the well. Water in this drain is largely from spills of canal water in the SRP. The primary source of water in the perched zone at Well 33bba appears to be from irrigation return flow. However, seepage from an irrigation lateral immediately to the north and from the Kyrene Canal, which is

TABLE 17 - CHEMICAL ANALYSES OF PERCHED
GROUNDWATER NEAR CHANDLER

Constituent (mg/l)	(D-1-4) 33aba	(D-1-4) 33bba	(D-1-4) 36add	Cascading Water	(D-2-5) 5dbb	Well Discharge
Calcium	29	25	23	180		390
Magnesium	17	21	11	61		110
Sodium	320	744	445	430		350
Potassium	7	5	6	4		9
Carbonate	14	17	0	0		0
Bicarbonate	405	307	319	218		205
Sulfate	130	385	255	320		520
Chloride	251	765	359	690		1120
Nitrate	16	43	36	88		48
Fluoride	3.0	4.2	2.2	-		-
Boron	0.5	0.9	0.7	0.7		0.8
pH	8.4	8.4	8.0	8.3		7.4
Electrical Conductivity (micromhos/cm @ 25°C)	1500	3500	2250	3340		-
Total Dissolved Solids	980	2340	1273	1960		-
Well Depth (feet)	81	75	85	350		350
Water Sample Depth (feet)	40	45	55	130		N.A.
Date	1/22/81	1/21/81	9/17/80	8/13/73		3/12/72

Chemical Analyses for Well (D-2-5) 5dbb from files of U.S. Geological Survey, Phoenix.

about one-quarter mile to the northwest, may also be important. The primary source of water in the perched zone at Well 36add appears to be from seepage from an irrigation lateral immediately to the east. The primary source of water in the perched zone at Well 5dbb is likely irrigation return flow. However, seepage from the Gila Drain, which is less than 1,000 feet from the well, may also be important.

Water at Wells 33aba and 36add has a total dissolved solids content ranging from about 1,000 to 1,300 mg/l. The water is of the sodium bicarbonate-chloride type, and nitrate contents range from 16 to 36 mg/l. This composition is consistent with the fact that canal seepage is the major source of recharge. Water in the perched zone at Wells 33bba and 5dbb has a total dissolved solids content of about 2,000 to 2,300 mg/l, or about twice that of the perched water at the previous two wells. The water is sodium chloride in type, and nitrate contents range from 43 to 88 mg/l. This composition is consistent with the fact that irrigation return flow is the major source of recharge. At Well 5dbb, the total dissolved solids content of water in the perched zone was lower than for water in the main aquifer. At this location, there may be substantial recharge to the main aquifer from groundwater underflow. The higher nitrate contents in the perched zone suggest that irrigation return flow is a major source of recharge of the perched zone. Fluoride contents in perched water at three of the wells ranged from 2.2 to 4.2 mg/l. There is some indication that these relatively high contents may be due to mechan-

ical disturbance during drilling of the dry well. Fluoride may be present in the solid materials comprising the vadose zone. Water samples collected from the dry wells generally contain a significant amount of suspended solids. Thus it is presently unknown whether the fluoride is actually in the perched water body, or is present in solid materials.

Central Phoenix

Table 18 shows the results of chemical analyses of perched water encountered during drilling of four dry wells in Phoenix. The waters are generally of the sodium bicarbonate-chloride type. Total dissolved solids contents range from about 800 to 1,600 mg/l. Two of the wells are located along the Grand Canal, between 7th Avenue and 7th Street. The other two wells are located between Thomas and McDowell Roads, near the Grand and Crosscut Canals.

Depth to water in the perched zone near Wells (A-2-3) 19ddd and 21bbc ranges from about 50 to 60 feet. The perching layer is a clay or silty clay stratum between about 60 and 90 feet in depth. Total dissolved solids content in water from these wells ranged from about 1,000 to 1,200 mg/l and nitrate content ranged from 23 to 39 mg/l. Fluoride contents ranged from 1.5 to 3.2 mg/l. Seepage from the Grand Canal appears to be the source of water in the perched zone. Well 21bbc is about 700 feet north of the Grand Canal and Well 19ddd is about one-half mile south of the canal.

Depth to water in the perched zone near wells (A-2-4)

TABLE 18 - CHEMICAL ANALYSES OF PERCHED
GROUNDWATER IN NORTH PHOENIX

Constituent (mg/l)	(A-2-3) 19ddd	(A-2-3) 21bbc	(A-2-4) 31bad	(A-2-4) 31cb
Calcium	23	33	53	4
Magnesium	27	28	8	2
Sodium	300	350	422	245
Potassium	4	4	4	1
Carbonate	0	14	55	18
Bicarbonate	336	327	454	336
Sulfate	135	160	170	77
Chloride	280	333	294	107
Nitrate	23	39	7	9
Fluoride	3.2	1.5	11.6	10.4
Boron	0.4	0.8	-	0.5
pH	8.0	8.2	8.5	8.6
Electrical Conductivity (micromhos/cm @ 25°C)	1650	1850	2170	1100
Total Dissolved Solids	987	1177	1640	813
Well Depth (feet)	90	80	100	65
Water Sample Depth (feet)	60	61	33	47
Date	9/17/80	12/24/80	1/16/80	9/22/80

31bad and 31cb ranges from about 30 to 50 feet. The perching layer is a clay stratum above a depth of 60 feet. Total dissolved solids contents range from 800 to 1,600 mg/l, and nitrate contents range from 7 to 9 mg/l. Fluoride contents ranged from 10.4 to 11.6 mg/l. The reason for the high fluoride contents is unknown, but these values may not be representative of the perched water due to the sampling method. Seepage from the Grand and/or Crosscut Canal appears to be the major source of recharge to perched groundwater near Well 31cb. Seepage from the Crosscut Canal and irrigation return flow appear to be the major sources of recharge near Well 31bad. Well 31cb is about one mile northeast of the Grand Canal and three-fourths of a mile northwest of the Crosscut Canal. Well 31bad is about one-half mile west of the Crosscut Canal.

Conclusions

The chemical quality of water perched above the main aquifer has been evaluated in the Lower Harquahala Valley, Lower Hassayampa Area, and the Salt River Valley. In general, the chemical quality of water in the perched zone at the PVNGS in the Lower Hassayampa Area is of the poorest quality. Deep percolation of irrigation return flow was the major source of recharge until irrigation ceased in the mid-1970's. The top of a fine-grained unit comprises the perching layer. High salinity and nitrate contents are present in water from many monitor wells tapping the perched zone. Dissolution of

salt in the soil-aquifer system and nitrogen fertilizers appear to be important causative factors. High contents of arsenic and cyanide are present in water from several wells tapping the perched zone, and these constituents are likely derived from previous pesticide applications.

Because irrigation at the PVNGS has ceased, control measures should focus on water in the perched zone. However, there appears to be little use of groundwater in the main aquifer in the area. Water-level measurements indicate that there is substantial downward flow of perched water through the perching layer. Improved well construction techniques could mitigate adverse impacts on the main aquifer. These would include placement of adequate annular seals and limitations on perforated and gravel packed intervals.

In the Lower Harquahala Valley, high nitrate and fluoride contents in perched water are the major concern. Here also, a finer-grained unit acts as the perching layer. There are very few domestic wells in the area. In the future, improved well construction techniques could minimize the downward flow of perched water to the main aquifer. Use of proper well construction techniques can also enable water of suitable quality to be pumped from new domestic wells.

In the Salt River Valley, localized shallow perched water has been found in two places. Such water is present in central Phoenix and near Chandler, and clay strata comprise the perching layers. This water is commonly from 30 to 60 feet deep and canal seepage is believed to be the primary source

of recharge. Chemical quality of water in these shallow perched zones is often similar to that of canal water. Two regional perched zones have been delineated in the valley, one in the East Basin and one west of the Agua Fria River in the West Basin. Depth to water in the regional perched zones is often between 100 and 250 feet below the land surface. Finer-grained deposits appear to comprise the perching layers. Near the Salt River in the East Basin, seepage of streamflow is a source of water in the regional perched zone. Elsewhere, deep percolation of irrigation return flow appears to be the major source of recharge, although canal seepage is important. Few samples of water in the regional perched zones have been collected.

Because irrigation return flow is the major source of recharge in most of the valley and urbanization is rapidly occurring, more attention should be given to perched groundwater in the valley in the future. High contents of nitrate, salinity, and possibly fluoride, some trace elements and pesticides in perched water are a concern for future use of groundwater in the valley for public supply. More information on perched groundwater and irrigation return flow in the valley is vital for proper management of groundwater in the future. Some of this information can be obtained by sampling during the drilling of new wells, by sampling specially installed monitor wells, and by additional sampling of cascading water. Specific studies of irrigation practices are also necessary.

CHAPTER V LANDFILLS

In the MAG 208 report "Nonpoint Sources of Groundwater Pollution" (June 1979), several point sources, including landfills, were recommended for monitoring. As mentioned in that report, the concentration of active and abandoned landfills near the Salt River is a problem in the Phoenix urban area. Substantial information on groundwater quality has been gathered during the past few years at four landfills in particular, three in the West Basin, and one north of Mesa in the East Basin.

City of Phoenix

Flood releases down the Salt River from 1978 through 1980 caused substantial rises in groundwater levels near the channel. Because some refuse was placed in abandoned gravel pits about 70 to 80 feet deep and water levels rose to above a depth of 40 feet in many places, the lower portions of some landfills were covered by groundwater. Also, the past disposal of liquid wastes, such as septic-tank pumpage in the landfills, provided an additional source of water that could produce leachate. Liquid industrial wastes were disposed in ponds or pits at one landfill in particular, the 19th Avenue landfill.

The Bureau of Waste Control, Arizona Department of Health Services (ADHS), issued a cease and desist order in February 1979 to the City of Phoenix to stop landfill operations at

three sites along the Salt River. These were the 16th Street or Del Rio, the 19th Avenue, and the 27th Avenue landfills. A consent agreement was subsequently signed by the City of Phoenix and ADHS. Pursuant to this agreement, James M. Montgomery, Consulting Engineers, Inc. (1979) prepared a report describing the geologic and hydrologic conditions at the three landfills.

Subsurface geologic materials within the upper several hundred feet are primarily coarse-grained Recent alluvium. Boulders, cobbles, pebbles, and sand are predominant. Sverdrup & Parcel and Associates, Inc. (1980) presented water-level maps for the vicinity of these three landfills. The regional direction of groundwater flow was to the northwest in Spring 1972. Water levels have usually declined, in the absence of flood releases down the Salt River, about four feet per year near the 19th Avenue and 27th Avenue landfills. However, in the presence of flood releases, water levels tend to be stable or rise. There are substantial seasonal water-level fluctuations in this vicinity, primarily due to pumpage patterns for numerous Roosevelt Irrigation District wells which are located north of the 19th Avenue and 27th Avenue landfills.

Relatively large flood releases occurred from December 1978 through May 1979. Rises in groundwater level along the river depend on the amount and duration of flow. Water-level rises of 20 to 30 feet along the river channel were common following the 1978-79 releases. Sverdrup & Parcel and Associates, Inc. (1980) indicated that part of the 16th Street landfill was inundated beginning in December 1978. Part of

the 19th Avenue landfill was inundated beginning in May 1979. The 27th Avenue landfill was apparently not inundated prior to 1980.

The James M. Montgomery, Consulting Engineers, Inc. (1979) report provided background information for the installation of twelve monitor wells at the three landfills in late 1979 (Figure 10). Two 105-foot deep monitor wells (West Well and East Well) were already in existence at the Del Rio landfill. Three new monitor wells were drilled at the Del Rio landfill, four at the 19th Avenue landfill, two at Cell A-1 (across the Salt River and south of the 19th Avenue landfill), and three at the 27th Avenue landfill. The twelve wells were drilled on the perimeter of the landfills to a depth of about 100 feet. The casing hammer method was used because of the difficulty in drilling through the coarse-grained shallow deposits adjacent to the Salt River. All wells were equipped with four-inch diameter PVC casing without a gravel pack. The diameter of these wells is sufficiently large to allow installation of a submersible pump for collection of a water sample. In most of these wells, well screen was used between 40 and 100 feet and slotted casing between 30 and 40 feet in depth. A 20-foot annular well seal and protective steel pipe was installed at each well.

Initial Sampling

After completion, each well was developed by pumping and surging. After each well was developed, a water sample was

collected following about one-half hour of pumping at about 15 gpm.

Water-level contour maps for the vicinity of the 19th Avenue landfill indicated that the direction of groundwater was to the northwest in January 1980. Monitor Wells I-3 and I-4 were thus downgradient of the landfill, whereas monitor Wells I-1 and I-2 were upgradient and thus provide an indication of background conditions. As noted by James M. Montgomery, Consulting Engineers, Inc. (1980), water from both Wells I-3 and I-4 was brown in color and had high contents of many constituents that are indicative of landfill leachate. Water from Well I-3 showed the greatest degradation. This well is located in immediate proximity to Cell C, which is believed to be the first cell to be inundated at the landfill. This cell is adjacent to the river, where maximum water-level rises occur, and fill was placed relatively deep. Water from this well had a barium content of 27.5 mg/l, an ammonium content of 82.2 mg/l, a bicarbonate content of 2,103 mg/l, a manganese content of 18.2 mg/l, a potassium content of 152 mg/l, a gross beta activity of 270 picocuries per liter, a Kjeldahl nitrogen content of 106 mg/l, and a total organic carbon content of 116 mg/l. Values of barium, ammonium, gross beta activity and Kjeldahl nitrogen were usually less than the detection limits in unpolluted groundwater in the vicinity. Bicarbonate content was usually less than 300 mg/l and manganese less than 3 mg/l in unpolluted groundwater. Potassium content was usually less than 10 mg/l and total organic

carbon content less than 20 mg/l in unpolluted groundwater. Contents of arsenic, chromium, copper, iron, lead, nickel, phenols, and zinc were also above normal in water from Well I-3.

Water from Well I-4 had high contents of ammonium, arsenic, barium, bicarbonate, cyanide, iron, manganese, nickel, potassium, Kjeldahl nitrogen, total organic carbon, and gross beta activity compared to normal groundwater. This well is downgradient of Cell C, but may also be affected by other cells. There were indications that industrial wastes had been disposed at the 19th Avenue landfill. Subsequent sampling of water from Well I-3 by ADHS for a list of priority organic pollutants indicated that toluene was one of the few organic chemicals identified at significant contents. Analyses for radiological constituents in water from this well indicated high contents of tritium (2,600 picocuries per liter). Numerous borings were subsequently drilled into buried refuse at the 19th Avenue landfill and solid materials were sampled for determination of selected trace inorganic constituents and some pesticides (Arizona Testing Labs, 1980). High contents of barium, chromium, lead, zinc, copper and nickel were found at some sites. There was a direct correlation between contents of these trace elements in solid materials in the landfill near Wells I-3 and I-4 to those in water from these wells. The pesticides DDE and methyl parathion were also found at numerous sites.

The direction of groundwater flow in the vicinity of the Del Rio landfill was to the northwest in January 1980. Well

II-3 was downgradient of a cell first inundated in January 1979 and the West Well was downgradient of an old cell, first inundated in January 1979. The remaining three wells appeared to be upgradient of the landfill according to the direction of groundwater flow in January 1980. Water samples collected from two of the new monitor wells (II-1 and II-2) at the landfill indicated high contents of iron. Water from Well II-1 also had a high nitrate content. These results are indicative of landfill leachate. These results suggested that the direction of groundwater flow may not always be to the northwest. Later water-level measurements have shown that the direction of flow during flood releases is to the southwest. Thus Wells II-1 and II-2 are downgradient of the landfill at such times. However, in the absence of flood releases, these wells are upgradient of the landfill. Water samples from the East and West Wells were bailed, because these wells were not equipped with pumps at that time. The water from the West Well had a slight brown color, suggestive of leachate, and water from the East Well had an oily appearance.

The direction of groundwater flow at the 27th Avenue landfill was to the northwest in January 1980. All three monitor wells were located upgradient of the landfill and waters from these wells showed no unusual characteristics, except for high nitrate contents, which apparently came from a source other than the landfill.

Regular Monitoring Program

Installation of permanent submersible pumps in 13 of the 14 landfill monitor wells was completed in August 1980. By this time, Well I-5 at Cell A-1 had been vandalized and it was not possible to install a pump. Under an intergovernmental agreement between the City of Phoenix and the MAG, the routine quarterly sampling program commenced in late August 1980. Wells I-3, I-6, II-1, II-2, III-1, III-2, and III-3 were sampled during August 27 and 28. Problems with either the pumps or generators delayed the sampling of the remaining wells until September 15, 1980. The East Well at the Del Rio landfill could not be sampled during this round due to problems that could not be remedied. Each well was generally continuously pumped until the temperature, electrical conductivity, and pH of the discharged water stabilized. Water samples were collected at this point for laboratory analysis. The pumping duration was usually about one hour for each well. Care was taken to pipe the pumped water at least 100 feet from the pumped well and to prevent infiltration of discharged water above buried refuse.

Table 19 contains chemical analyses of water collected from monitor wells at the Del Rio landfill during the first regular quarterly sampling round. Water-level contour maps indicate that the direction of flow in August 1980 had changed compared to that in January 1980. This is attributed to recharge from flood releases down the Salt River channel, which created a southwesterly flow. A recharge lobe was thus present.

TABLE 19 - CHEMICAL ANALYSES OF WATER FROM MONITOR
WELLS AT DEL RIO LANDFILL

Constituent (mg/l)	II-1	II-2	II-3	West Well
Calcium	104	140	76	101
Magnesium	46	88	26	29
Sodium	250	365	70	264
Potassium	16	13	6	12
Carbonate	0	0	0	0
Bicarbonate	762	1065	310	662
Sulfate	50	17	87	72
Chloride	250	464	69	249
Nitrate	<1	<1	<1	<1
Fluoride	0.15	0.17	0.23	0.23
Boron	1.22	1.2	0.12	0.43
Iron	<0.05	<0.05	0.05	<0.05
pH	6.8	6.9	6.8	6.6
Electrical Conductivity (micromhos/cm @ 25°C)	2000	3000	840	2000
Total Dissolved Solids	1100	1767	487	1067
Cyanide	0.02	<0.01	<0.01	<0.01
Ammonia Nitrogen	<0.5	1.7	<0.5	<0.5
Kjeldahl Nitrogen	3.9	2.0	<1	1.2
Phenols	<0.1	<0.1	<0.1	<0.1
Total Organic Carbon	136	248	23	16
Color	10	45	1	1
Temperature (°F)	78	77	65	87
Date	8/28/80	8/28/80	9/15/80	9/15/80
	Downgradient	Downgradient	Upgradient	Downgradient

At the Del Rio landfill, Well II-3 represented upgradient conditions at the time of sampling. The low contents of salinity, boron, color, and total organic carbon in water from this well were indicative of recharge from the flood releases. On the other hand, Wells II-1 and II-2 were down-gradient wells at the time of sampling. Relatively high contents of bicarbonate, boron, ammonia, Kjeldahl nitrogen, total organic carbon, and color in water from these wells was indicative of landfill leachate. Water from these wells had an organic taste and odor, foamed, and was about 12 to 13°F warmer than water from Well II-3. Water from these wells was of an almost identical chemical type to that of leachate in an open pit at the landfill, which was sampled in July 1978 by ADHS. However, there was no indication of groundwater degradation due to industrial waste disposal. Water from the West Well did not have an organic taste or odor but did have high bicarbonate and Kjeldahl nitrogen contents and a low pH compared to normal groundwater. Since leachate has apparently reached Wells II-1 and II-2, there may be a need in the future to install several more wells in the south or west part of the Del Rio landfill, in order to determine the extent of degradation. The pump in the East Well was made functional for sampling in March 1981.

Table 20 contains chemical analyses of water collected from monitor wells at the 19th Avenue landfill during the first regular quarterly sampling round. The direction of groundwater flow at the 19th Avenue landfill was the same

TABLE 20 - CHEMICAL ANALYSES OF WATER FROM MONITOR
WELLS AT 19TH AVENUE LANDFILL

Constituent (mg/l)	<u>I-1</u>	<u>I-2</u>	<u>I-3</u>	<u>I-4</u>	<u>I-6</u>
Calcium	42	54	220	132	76
Magnesium	21	23	145	90	41
Sodium	116	71	545	404	230
Potassium	5	5	84	56	21
Carbonate	0	0	0	0	0
Bicarbonate	265	222	1590	1010	492
Sulfate	70	59	32	16	85
Chloride	112	98	807	571	279
Nitrate	<1	<1	<1	<1	<1
Fluoride	0.18	0.24	0.16	0.20	1.34
Boron	0.26	0.20	4.9	0.94	0.42
Iron	<0.05	<0.05	3.9	1.50	-
Manganese	2.2	2.1	13	5.6	-
pH	7.1	7.2	6.7	6.9	6.7
Electrical Conductivity (micromhos/cm @ 25°C)	850	740	4200	3200	1800
Total Dissolved Solids	493	413	2717	1557	1007
Arsenic	<0.01	<0.01	0.02	0.02	-
Barium	<1.0	<1.0	7.5	2.8	-
Chromium	<0.01	<0.01	0.03	<0.01	-
Copper	0.02	0.01	<0.01	<0.01	-
Lead	0.01	<0.01	0.06	0.04	-
Nickel	<0.05	<0.05	0.36	0.10	-
Ammonia Nitrogen	<0.5	<0.5	57	25	2.1
Kjeldahl Nitrogen	<1	<1	69	29	3.1
Phenols	<0.1	<0.1	<0.1	<0.1	<0.1
Total Organic Carbon	17.5	11.5	256	90	121
Color	1	1	350	150	15
Tritium (picocuries/l)	0	0	1000	600	-
Temperature (°F)	70	69	75	80	77
Date	9/15/80	9/15/80	8/28/80	9/15/80	8/27/80

in August 1980 as it was in January 1980, to the northwest. Wells I-1 and I-2 represented upgradient conditions. Water from Wells I-3 and I-4 was highly indicative of landfill leachate and the influence of past disposal of industrial wastes is evidenced by the high barium, nickel, and tritium contents. Contents of many constituents have decreased since the monitor wells were first sampled. Water from Wells I-3 and I-4 was sampled by ADHS in February 1980 and thus results of four sampling rounds were available by January 1981. Contents of constituents that are indicators of landfill leachate (bicarbonate, iron and manganese) apparently have slightly decreased. On the other hand, contents of constituents indicative of industrial waste disposal (barium, arsenic, chromium, nickel, copper, and tritium) have significantly decreased. For example, barium content in water from Well I-3 has declined from 27 mg/l to less than 3 mg/l. In part, this latter trend is due to the cessation of industrial waste disposal at the landfill. The shallowest water levels measured at the landfill were in February 1980 and there have been no flood releases down the Salt River since Spring 1980. The maximum extent of buried refuse coverage by groundwater thus occurred in February 1980. Water levels are now declining and with time, contents of these indicator constituents should decrease in water from monitor wells at the 19th Avenue landfill. Also, because Well I-3 is near the southwest corner of the 19th Avenue landfill, down-gradient movement of polluted water will eventually result in a decrease in pollutant levels in water from the well.

Presently, the downgradient extent of degraded groundwater at the 19th Avenue landfill is unknown. The apparent decrease in pollutant levels may be partially due to downgradient movement of pollutants from the landfill. Additional monitor wells are necessary to determine the extent of pollution and evaluate pollutant attenuation. Three additional monitor wells are recommended. One would be near the intersection of Lower Buckeye Road and 19th Avenue. The others would be about one-quarter mile west of 19th Avenue and downgradient from the landfill. Monitor Well I-6 is downgradient of Cell A-1. High contents of bicarbonate, ammonia, and total ~~in~~organic carbon in water from this well are indicative of landfill leachate. There is a need to replace Well I-5, which was vandalized, in order to provide an indication of upgradient conditions at Cell A-1.

Table 21 contains chemical analyses of water collected from the three monitor wells at the 27th Avenue landfill during the first regular quarterly sampling round. As mentioned previously, these three monitor wells are all upgradient of the landfill. Although high nitrate contents were reported during the original sampling, the results shown in Table 21 indicate relatively low nitrate contents, which have been confirmed in subsequent sampling. Substantial recharge from flood releases may be the causative factor in decreasing nitrate contents. The relatively high contents of total organic carbon indicate that a source of this constituent other

TABLE 21 - CHEMICAL ANALYSES OF WATER FROM MONITOR
WELLS AT 27TH AVENUE LANDFILL

<u>Constituent (mg/l)</u>	<u>III-1</u>	<u>III-2</u>	<u>III-3</u>
Calcium	42	28	42
Magnesium	20	13	20
Sodium	158	120	130
Potassium	6	5	9
Carbonate	0	0	0
Bicarbonate	350	256	308
Sulfate	54	56	64
Chloride	131	87	109
Nitrate	5	7	9
Fluoride	0.20	0.24	0.44
Boron	0.36	0.2	0.29
Iron	<0.05	<0.05	<0.05
pH	7.1	7.0	7.0
Electrical Conductivity (micromhos/cm @ 25°C)	1050	750	925
Total Dissolved Solids	593	423	520
Cyanide	<0.01	<0.01	<0.01
Ammonia Nitrogen	<0.5	<0.5	1.6
Kjeldahl Nitrogen	<1	<1	1.7
Phenols	<0.1	<0.1	<0.1
Total Organic Carbon	66	36	57
Color	2	1	3
Temperature (°F)	76	73	76
Date	8/27/80	8/27/80	8/27/80
	Upgradient	Upgradient	Upgradient

than landfill leachate is present upgradient of the monitor wells. This is believed to be sludge drying beds, holding ponds, and effluent distribution channels associated with the 23rd Avenue Sewage Treatment Plant. These facilities are immediately east and south of the 27th Avenue landfill and the direction of groundwater flow is to the northwest. Two additional monitor wells should be drilled in order to determine groundwater quality downgradient of the 27th Avenue landfill. One should be south of Lower Buckeye Road, about one-quarter mile west of Well III-1. The second should be south of Lower Buckeye Road, about one half mile west of Well III-1.

Summary

In summary, all downgradient monitor wells at the Del Rio and 19th Avenue (including Cell A-1) landfills indicate the presence of landfill leachate. High contents of total organic carbon, ammonia, Kjeldahl nitrogen, iron, manganese, bicarbonate, boron, low pH, high temperature, and brown color are indicators of landfill leachate. A typical example is at the 19th Avenue landfill, where upgradient groundwater has a temperature of about 70°F and pH greater than 7.0, whereas degraded groundwater has a temperature greater than 75° and a pH of 6.5 or less. High contents of trace elements other than iron and manganese are indicative of the past disposal of industrial wastes. The only landfill where the existing monitor wells indicate that this practice has affected

groundwater quality is the 19th Avenue landfill.

Significant control measures are being implemented as part of the consent agreement between ADHS and the City of Phoenix. The 19th Avenue and 16th Street landfills have been closed. The landfills are to be protected from flood releases down the Salt River. A routine water-level measurement program for the monitor wells is being conducted by City of Phoenix staff at all three landfills. Sverdrup & Parcel and Associates, Inc. (1980) have recommended necessary control measures to enable continuation of landfilling at the 27th Avenue landfill. Sufficient soil has been placed in excavations at the 27th Avenue landfill to prevent the direct contact of buried refuse with the groundwater. A sampling program has been underway since May 1980 for selected liquid wastes, which are allowed to be disposed at the 27th Avenue landfill. A manifest system has been instituted to discourage disposal of hazardous wastes at this site. The ADHS has required three items for expansion of the 27th Avenue landfill:

1. Additional monitor wells.
2. A hydrogeologic assessment of groundwater impacts from an expansion and recommendations for groundwater protection measures.
3. A detailed contingency plan for corrective measures to mitigate and abate groundwater contamination.

Also, a report is to be prepared on hazardous waste disposal at the 19th Avenue landfill. This report is to include an evaluation of environmental impacts of past hazardous waste disposal, recommendations for long-term monitoring and/or neutralization of hazardous waste, and recommendations for

post-closure measures.

The quarterly sampling of the 13 existing monitor wells at the three landfills is to continue. Specific items recommended in this report include:

1. Installation of additional downgradient monitor wells at the 19th Avenue landfill to enable determination of the extent of groundwater degradation and to evaluate pollutant attenuation.

2. Installation of downgradient monitor wells at the 27th Avenue landfill to determine if leachate has affected the groundwater.

3. Repair or replacement of the upgradient well at Cell A-1.

4. Care should be taken to not create leachate at the 16th Street landfill due to post-closure activities. Specifically, the site should not be irrigated.

The results of future monitoring will indicate if additional control measures are advisable for groundwater protection.

Tri-Cities Landfill

The Tri-Cities landfill is located on the north side of the Salt River in the north half of section 34, T2N/R5E. SCS Engineers, Inc. (1980) evaluated the landfill according to EPA criteria and reported on this study. As part of the MAG 208 program, a hydrogeologic investigation of this vicinity was conducted (Schmidt, 1980) for input into this study. In the vicinity of the Tri-Cities landfill, depth to water is normally about 220 feet below the land surface and the direction of groundwater flow was to the southeast in January 1980. Because of this relatively great depth to water, the base of the landfill has not been inundated by groundwater. However,

liquid wastes have been disposed at the landfill and flood flows have eroded part of the filled materials. Water from three gravel processing plant wells within about one mile of the landfill was sampled for chemical analyses in January 1980. In addition, chemical analyses were collected for water from other wells in the vicinity, primarily downgradient Salt River Project wells. There was no indication of leachate in water from any of these wells, although low levels of arsenic were present. It was subsequently decided that two down-gradient monitor wells would be drilled at the landfill. Other nearby wells would serve as background or upgradient monitor wells.

Both monitor wells were drilled in summer 1980 by the cable-tool method, whereby an 8-inch diameter steel casing was driven to the total depth of the hole. A 6-inch diameter perforated PVC casing was then inserted and the outer casing was to be pulled up until it was above the main water level. Well No. 1 was drilled to a depth of 300 feet and PVC casing installed, perforated from 240 to 300 feet in depth. Approximately 170 feet of steel casing were left in the well. Perched water was encountered at depths of 65, 135 and 180 feet by this well. A cemented layer apparently acts as the perching layer for the shallowest water, whereas clay strata are the perching layers for water at the lower depths. There was a significant decrease in grain size at a depth of 152 feet, and this is believed to be the base of the Recent alluvium. Water samples were collected from each perched zone

during drilling. Color, odor, and electrical conductivity indicated that this water had not been affected by landfill leachate. The well was not perforated opposite the perched layers because little or no water production could be expected over the long term. A minimum of 20 to 30 gpm was desired for monitoring purposes. The static water level was 191 feet after well completion.

Monitor Well No. 2 was drilled to a depth of 305 feet. When the steel casing was pulled up, the PVC inner casing partly stuck and was partly pulled from the hole. Thus the well could not be completed as planned. Instead, the completed well had steel casing to a depth of about 210 feet. PVC casing was installed, perforated between 210 and 232 feet in depth. Perched groundwater was encountered at 85 feet in depth in this well, and appeared to be the result of a cemented layer. A significant decrease in grain size occurred at a depth of 164 feet, and this is believed to be the base of the Recent alluvium. The static water level in Monitor Well No. 2 was 194 feet after well completion.

Results of chemical analyses of four samples of perched water and one sample of water in the main aquifer are shown in Table 16. There was no indication of landfill leachate for any of the water samples. Instead, water in the perched zones appeared to be from recharge of flood flows down the Salt River. Permanent pumps were installed in late 1980, and the first quarterly sampling round was undertaken by MAG in January 1981.

Well No. 1 was pumped at about 60 gpm and Well No. 2 at about 20 gpm. Temperature, electrical conductivity, and pH were measured frequently until values stabilized. Water samples were then collected for laboratory analysis (Table 22). Depth to static water level at this time was about 208 feet below land surface at the landfill. Water was of the sodium bicarbonate type with total dissolved solids contents ranging from about 630 to 750 mg/l. The water was of similar chemical quality to that pumped from nearby gravel plant processing wells. The water was derived primarily from recharge of flood flows in the Salt River channel. There was no indication of landfill leachate in either sample. Quarterly sampling is continuing. There is no indication of groundwater pollution at the Tri-Cities landfill.

CHAPTER VI MULTI-SOURCE AREA

An area along the Salt River was selected for study because of the presence of numerous potential sources of groundwater pollution. This area is herein termed the "Multi-Source Area" (Figure 11) and extends along the Salt River, from 16th Street to 91st Avenue. The eastern boundary was selected because a field reconnaissance indicated that there were few active wells to be sampled between the Tempe Bridge and 16th Street.

Background

The MAG 208 program report "Nonpoint Sources of Groundwater Pollution" (June 1979) contains two maps of special importance to this discussion. Plate 1 of that report shows the location of various municipal and industrial waste disposal sites. Included are municipal wastewater ponds, sewage effluent disposal to stream channels, and landfills. Plate 2 of that report shows the location of major outfalls to the Salt River for urban storm runoff disposal. The recently completed facility plans for the 23rd and 91st Avenue sewage treatment plants contain substantial information on future amounts and methods of disposal of sewage sludge and effluent.

The ADHS Bureau of Waste Control conducted an assessment of surface impoundments in Arizona. Impoundments were grouped into municipal, industrial, agricultural, and mining and

locations plotted on U.S. Geological Survey 7.5-minute quadrangle maps. Each impoundment was ranked for pollution potential according to EPA criteria. This information was made available to the MAG 208 program for use in groundwater quality monitoring in the Multi-Source Area. The U.S. Environmental Protection Agency (1980) reported on a remote sensing investigation of solid and liquid waste disposal sites in Arizona. Such sites were identified from aerial photographs and their locations were plotted on U.S. Geological Survey 7.5-minute quadrangle maps. According to the Bureau of Waste Control, ADHS, there were at least six facilities within the Multi-Source Area which had been classified as hazardous waste facilities. Both unlined impoundments and injection wells were included.

Potential Sources of Pollution

Previous chapters in this report have included discussions of the results of monitoring urban storm runoff and groundwater near landfills in the Multi-Source Area. Figure 11 shows the location of potential point and line sources of groundwater pollution in the Multi-Source Area, determined from a combination of the previously referenced information. Although not shown, irrigation return flow is the primary potential diffuse source of groundwater pollution, and it occurs over a large part of the Multi-Source Area. The location of storm drain outfalls was updated in December 1980 from City of Phoenix records. There are eight storm drain outfalls entering the Salt River between 19th Avenue and 12th Street.

Water Levels

Originally it was planned to measure water levels in the Multi-Source Area in February 1980, at a time of minimum pumping. However, large amounts of flood water were released down the Salt River channel in February. These releases produced large short-term changes in water levels in the Multi-Source Area. By the time these releases stopped, numerous large-capacity irrigation wells in the area were being pumped. Therefore, a water-level measurement program was not undertaken in the Multi-Source Area as part of the MAG 208 program. However, detailed water-level elevation contour maps for January 1980 are available for the vicinity of the 16th Street, 19th Avenue, and 27th Avenue landfills (Sverdrup & Parcel and Associates, Inc., 1980). The regional direction of groundwater flow in the Multi-Source Area is normally to the northwest. Except for short time periods associated with flood releases, this flow direction is predominant on both sides of the river. However, south of the Salt River, groundwater may flow to the southwest during and shortly after flood releases.

Summer 1980 Sampling

Water samples were collected from about 40 wells in the Multi-Source Area in June 1980 (Figure 12). The sampling was intentionally targeted on the part of the area within about two miles of the Salt River channel. All large-capacity wells that were pumping at this time were sampled. Included were numerous private irrigation and Roosevelt Irrigation District

wells and several Salt River Project and gravel-processing plant wells. An examination of construction data and drillers logs for wells in this area indicates that most tap only the upper several hundred feet of alluvium. An effort was made to insure that these wells had been pumping several days before the water samples were collected. In order to provide more dense coverage, particularly near potential sources of pollution, numerous individual domestic wells were also sampled. In general, there is a paucity of active wells near the Salt River between Tempe Bridge and Central Avenue. Temperature, electrical conductivity, alkalinity, and pH of the discharged water were determined in the field. The major inorganic chemical constituents, cadmium, and cyanide were determined on all samples. Dissolved organic carbon and numerous trace inorganic constituents were also determined on about one-fourth of the samples. Wells in the smaller group of samples were selected in order to provide adequate coverage on a geographic basis. These trace constituents included aluminum, arsenic, barium, beryllium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, selenium, strontium, vanadium, and zinc.

Figure 12 shows the locations of sampled wells and electrical conductivity contours for the Multi-Source Area. Prior to this sampling, little information was available on the regional chemical quality of groundwater in the Multi-Source Area. Electrical conductivity of well water was less than 1,500 micromhos per centimeter at 25°C along the Salt River

channel and for a distance of almost one mile to the north. This electrical conductivity corresponds to a total dissolved solids content of about 1,000 mg/l. Contours indicate the effect of recharge of low salinity floodwaters down the Salt River channel in recent years and recharge of sewage effluent west of the 23rd Avenue sewage treatment plant. Because of the regional direction of groundwater flow, the influence of recharge from these two sources extends primarily north of the Salt River. The electrical conductivity of sewage effluent averages about 1,200 micromhos and the average electrical conductivity of flood releases is estimated to be about 700 micromhos.

The salinity of groundwater in summer 1980 increased with distance from the Salt River in both directions. Electrical conductivity usually exceeded 4,000 micromhos about one mile south of the river and 3,000 micromhos about one to two miles north of the river. Because water levels are normally deeper beneath the eastern part of the Multi-Source Area than beneath the western part, more recharge can occur in the eastern part. This is because deeper water levels provide more storage space for recharge. Consequently, recharge of low salinity water has had a greater impact beneath the eastern part of the Multi-Source Area than beneath the western part.

Cadmium and cyanide are common constituents in a number of types of wastes disposed in the Multi-Source Area. Contents of these two constituents were determined in water from

all wells sampled and were below the detection limits of 0.01 mg/l.

Contents of dissolved organic carbon and many other trace inorganic constituents were normally low, except near several point sources of groundwater pollution. A dissolved organic carbon content of 31 mg/l, compared to a normal content of less than 3 mg/l in groundwater of the area, was found in water from a well downgradient of the 91st Avenue sewage sludge drying beds. A lead content of 0.08 mg/l, exceeding the drinking water limit of 0.05 mg/l, was found in water from a well downgradient of the 19th Avenue landfill. A chromium content of 0.04 mg/l (below the drinking water limit of 0.05 mg/l, but above normal levels in the area) was found in water from another well downgradient of this landfill. High contents of both of these constituents have been found in water from downgradient monitor wells at the landfill. An arsenic content of 0.03 mg/l (less than the drinking water limit of 0.05 mg/l, but above normal levels in the area) and a dissolved organic carbon content of 10 mg/l were found in water from a well near an industrial liquid waste disposal site north of the Salt River at 43rd Avenue. A barium content of 1.4 mg/l, exceeding the drinking water limit of 1.0 mg/l, and a dissolved organic carbon content of 33 mg/l were found in water from a well near a landfill at 40th Street and the Salt River.

The results of the summer 1980 sampling in the Multi-Source Area must be interpreted with caution. First, the quality of groundwater in this area at that time was highly

influenced by substantial recharge from flood releases in 1979 and 1980. The quality of groundwater as shown by Summer 1980 sampling may not be typical on a long-term basis. Recharge of low salinity water would tend to dilute pollutants in the groundwater, particularly from point sources. Second, the wells sampled were often not sufficiently close to a point source to show an impact. Third, these wells were not designed to monitor pollution sources. In some cases they tap water at a depth below that which would be impacted by a pollution source. Lastly, specific organic constituents were not determined in the samples collected during this sampling. Numerous pollution sources in the Multi-Source Area have the potential to introduce high contents of trace organics to the groundwater.

Conclusions

Sampling of about 40 wells in the Multi-Source Area in Summer 1980 provided substantial new information. This information is especially pertinent in assessing the impacts of river channel disposal of sewage effluent and urban storm runoff. Contents of major inorganic chemical constituents, dissolved organic carbon, and selected trace inorganic constituents indicated no substantial adverse impacts from these sources. Both lead and cadmium contents were low in groundwater near outfalls for storm runoff, thus confirming the results expected based on sampling of storm runoff. However, conditions in Summer 1980 were not typical because of large

releases of flood flows down the Salt River in 1979 and 1980. Recharge of low salinity water could substantially dilute levels of some pollutants. Also, contents of specific trace organic chemical constituents were not determined. Thus these results should be interpreted with caution.

Numerous point sources of pollution are present in the Multi-Source Area. Several of these have impacted well water quality in specific locations. These include two landfills and one industrial impoundment. Few wells have apparently been impacted by point sources for several reasons. In general, existing wells are often not sufficiently close or properly constructed to show the influence of a specific source. There are few wells in the Multi-Source Area, particularly east of 15th Avenue (exclusive of monitor wells). Experience at several City of Phoenix landfills indicates that site-specific monitoring is necessary to evaluate groundwater pollution from point sources. This usually entails installation of specially designed monitor wells. The results from the Summer 1980 sampling indicated problems near several point sources. Determination of specific organic chemical constituents in the future could indicate problems not now evident. Also, sampling during drought periods, when there have not been flood releases for several years, could produce different results.

There is a need in the future to monitor near specific pollution sources and also to determine the contents of selected trace organics in groundwater near such sources. Except for several landfills, such monitoring has not been done in

the Multi-Source Area. A comprehensive groundwater quality monitoring program includes the following components:

- 1) Waste sampling and analysis
- 2) Evaluation of infiltration potential
- 3) Monitoring in the vadose zone if water levels aren't shallow
- 4) Sampling and analysis of aquifer water

Substantial work remains to be done on defining waste disposal activities in the Multi-Source Area. The amounts and composition of various wastes in the area should be determined. The attenuation capacity of the vadose zone for specific pollutants should be evaluated. Site-specific monitoring can provide the necessary background information for formulation and implementation of sound control measures. The impact of groundwater pollution on water use in the Multi-Source Area and downgradient should be determined.

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