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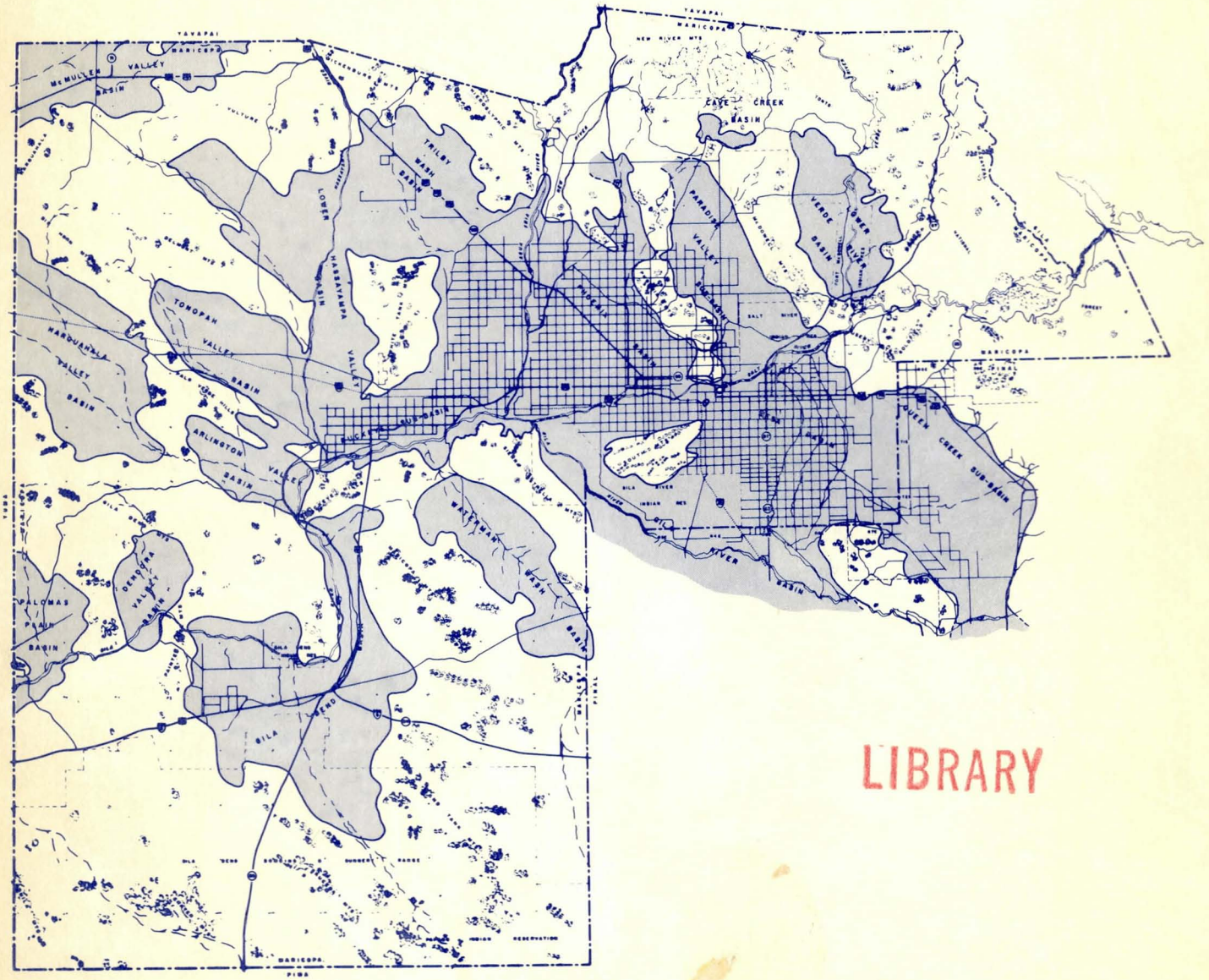

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Prepared in cooperation with the Maricopa County Planning and Zoning Department

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PRESENT AND FUTURE WATER USE

AND

ITS EFFECT ON PLANNING

IN

MARICOPA COUNTY, ARIZONA

A Study for the

MARICOPA COUNTY BOARD OF SUPERVISORS

and the

MARICOPA COUNTY PLANNING AND ZONING COMMISSION

AND DEPARTMENT

By

Dr. Heinrich J. Thiele
Consulting Hydrologist
Scottsdale, Arizona

September 1965

Price: Five Dollars

HEINRICH J. THIELE

CONSULTING HYDROLOGIST

WATER RESOURCE
ANALYSES
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The Maricopa County Board of Supervisors
The Maricopa County Planning and
Zoning Commission

Honorable Board:

In compliance with our agreement of March 2, 1964, and its extention granted January 11, 1965, I submit the study: "PRESENT AND FUTURE WATER USE AND ITS EFFECT ON PLANNING IN MARICOPA COUNTY, ARIZONA".

Collecting the basic data, I have been offered the most objective and cooperative assistance by Federal agencies, State of Arizona, County offices, municipalities, irrigation districts, utility companies, and many individuals. To each one of these I am truly indebted.

Individual members of the Maricopa County Planning and Zoning Commission; Mr. Donald W. Hutton, Director of Maricopa County Planning and Zoning Department and his staff; Mr. Joseph J. Weinstein, Director of the Division of Environmental Sanitation, Maricopa County Health Department; and Mr. Eddie M. Brown, Director, Maricopa County Parks and Recreation Department provided most valuable assistance during the accumulation and analysis of the information upon which this report is predicated. Mr. Henry Shipley, Associate General Manager of the Salt River Valley Water Users Association; Mr. Earl E. Komie, Chief Administrative Geologist, Phoenix Department Office, U.S. Bureau of Reclamation; and Mr. J. K. Kipp, Consulting Economist, Phoenix, have to be mentioned especially for their helpful suggestions and contributions to this study.

The opportunity of serving the County of Maricopa in this capacity has been most appreciated, and I am happy that I have been able to assist its planning officials in one of the initial steps of establishing a long-range County Planning Program.

Respectfully submitted,

Heinrich J. Thiele

Dr. Heinrich J. Thiele
Consulting Hydrologist

PRESENT AND FUTURE WATER USE AND

ITS EFFECT ON PLANNING IN MARICOPA COUNTY, ARIZONA

Maricopa County Planning and Zoning Commission-Department

June 30, 1965

The material and data contained in this Report were prepared under the supervision and direction of the undersigned, whose seals, as professional engineer and professional geologist licensed to practice as such in the State of Arizona, are affixed below.

Dr. Heinrich J. Thiele
Consulting Hydrologist

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PREFACE

Urban land uses such as residential, commercial, industrial, public and semi-public, and rural land uses such as agriculture, are dependent upon a water supply of sufficient quantity and quality to meet present and future needs. Therefore, the location, availability, quantity, and quality of water influence or determine the location, type, and extent of land uses that can be supported.

This report contains an analysis of water conditions in Maricopa County together with an estimate of future water requirements based upon projected population estimates for certain select years. The magnitude of quantitative and qualitative water conditions and their significance and implications with respect to physical planning for future growth of the County are discussed herein. This report is not intended to be definitive for specific geographical areas because of certain inherent limitations of information and data which, of necessity, were obtained from secondary sources.

This report upon water resources was prepared by Dr. Heinrich J. Thiele in close cooperation with the staff of the Maricopa County Planning Department and data has been compiled, analyzed, and presented in a form that will be of invaluable use in future area-wide land-use planning. In addition to its anticipated usefulness for public planning purposes, this report should be of interest and use to various private agencies and individuals concerned with water conditions.

Findings contained herein should be brought up to date, supplemented, and expanded as conditions permit. This report provides a sound basis for an approach toward future land-use planning that would be correlated with water resources.

Donald W. Hutton

Donald W. Hutton, Director
Maricopa County Planning and Zoning Department

SYNOPSIS

Water is a necessity for the support of life anywhere, but especially in the Southwest. In the rapid growth of Maricopa County and the Phoenix Metropolitan Area it becomes evident that present and future water use will have a far-reaching effect on development and planning therefor. A long-range planning policy should look forward to an adequate supply of water at all times. This report presents an analysis of water supply and need in Maricopa County, and especially the Phoenix Metropolitan Area, beyond the year 1980.

Ground water use in the western basins of the County averages 650,000 to 700,000 acre-feet per year, most of it used for agricultural purposes. In some of the basins ground water storage reserves are considerable. For domestic use, most of the ground water in western Maricopa County will have to be treated because of excessive fluorides.

In the Phoenix Metropolitan Area in 1963, 2,962,000 acre-feet were made available at diversion points, 72 percent of it being ground water. Of this amount, 2,363,000 acre-feet arrived at the points of use, about 88 percent of which was used for irrigation agriculture. The difference between the two quantities, 599,268 acre-feet were lost by seepage and evaporation. The actual "mining" of the ground water reserves amounted to 1,313,000 acre-feet.

The ground water storage reserve to 1,000 feet depth was roughly 100 million acre-feet, 54 percent were located in the Phoenix Basin and 46 percent in the Mesa Basin, forming two more or less independent ground water units. The depletion during the 7 year period 1956-1963 was 5,920,000 acre-feet, causing an average water-table decline of 42 feet in the Phoenix Basin and 49 feet in the Mesa Basin. Local depletion by over-pumping was and still is considerably higher, especially east of Mesa; and in the Glendale-Deer Valley and Litchfield-Beardsley areas. The 1,313,000 acre-feet of ground water "mined" and the 900,000 acre-feet of surface water brought into the Phoenix Metropolitan Area in 1963 left a salt residue in the order of 1.8 million tons per year in the underground which slowly increased the concentration of the remaining ground water reserve. Good quality water in larger quantity still is to be found in Paradise Valley and the Queen Creek Basin areas.

The Salt River Project supplies water as the life blood to the Phoenix Metropolitan Area, in the order of 900,000 acre-feet per year. By the year 2020, the foreseeable need will be 1.9 million acre-feet, with the ground water storage reserve reduced to 38.6 million acre-feet. It is mandatory that at least this volume be maintained as an iron reserve to be used only during periods of surface water shortage. The Central Arizona Project and its water supply from outside sources are of paramount importance to Maricopa County and the Phoenix Metropolitan Area, and their planning for future growth.

TABLE OF CONTENTS

Chapter		Page No.
I	INTRODUCTION	1
	1. Authority for Work	1
	2. Purpose and Importance to Advance Planning	1
	3. The Study Area	2
	4. Source of Information	3
	5. Formulation of a Program	3
	6. Accuracy of Estimates and Limitations	4
II	SUMMARY OF FINDINGS AND CONCLUSIONS	6
	1. Water Need	6
	2. Present Water Supply	7
	3. Future Water Demand	9
	4. Water, A Land Development Factor	10
	5. Water Resources Management and its Relationship to Regional Planning	11
III	PHYSICAL FEATURES OF THE WATER SUPPLY AREAS	12
	1. Precipitation and Ground Water Replenishment	12
	2. Hydrogeology	13
IV	TRENDS IN WATER CONSUMPTION	15
	1. Water History	15
	2. Agricultural Water Use	17
	3. Nonagricultural Water Use	19
V	WATER SUPPLY SOURCES	23
	1. The Phoenix Metropolitan Area	23
	2. Outlying Ground Water Basins	35

Table of Contents

Chapter		Page No.
VI	FUTURE WATER NEEDS AND POPULATION POTENTIAL OF THE PHOENIX METROPOLITAN AREA	42
	1. Population Potential	42
	2. Augmenting the Available Water Supply	48
	3. Water Resources Management and its Effects Upon Planning in Maricopa County	53
	REFERENCES	57

CHARTS

Chart No.		Page No.
1	Forecast of Water Requirements for all Nonagricultural Purposes	21
2	Total Water Supply, 1953-1963, Phoenix Metropolitan Area	23-24
3	Water Table Decline Per Annum of Representative Wells	26-27
4	Area of Basin Extent Underneath Ground Surface	28-29
5	Specific Yield Assumptions, Phoenix and Mesa Basins	30
6	Ground Water Depletion Curves to 1000 Foot Depth, Phoenix Metropolitan Area	30-31
7	Growth Potential of the Phoenix Metropolitan Area	46

PLATES

Plate No.		Page No.
1	Basin-Area Location Map	2
2	Depth to Bedrock	14
3	Changes in Agricultural Acreage 1953 to 1963	18-19
4	Cross Section A-A, Phoenix Metropolitan Area	26-27
5	Depth to Ground Water, Spring 1963	26-27
6	Annual Rate of Ground Water Level Decline, 1963	26-27
7	Dissolved Solids Content of Ground Water, 1963	32-33
8	Total Hardness of Ground Water, 1963	32-33
9	Fluoride Content of Ground Water, 1963	32-33
10	Temperature of Ground Water, 1963	35
11	Dissolved Solids Content of Ground Water, Forecast 1980	45
12	Depth to Ground Water, Forecast 1970	45-46
13	Depth to Ground Water, Forecast 1980	45-46

TABLES

Table No.		Page No.
1	Summary of Quantitative and Qualitative Ground Water Information, Spring 1963, Phoenix Metropolitan Area	7
2	Summary of Quantitative and Qualitative Ground Water Information, Spring 1963, Outlying Ground Water Basins	8
3	Summary of Population Potential, Total Water Requirements, and Ground Water Depletion, 1963-1980, Phoenix Metropolitan Area	9
4	Surface Water Reservoirs	15
5	Net Income Maricopa County, 1953 and 1963	16
6	Total Water Uses and Net Incomes Created by Industrial Sectors, Arizona 1958	16
7	Total Cropped Acreage, Maricopa County, 1950-1965	17
8	Irrigated Acreage, 1953 and 1963, Phoenix Metropolitan Area	18
9	Ground Water Pumpage (in Acre-Feet) From Wells in Principal Ground Water Basins, 1946-1963, Maricopa County	19-20
10	Population Growth, Maricopa County, 1950-1963	19-20
11	Nonagricultural Water Use, Phoenix Metropolitan Area	20
12	Water Requirements and Water Supply, 1963, Phoenix Metropolitan Area	23
13	Total Water Supply at Points of Diversion, Phoenix Metropolitan Area	23-24
14	Spring 1963 Water Tables, Rates of Annual Decline and Forecasts, 1970 and 1980, Assuming Continuous Past Decline Rates, Phoenix Metropolitan Area	28

Tables

Table No.		Page No.
15	Basin Extent, Average Depth to Water, Average Annual Decline Rates, 1956, 1963, and Forecasts 1970 and 1980, Phoenix Metropolitan Area	28-29
16	Ground Water Pumpage, Return-Recharge and Loss, 1956 to 1963	29
17	Ground Water Storage to 1000 Foot Depth, Spring 1963, Phoenix Metropolitan Area	30-31
18	Quality of Ground Water, 1963, Phoenix Metropolitan Area	34
19	Suggested Upper Limits of Fluoride in Drinking Water	34-35
20	Ground Water Basins Outside the Phoenix Metropolitan Area, Water Tables, Spring 1963, Rates of Annual Decline and Forecasts, 1970 and 1980	36
21	Ground Water Basins Outside the Phoenix Metropolitan Area, Quality of Ground Water 1963	37
22	Computation of Average Specific Yield and Volume of Recoverable Water, Waterman Wash Basin	38
23	Water Requirements Forecast, Phoenix Metropolitan Area	43
24	Forecast of Water-Table Decline and Ground Water Depletion, 1963-1980	47
25	Forecast of Urban and All Other Nonagricultural Water Requirements, 1963-1980	47-48
26	Forecast of Agricultural Requirements, 1963-1980	47-48
27	Forecast of Total Water Requirements	48
28	Brackish Water Demineralization at Buckeye, Phoenix Metropolitan Area	51

ERRATA SHEET

page 7, paragraph 4, line 5
delete "used approach"
insert "approach used"

page 7, footnote, line 2
delete "acre-feet"
insert "acre-foot"

Page 18, paragraph 2, second sentence
should read "New additional lands are continuously developed for irrigation wherever ground water supplies can be found except in those areas which are curtailed by critical water area laws."

page 19, paragraph 2, line 4
should read "...past changes of ..."

page 21, paragraph 1, line 3
should read "...this major reason, daily water deliveries by different water companies vary between an average of 68.5 and..."

page 22, paragraph 2, line 5
delete "and"
insert "per"

page 26, paragraph 4, line 4
should read "...2 to 10 feet per year."

page 34, paragraph 2, line 5
delete words "offset by an increase in sodium.

page 24, paragraph 5, line 1
delete "project-irrigated areas"
insert "project-irrigated acres"

I INTRODUCTION

Within a short span of years, Maricopa County has increased several times in population. There is every indication that this expansion will continue unabated into the foreseeable future. The problems of the future will require a high degree of coordination and integration of land uses as related to water uses. The County's interest in water is necessarily a general one in all aspects of development and use. However, the ultimate objective of comprehensive planning is to enable the people in the County to achieve maximum benefits from all resources by the development, use and conservation of water and an appropriate use of land. Effective and equitable long-range planning is dependent upon an adequate knowledge of the County's water resources.

1. Authority for Work

This study is submitted to the Maricopa County Board of Supervisors in accordance with a resolution passed March 2, 1964. The purpose of the report is to provide factual data on water resources and needs to the County Board of Supervisors, the County Planning and Zoning Commission, and various other County departments, public agencies and interested citizens.

2. Purpose and Importance to Advance Planning

As the County's population spreads from the cities to the fringe areas and to suburban or detached subcenters and satellite towns, guide lines for forecasting growth and land use will have to be adjusted. Customarily, land development plans provide information on the amount of land that will be devoted to each purpose and how intensively it will be utilized through gradual development. Land use plans should take into consideration water resources and their ability to serve a basin area. An understanding of the most suitable patterns of growth is based on growth and balance characteristics of development. The objective of this study is to understand economic forces such as water availability and water-use potential by geographical area. This report sheds light on some water-related issues which are

significant far beyond those of a mere water resources study. Urbanization and agricultural irrigation should be brought into balance, their respective water needs with their water base. The study represents more than a compilation of existing data; it involves considerable research and evaluation of findings.

3. The Study Area

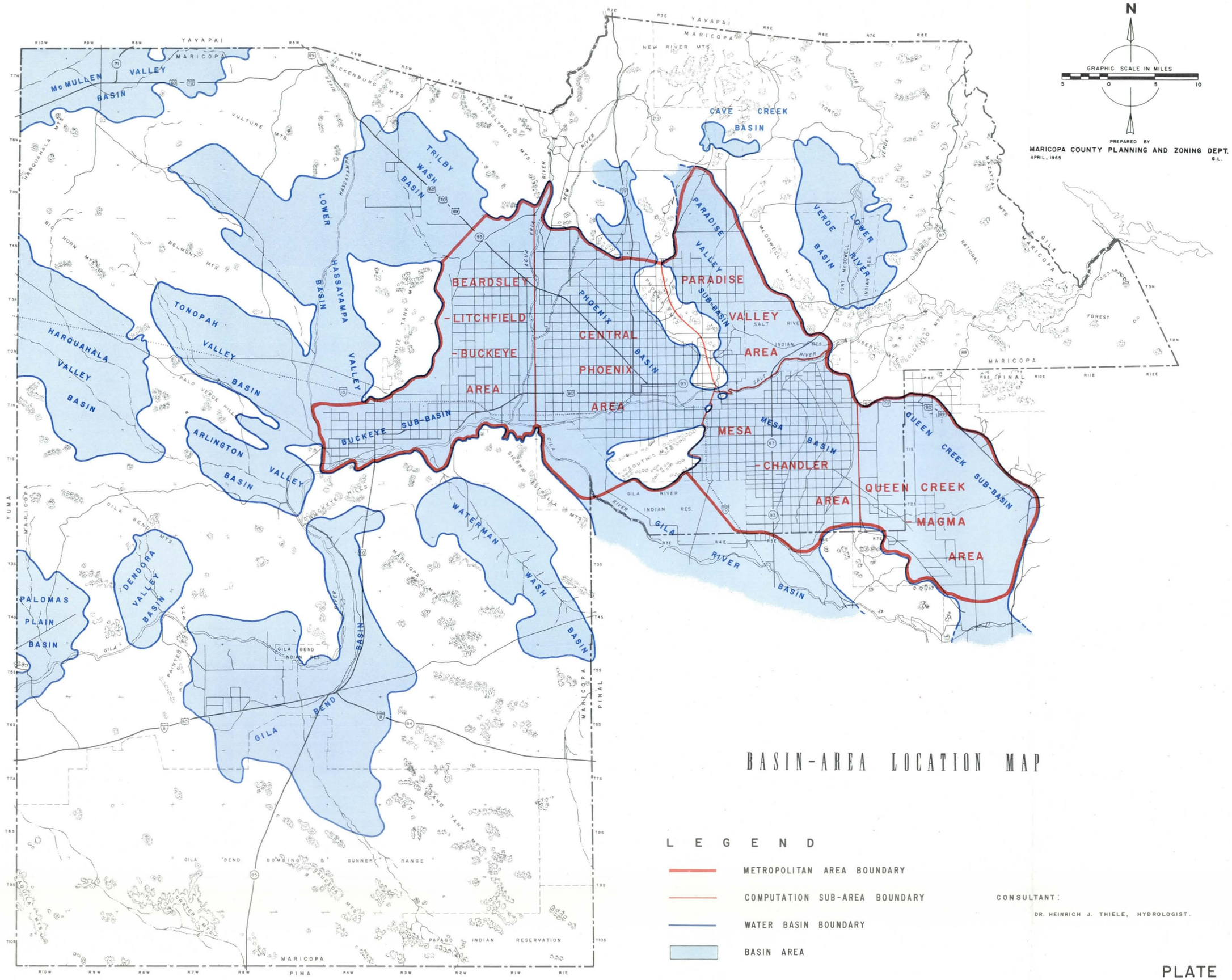
For purposes of this study, Maricopa County was divided into (1) basin-areas with major ground water resources; and (2) the remaining area of the County which in general holds some local water reserves too limited for any land development beyond that of scattered family houses. This second and larger area beyond present and probable future areas of urbanization will be generally subject to only sparse development in all likelihood. Moreover, such areas would require water to be piped into them.

The hydrologic unit boundaries of the ground water basins were determined from considerations of water availability. Locations of the major ground water basins are shown in Plate 1: McMullen Valley, Harquahala Basin, Palomas Plains, Dendora Valley, Gila Bend Basin, Waterman Wash Basin, Arlington Valley, Tonopah Valley, Lower Hassayampa Valley, Cave Creek Basin, Salt River Valley which includes the Phoenix and Mesa Basins.

The Salt River Valley area is called the Phoenix Metropolitan Area,* for purposes of this study, and is limited in the north by the Hieroglyphic Mountains, New River Mountains and Cave Creek Basin; in the northeast and east by the McDowell Mountains, Usery Mountains, and Superstition Mountains; in the south by the San Tan Mountains, South Mountains, Sierra Estrella Mountains and Buckeye Hills; and in the west by the Hassayampa River and the White Tank Mountains (see Plate 1).

The Metropolitan Area is subdivided into two ground water hydrologic units, the Phoenix Basin in the west and the Mesa Basin in the east. The Phoenix Basin's sub-units are the Central Phoenix Area east of the Agua Fria River, and the Beardsley-Litchfield-Buckeye Area to its west. The Mesa Basin is divided into the Paradise Valley unit north of the Salt River; the Mesa-Chandler area west of a north-south line connecting Usery Mountains and San Tan Mountains; and the Queen Creek-Magma area extending into Pinal County to the east of said dividing line. The Mesa Basin unit crosses the political boundary line of the

*This is not to be confused with the Standard Metropolitan Statistical Area as defined by the U.S. Census Bureau which includes all of Maricopa County.



BASIN-AREA LOCATION MAP

LEGEND

- METROPOLITAN AREA BOUNDARY
- COMPUTATION SUB-AREA BOUNDARY
- WATER BASIN BOUNDARY
- BASIN AREA

CONSULTANT:
DR. HEINRICH J. THIELE, HYDROLOGIST.

PLATE I

County, which does not however stop population movements and developments as demonstrated by the extent of development in the Apache Junction area east of Mesa. The ground water area boundaries and subareas shown here within the Phoenix Metropolitan Area do not conform with boundaries and subareas of the Salt River Valley as established by the U.S. Geological Survey.

Several maps are included within this report depicting present and forecasted quantitative and qualitative water conditions. The maps were adapted from a base map constructed for this report by the Maricopa County Planning and Zoning Department.

4. Sources of Information

In preparation of this report, prior investigations and reports dealing with Maricopa County water resources and water uses were studied. Information was obtained from the files of the U.S. Geological Survey, Phoenix and Tucson; U.S. Bureau of Reclamation, Phoenix; Arizona State Health Department, Phoenix; University of Arizona, Agricultural Extension Service, Tucson and Phoenix; Arizona Corporation Commission, Phoenix; Maricopa County Planning and Zoning Department, Phoenix; Maricopa County Health Department, Phoenix; the cities and towns of Phoenix, Mesa, Scottsdale, Tempe, Gilbert, Chandler, Glendale, Peoria, Litchfield, Goodyear, Avondale, Tolleson and Buckeye; Salt River Project; Maricopa County Municipal Water Conservation District No. 1; Roosevelt Water Conservation District; private water companies and other agencies; and from other sources and publications (see References).

5. Formulation of a Program

This study encompasses three basic components:

(1) Water-Use Study: Water used for agricultural and nonagricultural purposes; trends in nonagricultural consumption;

(2) Water-Resources Study: Water table information and water quality;

(3) Water-Utilization-Potential Study: Water availability in the Phoenix Metropolitan Area; forecast in water use trends, probable population and irrigated acreage, until and beyond 1980.

6. Accuracy of Estimates and Limitations

The water use and resource analysis in this report is reconnaissance in nature and limited by the data presently available.

The detailed determination of present and projected population, land use, and water use by small geographic units would require a detailed inventory and corollary analysis which are beyond the scope of this study. To cope with the basic data problem, the entire Phoenix Metropolitan Area is considered as a unit subdivided into the Phoenix Basin and Mesa Basin sub-units. This procedure permits using those numbers for population, land and water use which are most definitely established and sufficient for the type of overall determinations made in this study.

The basic data available in files and publications have been scrutinized carefully. A thorough appraisal of the available geologic and ground water hydrologic information indicated a lack of quantitative data necessary for an accurate evaluation. The depth and configuration of the ground water basins and the type and distribution of materials comprising their alluvial fill are known from a relatively small number of wells and test holes. The method used is to correlate the safe yield of the alluvial fill, dewatered in the past, with the gross water supply at diversion points, net supply at points of use, and water table decline rates. A more accurate accounting can be accomplished only with very high expenses of test drilling and test pumping. On the other hand, broader considerations, and those of general reconnaissance to best advantage, often do not require a higher accuracy.

The method used to make predictions herein consists mainly of determining past trends in water-table declines and projecting these into the future. This approach takes into account the complete extent of a ground water-filled basin, to an average depth of 1,000 feet from ground surface, changes in the basin shape and in specific yield caused by greater compaction with increasing depth and intervening clay layers. The specific yield of the dewatered part of the Salt River Valley aquifers averages 20 to 21 percent above 248 feet depth, and a straight-line assumption of declining rates to 10 percent at 1,000 feet is the best approximation possible, without detailed studies. Any deviation from this hypothesized set of conditions will directly affect the amount of change in forecasted water levels and affect the accuracy of the predictions made. However, local deviations from these projections will not necessarily

constitute a major deviation from the predictions made for a ground water basin as a whole.

The population projections for the Phoenix Metropolitan Area, made by the Maricopa County Planning and Zoning Department and others, to and beyond 1980, constitute preliminary projections on the basis of which the nature of likely changes in the agricultural pattern may be observed. If the population projection for 1980 should not be attained until 1985, the changes in the relative proportions of the projected agricultural acreage, accompanying such an extension of time for an attainment of a given population, would not materially change the relative proportions of these two major types of water users. High precision in population projection is not essential for obtaining a fairly reasonable apportionment of the remaining irrigated acreage. Nonagricultural and agricultural water uses determine the area's total water consumption.

II. SUMMARY OF FINDINGS AND CONCLUSIONS

> "At a time when use of water is increasing rapidly and is approaching feasible limits of development in area after area, and when there is growing national awareness of the true importance of water in our economy, we must admit that we do not even know how much we use, to say nothing of how much we have that can be used."

The U.S. Geological Survey Report presented to the President's Water Resources Policy Commission, 1950, contained this statement. The validity of this assertion is becoming all too apparent when studying this report. The optimum utilization of Maricopa County's water resources, in the need of long-term planning, can result only out of the correlation of future water requirements and the available water reserves. Without augmenting the available water supply, growth and development of Maricopa County, and especially of the Phoenix Metropolitan Area, will be retarded before the year 2000. The objective of this report is to present an analysis of water supply and demand as they influence land development factors in future County planning.

In this study, ground water basins of Maricopa County are being investigated, and in more detail, those of the Phoenix Metropolitan Area.

1. Water Need

In determining water needs, past trends in water usage were evaluated and continued into the future. The nonagricultural water use, for the year 1963, was 309 gallons per capita per day (gpcd) and the total consumption for 815,000 people amounted to 282,000 acre-feet. The total population of the County, at that time, was 831,000 persons. The agricultural gross water use, at 4.84 acre-feet per acre, amounted to 2,081,000 acre-feet required to irrigate 430,055 acres in the Phoenix Metropolitan Area. The total irrigated acreage of the County was 509,400 acres. The present analysis concentrates on the Phoenix Metropolitan Area because of the magnitude of population here and because the compilation of the available data furnishes a broad basic source of information for this particular area. Data available for all water uses and sources in other areas of the County are admittedly incomplete in many respects.

TABLE 1

SUMMARY OF QUANTITATIVE AND QUALITATIVE GROUND WATER INFORMATION, SPRING 1963
Phoenix Metropolitan Area

	Quantitative Information				Qualitative Information (Average Values)			
	Depth to Water Spring 1963 Feet	Rate of Annual Water Table Decline Feet	Depth to Water Forecast 1970 Feet	Depth to Water Forecast 1980 Feet	Total Dissolved Solids ppm*	Total Hard-ness ppm*	Fluorides ppm*	Temper-ature °F
I. PHOENIX BASIN								
West of Agua Fria River								
Gila River Valley	40-150	0- 4.0	50-180	60-220	2100	600	1.3	80
Litchfield-Beardsley Area	150-440	4.0-15.0	180-530	220-680	280	77	1.4	82
East of Agua Fria River								
Salt River Valley	40-150	0- 4.0	50-180	60-220	1900	530	0.8	77
Phoenix-Glendale-Deer Valley Area	150-470	4.0-17.0	180-570	220-740	490	250	0.6	81
II. MESA BASIN								
Paradise Valley								
South of Indian Bend	60-315	10.5-17.5	200-420	200-580	625	225	0.7	83
North of Indian Bend	186-850	1.0- 9.2	240-860	300-880	305	160	0.7	86
Mesa-Chandler Area								
North of Baseline	60-513	1.4-15.4	70-615	84-745	770	270	0.8	75
South of Baseline	57-445	0-18.6	75-575	200-761	2100	790	0.6	78
Queen Creek-Magma Area								
North of Apache Blvd.	230-501	6.0-13.5	279-527	350-637	1130	350	1.8	95
South of Apache Blvd.					440	150	0.7	88
Pinal County Area	245-412	6.0-13.0	287-457	350-633	550	210	0.6	79

*ppm = parts per million

2. Present Water Supply

The approach to the present water study has been adjusted to fit the nature of the special conditions and the available data within Maricopa County. To cope with the basic data problems, an entire basin area has been selected as a unit, which is the customary procedure of this kind. Basin depths are often several thousand feet. Total ground water storage to 1000 feet depth of the Phoenix Metropolitan Area was estimated as follows as of spring 1963:

Phoenix Basin	53,971,000 acre-feet
Mesa Basin	46,337,000 acre-feet
Phoenix Metropolitan Area	100,308,000 acre-feet

The 1963-depletion of the ground water reserve of the Metropolitan Area was 1,313,000 acre-feet, which represents 1.3 percent of the combined storage. It also should be mentioned that 828,268 acre-feet of surface water were available during this specific year, and that the total gross water use amounted to:

Surface Water	828,268 acre-feet
Ground Water	2,134,000 acre-feet
Total Water Supplied	2,962,268 acre-feet

The consumptive use of almost 2.2 million acre-feet of water for various purposes added about 1.8 million tons of salt to the underground and part of it to the remaining ground water storage, thus increasing its concentration.*

Data has been assembled on the water supply situation in various parts of the Phoenix Metropolitan Area (Table 1), exposing the range of spring 1963 water tables; and annual water-table drop rates based on observations during the preceding 10-year period. Future forecasts using these decline rates to 1970 and 1980, and water quality criteria, also are summarized in Table 1. It might be stressed that the used approach is conservative, requiring some restrictions in water use during the 1963-1980 period since the basin extent shrinks in greater depth. Maximum changes in depth to water become obvious:

---

*Average content of total dissolved solids equals 600 parts per millions (ppm)
0.00137 x ppm = tons per acre-feet, 0.00137 x 600 = 0.822 ton of salt per acre-feet
2.2 million acre-feet x 0.822 ton = 1,808,400 tons of salt.

Area of Observation	Depth to Water (Feet) Forecast		
	1963	1970	1980
Litchfield-Beardsley Area	440'	560'	680'
Glendale-Deer Valley Area	470'	570'	740'
Northern Paradise Valley	850'	860'	880'
East of Mesa	513'	615'	745'

It also should be mentioned that these forecasts consider total basin water use, i.e. for the Mesa Basin including Paradise Valley and the Queen Creek-Magma area in Pinal County. The likely water table decline rates per year do not differ essentially from those experienced in the past. The chemical quality of ground waters is unfavorable for domestic use in downstream areas which receive each year, with the irrigation return flow, a larger portion of the yearly added 1,800,000 tons of salt (see values for total dissolved solids and hardness).

Present (1963) decline conditions are relatively favorable compared with those of 1980, 17 years from now, for a series of ground water basins to the west of the Phoenix Metropolitan Area (Table 2). The seriousness of heavy water-table declines is apparent in McMullen Valley and Harquahala Plains:

Area of Observation	Depth to Water (Feet) Forecast	
	1963	1980
McMullen Valley	484'	637'
Harquahala Plains	390'	730'

Economic limits of irrigation farming with local ground water supplies might have an impact on these two farming districts. The ground water reserve in the Harquahala Basin is expected to shrink horizontally, another cause for a reduction in irrigated acreage. The water quality is detrimental to public health because of fluorides exceeding the optimum of 1.4 in most of the outlying basins. Also the total salt content is often marginal. The quality factors alone would be a detriment to urban development in these areas.

Favorable water supply areas remaining for long-term use, from a quantitative as also from a qualitative standpoint, are Paradise Valley and the Queen Creek-Magma Area of Maricopa and Pinal Counties, two important parts of the potential Phoenix Metropolitan Area. The Cave Creek Basin with its limited ground water reserve will have to depend in the future on the aquifer of Paradise Valley.

TABLE 2

SUMMARY OF QUANTITATIVE AND QUALITATIVE GROUND WATER INFORMATION, SPRING 1963
Qutlying Ground Water Basins

	Quantitative Information				Qualitative Information (Average Values)			
	Depth to Water Spring 1963 Feet	Rate of Annual Water Table Decline Feet	Depth to Water Forecast 1970 Feet	Depth to Water Forecast 1980 Feet	Total Dissolved Solids ppm*	Total Hard-ness ppm*	Fluorides ppm	Temper-ature °F
Waterman Wash Basin	215-356	2.0-10.0	277-385	265-454	1100	130	4.5	89
Gila Bend Basin (North	110-329	2.0- 9.7	140-364	204-414	1900	490	2.9	87
Gila Bend Basin (South	24-252	0- 4.2	84-261	24-274				
Dendora Valley	30- 60	0.7- 1.8	35- 65	40- 78	3200	1450	3.9	85
Palomas Plains (North	76-244	0- 1.0	77-253	78-263	660	56	4.5	95
Palomas Plains (South	30- 76	0- 1.0	30- 77	30- 78				
McMullen Valley	406-484	2.6- 9.0	424-547	450-637	300	85	2.8	86
Harquahala Basin	31-390	0.9-22.0	200-525	350-730	600	100	3.2	90
Tonopah Valley	64-245	0.3- 7.7	70-273	75-313	480	65	6.0	96
Arlington Valley	63-200	0.6- 3.0	88-215	120-235	1200	130	2.3	87
Lower Hassayampa Valley	30-480	0- 1.3	30-490	30-500	260	140	0.5	78

*ppm = parts per million

TABLE 3

SUMMARY OF POPULATION POTENTIAL, TOTAL WATER REQUIREMENTS AND GROUND WATER DEPLETION, 1963 TO 1980
Phoenix Metropolitan Area

	NONAGRICULTURAL WATER USE			AGRICULTURAL WATER USE			GROUND WATER DEPLETION, PHOENIX AND MESA BASINS				
Year	Population[1]	Total Non-Agricultural Water Use gpcd[2]	Total Non-Agricultural Water Use acre-feet/year	Total Agricultural Acreage (Acres)	Agricultural[3] Water Use (acre-feet)	Combined Water Use (acre-feet)	Average Depth to Water (feet)	Basin Area Below Water Table (acres)	Depletion Per Annum (acre-feet)	Accumulative Depletion (acre-feet)	Total Basin Reserve (acre-feet)
1963	815,000	309	282,000	430,055	2,081,000	2,363,000	248	1,012,000	1,313,000	1,313,000	98,995,000
1964	872,941	310	303,000	424,000	2,050,000	2,353,000	254	1,008,880	1,303,000	2,616,000	97,692,000
1965	930,882	311	324,000	417,000	2,019,000	2,343,000	261	1,005,750	1,293,000	3,909,000	96,399,000
1966	988,824	312	345,000	411,000	1,989,000	2,334,000	267	1,002,620	1,284,000	5,193,000	95,115,000
1967	1,046,765	313	366,000	305,000	1,959,000	2,325,000	274	999,490	1,275,000	6,468,000	93,840,000
1968	1,104,706	314	388,000	398,000	1,928,000	2,316,000	280	996,360	1,266,000	7,734,000	92,574,000
1969	1,162,647	315	410,000	392,000	1,897,000	2,307,000	287	993,230	1,257,000	8,991,000	91,317,000
1970	1,220,589	316	432,000	386,000	1,866,000	2,298,000	293	990,000	1,248,000	10,239,000	90,069,000
1971	1,278,529	317.5	454,000	379,000	1,835,000	2,289,000	300	986,630	1,238,000	11,477,000	88,831,000
1972	1,336,471	319	477,000	372,000	1,802,000	2,279,000	306	983,260	1,228,000	12,705,000	87,603,000
1973	1,394,412	321	501,000	365,000	1,768,000	2,269,000	313	979,890	1,218,000	13,923,000	86,385,000
1974	1,452,353	323	525,000	358,000	1,734,000	2,259,000	319	976,520	1,208,000	15,131,000	85,177,000
1975	1,510,294	325	549,500	351,000	1,699,500	2,249,000	326	973,150	1,199,000	16,330,000	83,978,000
1976	1,568,236	327	574,000	344,000	1,666,000	2,240,000	332	969,780	1,190,000	17,520,000	82,788,000
1977	1,626,176	329	599,000	337,000	1,631,000	2,230,000	339	966,410	1,180,000	18,700,000	81,608,000
1978	1,684,118	331	624,000	330,000	1,596,000	2,220,000	345	963,040	1,170,000	19,870,000	80,438,000
1979	1,742,059	333	649,500	322,000	1,561,000	2,211,000	352	959,670	1,161,000	21,031,000	79,277,000
1980	1,800,000	335	675,000	318,000	1,527,000	2,202,000	358	956,300	1,152,000	22,183,000	78,125,000
2000	2,660,000	388	1,156,000	181,000	876,000	2,032,000	488	900,000	21,310,000	43,493,000	56,815,000
2020	3,000,000	446	1,500,000	83,000	402,000	1,902,000	617	850,000	18,185,000	61,678,000	38,630,000

(1) Population for area defined in text and shown as Phoenix Metropolitan Area on Plate 1, not Maricopa County.

(2) Gallons per capita per day.

(3) Based on 4.84 acre-feet of water per year for each acre of irrigated agricultural land.

3. Future Water Demand

The development of a sound and prosperous future for Maricopa County relies heavily upon a carefully balanced water resource program. Table 3 shows the population potential, total water requirements and ground water depletion from 1963 to 1980 for that central portion of Maricopa County. Much can be accomplished by wise planning.

For discussion purposes a few figures may be repeated in a more condensed form:

Year	Population Potential For Phoenix Metropolitan Area	Irrigated Acreage Potential	Potential Water Need at Delivery Points	Remaining Ground Water Storage Reserve to 1000' Depth Acre-Feet
1963	815,000	430,055	2,363,000	100,308,000
1980	1,800,000*	315,000	2,202,000	78,125,000
2000	2,660,000**	181,000	2,032,000	56,815,000
2020	3,000,000**	83,000	1,902,000	38,630,000
Ultimate	3,200,000	0	1,800,000	Remaining Reserve to be used only during a period of surface water shortage

The planning approach used in this report does not take into account the augmenting of available water supply from outside sources such as 1) the Central Arizona Project, which is scheduled to import more than 1 million acre-feet of Colorado River water, most of it to Maricopa County and the Phoenix Metropolitan Area (the Central Arizona Project, delayed since 1947, has now been made part of the Pacific Southwest Water Plan); and 2) the ultimate possibility of ocean water desalinization and transport of same from the Gulf of California.

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* Source of estimate: Maricopa County Planning and Zoning Department

**Source of estimate: This Report.

The population potential of the Phoenix and Mesa Basins is estimated as follows:

Year	Phoenix Basin	Mesa Basin
1963	590,000 persons	225,000 persons
1980	1,000,000	800,000
2000	1,420,000	1,240,000
2020	1,560,000	1,440,000
Ultimate	1,700,000	1,500,000

In other words, a second metropolitan sub-center, in the Mesa Basin area, could be supported by present water resources within this century. The ultimate development approach presented here as a type-area study relies ultimately on surface water and treatment of waste effluent. Then ground water will be the catastrophe reserve to be touched only in times of surface water shortage. A planning program has to be directed toward a logical solution. For example, to rely on the possibility of a treaty with Mexico that would enable Arizona to construct a desalinization plant on the Gulf of California would be unrealistic right now, although this solution might be considered as reasonable 50 years hence.

4. Water, a Land Development Factor

Forecasting future water needs for a Metropolitan Area requires the consideration of three classes of information:

(1) Water Supply Data, i.e. the water resources available for public supply in each part of a basin area;

(2) Water Use Data: This includes the analysis of trends in water use, affecting the standards of consumption for each particular land use, in order to arrive at more reliable estimates of future requirements. It also involves the determination of criteria and policies of adequate water service.

(3) Development of the Area: This comprises the delineation of the present and ultimate boundaries of the development area; present and future population to be served by water utilities; distribution of this population in the area; existing land use characteristics; expected amount, location, and density of future land uses; and rates of growth at different stages of development of the area. The marginal limitations on water utilization will have to be focused primarily on agriculture, and their effect on the agricultural sector of the

economy have to be taken into consideration. Because of the rapidly changing environment of the Metropolitan Area, the statistical extrapolation of past population trends is sometimes of doubtful validity. Therefore, special emphasis should be given to case study techniques to identify, isolate and analyze more directly the judgment factors needed in forecasting.

5. Water Resources Management and its Relationship to Regional Planning

The basic methodology to coordinate water resources management with regional planning has been developed and practically worked out in a three-county area in Michigan. This comprehensive program is based on the following three steps:

(1) Consideration of 3 alternative geographic patterns of future economic developments as they may dictate future geographic patterns for water requirements;

(2) Developing specific plans for water resources management and evaluating the construction costs of the necessary water and sewage treatment facilities, for each of the alternative geographic patterns of economic growth;

(3) Selection of a model or combination of models as future planning guide.

An examination of several models reveals how closely integrated regional planning and water resources management will become in the future. Zoning patterns should evolve that will permit a population density that can be supported by adequate water supply at all times. Existing water supply systems of public and private utility companies may have to be consolidated to group water supplies. According to this study all water-related activities should fall under the control of a Metropolitan Water Authority. Additional studies in Maricopa County are suggested in line with the preceding thoughts.

III. PHYSICAL FEATURES OF THE WATER SUPPLY AREAS

The physical character of Maricopa County has been described sufficiently in a report prepared by the Maricopa County Planning and Zoning Department: "A Part of the Comprehensive Plan for Maricopa County, Part I: History, Economics, Physical Features," published in 1963.

It is of interest, however, to extend some of this information to the ground water-bearing desert basins of Maricopa County.

1. Precipitation and Ground Water Replenishment

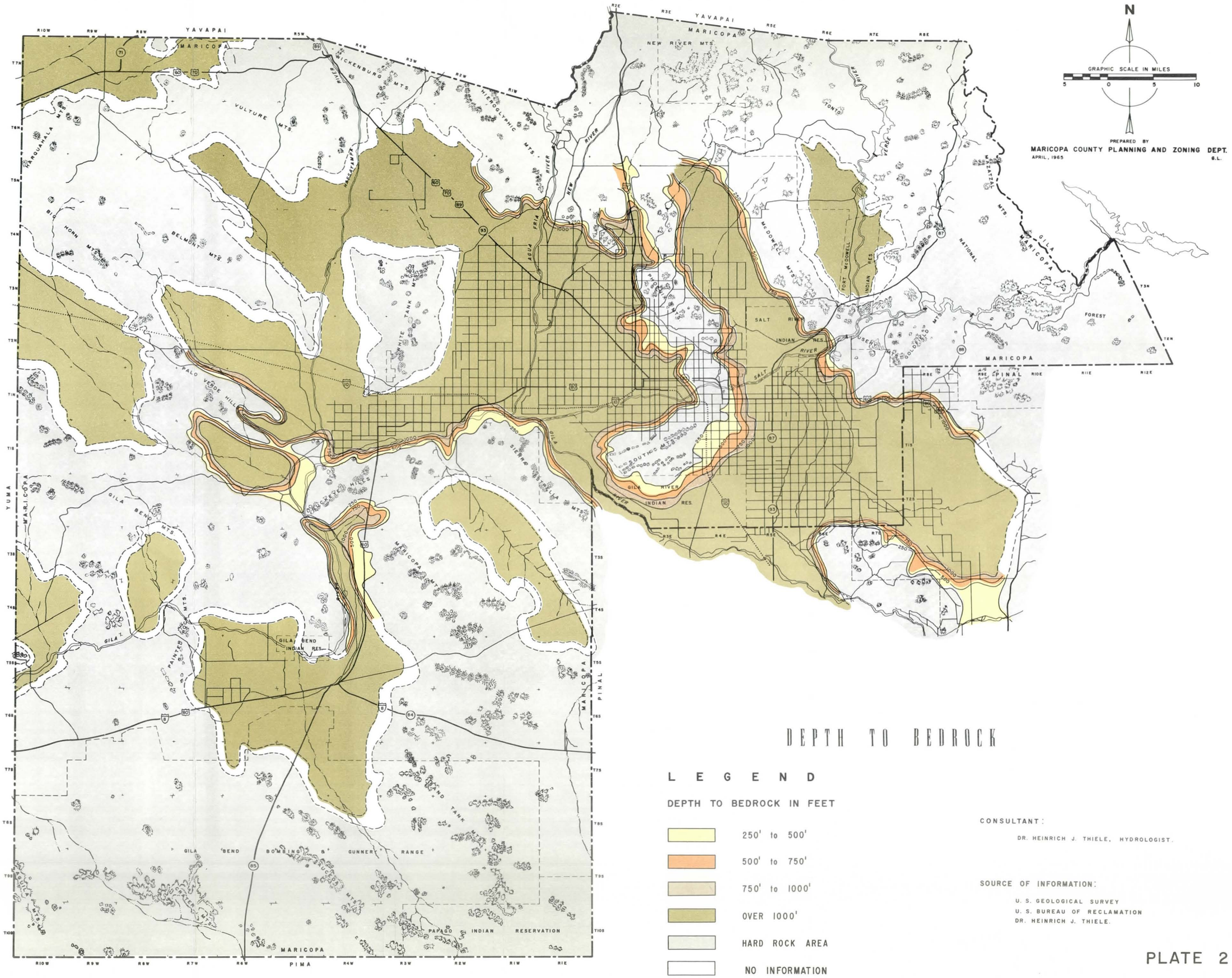
The average annual rainfall per year ranges from 4.51 inches at Sentinel in the west to 8.06 inches at Mesa in the east. The ground water basins of the County are being replenished primarily from the runoff originating in the surrounding mountains tributary to the basins. The U.S. Geological Survey, in Water Supply Paper 1669-F, has calculated the probable annual recharge from precipitation for the Waterman Wash Basin, Maricopa County. It is estimated that about 10 percent of the rainfall on the rugged mountain watershed of the Sierra Estrella Mountains, adjacent to the basin, becomes runoff. Perhaps as much as 5 percent of the precipitation actually is recharged to the ground water reservoir at the mountain fronts. The 50,000-acre drainage area of the basin receives an average annual precipitation of 7.5 inches, a total of about 30,000 acre-feet. Of this quantity a maximum of 1,500 acre-feet may be recharged, but probably considerably less. Most of the precipitation falling on the basin itself is lost to evapotranspiration by the vegetative growth, or just evaporates, and does not contribute to the replenishment of the aquifer. It may be concluded and generalized that the present-day recharge of the County's basin-aquifers by rainfall and rainfall-runoff is negligible.

The ground water basins form natural units within which climate, topography, natural vegetation, geology and types of land and water use are closely interrelated. The basin unit, therefore, becomes a suitable base for collection, analysis, and interpretation of its characteristic features.

2. Hydrogeology

The study area encompasses a group of structurally controlled depressions formed in crystalline and metamorphic rocks. During Tertiary times, a period of regional uplift occurred, and in connection with this uplift, a block-faulting and throwing up of mountain ranges. The chains of mountains are the upthrown parts of blocks. On their west side are alluvial-filled valleys, today's ground water reservoirs. It is believed that these valleys are bounded by faults of large displacement, which have been subsequently obscured by erosion and alluvial sediments. Caused by subsequent periods of faulting in two different directions, SW-NE and E-W, beneath the valley fill may exist irregularities of the old rock surface; buried ridges; and other natural barriers. Along the base of some of the mountain fronts pediments have been found, bedrock masses underneath a thin sheet of alluvium. The pediments terminate sharply at the faults.

The structural troughs, probably more than a million years ago, were filled with debris from the surrounding mountains, a heterogeneous complex of clay, silt, sand, gravel and boulders, and at the time of their deposition also with water, originating as runoff from the higher elevations. The deeper parts of the basins often hold, underneath the younger alluvium, now compacted lakebed deposits of clay, silt and fine sand, and underlying these are conglomerates of volcanic and granitic material. The total thickness of these sediments ranges up to 5,000 feet and more in the deepest parts of the basins. No extensive measurements of the valley fill have been made. The depth of existing wells varies from several hundred feet to over 1,500 feet, usually drilled without reaching the bedrock surface. However, sufficient information is available from well logs and geophysical surveys of some of the ground water basins to construct a bedrock map to 1,000 feet depth. Ground water contained in the younger sediments constitutes the main reserve, although deep wells have penetrated the lakebed deposits into the older sediments, tapping permeable zones in both deposits. The deeper aquifers usually are not as productive because of finer-grained texture and a greater degree of cementation. The existing geological information permits making certain assumptions. Economic considerations indicate that the present economic limits of pumping for agriculture are well above 1,000 feet depth.



DEPTH TO BEDROCK

LEGEND

DEPTH TO BEDROCK IN FEET

- 250' to 500'
- 500' to 750'
- 750' to 1000'
- OVER 1000'
- HARD ROCK AREA
- NO INFORMATION

CONSULTANT:

DR. HEINRICH J. THIELE, HYDROLOGIST.

SOURCE OF INFORMATION:

U. S. GEOLOGICAL SURVEY
U. S. BUREAU OF RECLAMATION
DR. HEINRICH J. THIELE.

PLATE 2

The available information of the ground water basins to the depth of 1,000 feet has been plotted on Plate 2. This Bedrock Map has been used for the Phoenix and Mesa Basins to measure basin length, width and depth to 1,000 feet as the first factor to determine ground water storage capacity. The second factor is the specific yield which determines the volume of water that can be withdrawn by pumpage from a unit volume of soil.

TABLE 4

SURFACE WATER RESERVOIRS

Location	Storage Capacity (acre-feet)	Completion Date	Surface Area (acres)	Drainage Area (sq. miles)	Cumulative Total Drainage Area (sq. miles)
SALT RIVER PROJECT					
Salt River					
T. Roosevelt Lake	1,382,080	1911	17,315	5,830	5,830
Apache Lake	245,000	1927	2,600	110	5,940
Canyon Lake	58,000	1927	950	160	6,100
Saguaro Lake	70,000	1930	1,264	120	6,220
Verde River					
Horseshoe Lake	142,800	1945	2,719	5,970	5,970
Bartlett Lake	179,500	1939	2,768	190	6,160
Agua Fria River					
Lake Pleasant	163,000	1927	3,585	1,460	1,460
Total	2,240,380		31,201	13,840	13,840

IV. TRENDS IN WATER CONSUMPTION

Insofar as water consumption is concerned, nonagricultural use in Maricopa County has been unimportant relative to agricultural use. The use pattern is changing with the steadily increasing urbanization of the Phoenix Metropolitan Area. This chapter presents consumption figures from the County's water history, their trends and significance for the future.

1. Water History

The water use by Indians and early white settlers was based entirely on available surface water supplies, essentially in the Salt and Gila River Valleys. These rivers were flowing, at least seasonally, and supplied water for agriculture and domestic use. Irrigation agriculture expanded soon and the available surface water supplies became inadequate. They were not assured until after the construction of Roosevelt Dam on the Salt River in 1911. As the agricultural area grew, more surface water was needed, and additional surface water reservoirs were built along Salt, Verde and Agua Fria Rivers. Their storage capacities, drainage areas and construction dates are shown in Table 4.

Before 1920, the total amount of ground water pumped did not exceed 100,000 acre-feet per year from shallow wells and most of it was used for irrigation.

At that time in the Salt River Valley, return recharge from surface water irrigation and seepage losses from canals caused considerable acreages to become waterlogged. Wells were first drilled for the purpose of lowering the high water table and later for supplemental irrigation. Organized irrigation districts were created, to distribute surface water and/or ground water to the agricultural areas as needed. The largest irrigation district is the Salt River Valley Water Users' Association of the Salt River Project with some 250,000 acres which more or less initiated the development of Metropolitan Phoenix.

During the early growth period of the County, other areas were also opened to agriculture, in several of the ground water basins shown in Plate 1.

Today's economic base is sustained by the County's water resources. The primary income, as recently as 10 years ago in 1953, was largely agricultural. The population explosion brought with it a shift in the economic base from farming to manufacturing.

TABLE 5

NET INCOME MARICOPA COUNTY 1953 AND 1963

Source of Income	1953		1963	
	Dollars	Percent of Total	Dollars	Percent of Total
Manufacturing	180,000,000	38.7%	640,000,000	57.1%
Farming	210,000,000	45.2%	295,800,000	26.4%
Tourist	75,000,000	16.1%	185,000,000	16.5%
Total Income	465,000,000	100%	1,120,800,000	100%

Source - Maricopa Facts and Figures, 1964-1965.

There is an emerging awareness of water as the controlling factor in the County's economic growth. M. M. Kelso studied for the year 1958 the net income created by water use in Arizona and came to the interesting figures shown on Table 6.

Irrigated agriculture produced a net income of $32 per acre-feet of water used, while manufacturing produced $2,909. An overall total income of $371 was created by the use of water. This table opens some intriguing problems. Further economic expansion in Maricopa County might have to come through transfer of water from one use to another. The question also rises by implication, whether nonuse of some presently used water in exchange for its use in a distant future year might not also be an economic exchange. N. Wollman found similar productivity values for the Rio Grande Valley in New Mexico expressed per acre-foot of water used: Agriculture, $44 to $51; and, Industry, $3040 to $3989.

TABLE 6

TOTAL WATER USES AND NET INCOMES CREATED BY INDUSTRIAL SECTORS
Arizona, 1958

Water Sector	Water Used (acre-feet)		Percent Water Used	Net Income (millions of dollars)		Percent of Net Income Generated in Water-Dependent Uses	Net Income (dollars per acre-foot) of Water Used
Agriculture							
Livestock	65,000		1.0	31.0		1.3	477
Crops	6,049,306		93.4	194.8		8.1	32
Total Agriculture		6,114,306			225.8		
Manufacturing							
Food processing	3,069			56.9			
Primary metal fabrication	30,690			41.3			
All other manufacturing	6,138			269.1			
Total Manufacturing		39,897	0.6		367.3	15.3	2,909
Mining: Total		85,900	1.3		189.0	7.9	2,200
Electrical Generation: thermal		9,207	0.1		46.3	1.9	5,029
All Other Sources of Net Income					1,575.8		7,651
Household-Municipal Water Use		235,000	3.6			65.5	
Grand Totals:							
Water Use		6,484,310	100%				
Net Income					2,404.2	100%	371

Source: M.M. Kelso, Department of Agricultural Economics, University of Arizona, In: The Economic Dilemna - An Excursion in Speculation - Chapter 7 of Fourth Arizona Town Hall on Arizona's water supply, Tables 1, 2, and 3, Arizona Academy, April 6-8, 1964.

2. Agricultural Water Use

The agricultural water supply will remain vital to the economic health of the Phoenix Metropolitan Area because of the local food consumption-production imbalance which will continue to increase as the County's population grows. Table 7 records the total cropped acreage of the County for the period 1950 to 1963.

TABLE 7

TOTAL CROPPED ACREAGE
Maricopa County, 1950-1965

Year	Acres
1950	435,000
1951	511,500
1952	560,000
1953	560,000
1954	530,000
1955	485,000
1956	465,000
1957	479,000
1958	516,700
1959	519,160
1960	523,863
1961	522,650
1962	501,370
1963	509,400

Source - University of Arizona, Agricultural Extension Service.

These figures seem to be of a comparable order of magnitude, not revealing changes which have occurred especially during the period 1953-1963. Plate 3 discloses, for instance for the Phoenix Metropolitan Area a reduction of about 90,000 acres in irrigated agricultural acres (see Table 8).

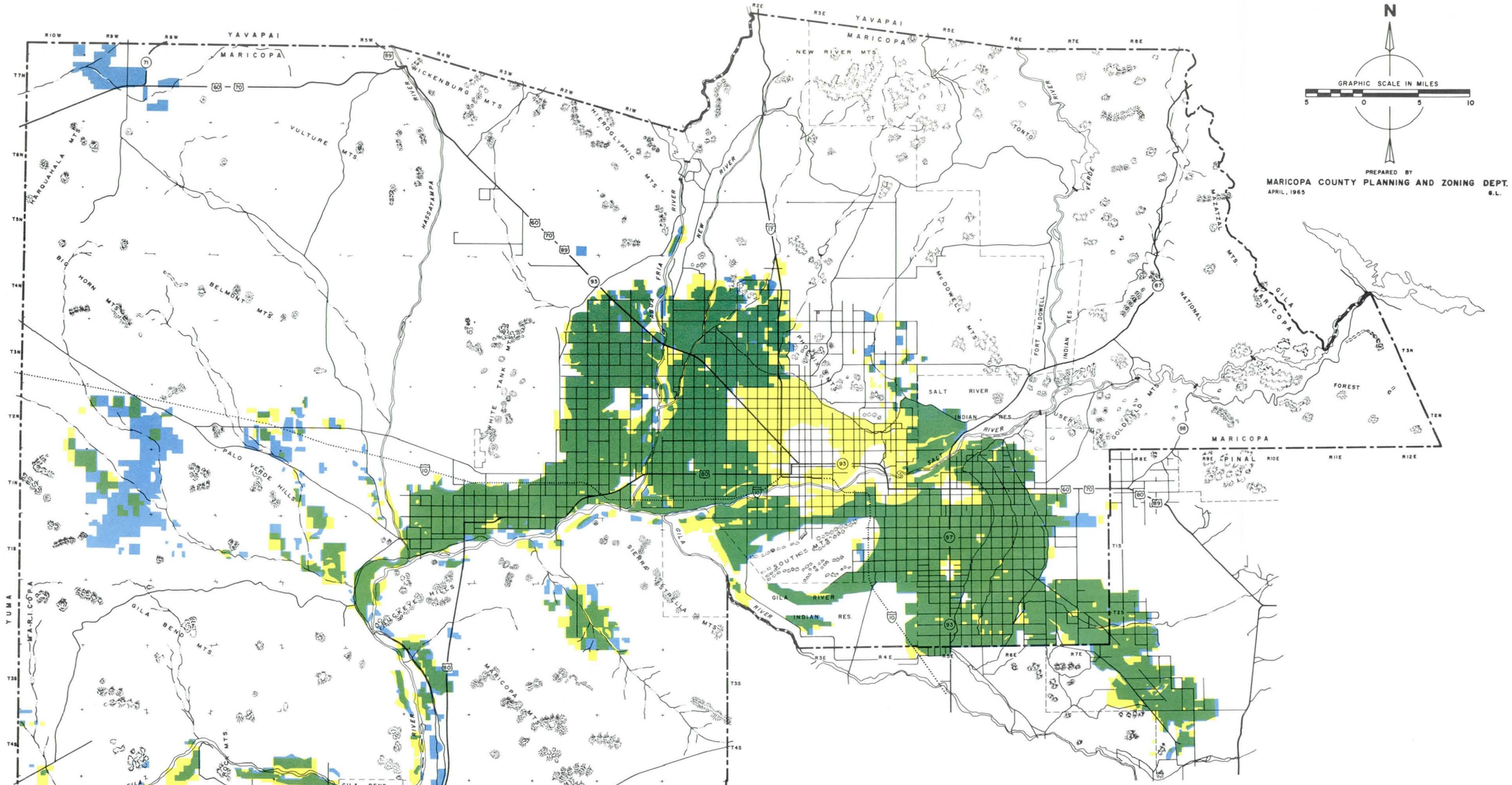
TABLE 8

IRRIGATED ACREAGE 1953 AND 1963
Phoenix Metropolitan Area

Area	Acres Cropped 1953	Acres Cropped 1963
Phoenix Basin		
East of Agua Fria	152,411	110,080
West of Agua Fria	144,422	125,710
Sub Total	296,863	235,790
Mesa Basin		
Paradise Valley	25,100	14,434
Mesa Chandler Area	151,411	128,211
Queen Creek-Magma Area	47,300	51,620
Sub Total	223,811	194,265
Phoenix Metropolitan Area Total	520,674	430,055

Much of the urban growth has been and obviously in the future will continue to be at the expense of agricultural acreage for which a water supply is assured.

The irrigated acreage fluctuates from year to year, in accordance with the available water supply and government acreage allotments. New additional lands are continuously developed for irrigation wherever ground water supplies can be found. Some of the older acreage is forced out of production either because the local ground water supply is exhausted, or has to be abandoned as pumping costs have increased beyond the point of diminishing returns as the result of the rapidly falling water tables. Plate 3 demonstrates new cultivated land developments in the Harquahala Basin, McMullen Valley, and west and northeast of Gila Bend, which all have been leveled and prepared for irrigated agriculture during the period 1953-1963. On the other hand, the cropped acreage decreased along some of the boundaries of the Queen Creek-Magma area, since receding water-tables intercepted the bedrock



CHANGES IN AGRICULTURAL ACREAGE

1953 TO 1963

LEGEND

- 1953 AGRICULTURAL AREAS OUT OF PRODUCTION.
- AGRICULTURAL AREAS 1953 & 1963
- NEW AGRICULTURAL AREAS 1963

CONSULTANT:

DR. HEINRICH J. THIELE, HYDROLOGIST.

SOURCE OF INFORMATION:

U. S. BUREAU OF RECLAMATION.
UNIVERSITY OF ARIZONA.
DEPTS. OF AGRICULTURAL ECONOMICS & AGRICULTURAL ENGINEERING.

PLATE 3

surface. Along the Gila River near St. Johns, Komatke and north of Gila Bend, land is out of production because of ground water salinity increasing beyond the concentration of agricultural use. Some shrinking acreage also can be observed in parts of the Waterman Wash and Harquahala Basins because of rapidly sinking water tables.

Urban needs have the first right to water so it becomes obvious that whatever impacts water shortages in Maricopa County may have on its future economic growth, they will arise in agriculture and be channeled through agriculture onto the rest of the economy. Table 9 illustrates past changes by the quantities of water in various ground water basins of the County. Agricultural water use from ground water reserves increased one million acre-feet per year to 2.4 million for 1946 to 1953, and since then fluctuated in between 2.4 and 2.7 million acre-feet.

The average annual rate of water used for crops grown and which is needed at the points of diversions and well sites, is between 4.5 and 5.0 acre-feet per acre. The U.S. Bureau of Reclamation* has selected an average gross water use of 4.84 acre-feet per acre which value is being adopted as base-value for calculations in this report. Although improvements are being made in irrigation methods, they are coming along slowly, and irrigation efficiency still can be improved.

3. Nonagricultural Water Use

For the average citizen, water is not a scarce commodity, especially not in the Phoenix Metropolitan area, where domestic water use never has been restricted. He still pays less for his water every day than for his daily quota of kilowatt hours and cubic-feet of natural gas, and therefore there is no indication to him that water will become more expensive as time advances. The population of Maricopa County increased during the period 1950-1963 a total of 500,000 people, as shown in Table 10. Ninety-eight percent of this population has settled in the Phoenix Metropolitan Area. In 1963, of a 815,000 population, approximately 590,000 persons resided in the Phoenix Basin, and the remaining 225,000 persons resided in the Mesa Basin.

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* Personal communication, U.S. Bureau of Reclamation

TABLE 9

GROUND WATER PUMPAGE (IN ACRE-FEET) FROM WELLS IN PRINCIPAL GROUND WATER BASINS
1946-1963
Maricopa County

Area	1946	1950	1953	1955	1959	1960	1961	1962	1963 *
Phoenix Metropolitan Area	1,360,000	1,852,000	2,300,000	2,200,000					
Queen Creek-Magma Area					170,000	155,000	165,000	160,000	
East of Agua Fria River					1,450,000	1,175,000	1,300,000	1,115,000	1,132,000
West of Agua Fria River **					550,000	675,000	750,000	700,000	891,700
Tonopah Basin					50,000	55,000	35,000	35,000	
Harquahala Valley Basin			20,000	30,000	100,000	125,000	100,000	200,000	200,000
McMullen Valley Basin			6,000	20,000	45,000	60,000	75,000	75,000	
Waterman Wash Basin			28,000	40,000	50,000	60,000	65,000	65,000	
Gila Bend Basin	33,300	59,000	145,000	140,000	250,000	250,000	200,000	170,000	
Palomas Plains Basin	6,700	6,000	5,000	6,000					
TOTAL	1,400,000	1,917,000	2,404,000	2,436,000	2,665,000	2,555,000	2,690,000	2,520,000	

* Incomplete
** Includes Arlington Valley

Source: U.S. Geological Survey and Arizona State Land Department

TABLE 10

POPULATION GROWTH, MARICOPA COUNTY, 1950-1963

City or Town	1950	1955	1960	1963
Avondale	2,505	4,328(2)	6,151	6,540
Buckeye	1,932	2,109(2)	2,286	2,350
Chandler	3,799	6,665(2)	9,531	10,961
El Mirage	500(1)	1,112(2)	1,723	2,820
Gila Bend	1,000(1)	1,407(2)	1,813	2,200
Gilbert	1,114	1,474(2)	1,833	2,100
Glendale	8,179	11,938(2)	15,696	27,250
Goodyear	1,254	1,454(2)	1,654	2,122
Mesa	16,790	25,281(2)	33,772	38,000
Paradise Valley			2,091	5,260
Peoria	2,000(1)	2,297(2)	2,593	3,100
Phoenix	106,818	140,000(3)	439,170	503,576
Scottsdale	2,032	6,029(2)	10,026	39,760
Surprise	500(1)	1,037(2)	1,574	1,720
Tempe	7,684	16,291(2)	24,897	40,151
Tolleson	3,042	3,464(2)	3,886	3,900
Wickenburg	1,736	2,091(2)	2,445	2,600
Youngtown			1,559	1,800
Cities and Towns, Sub-Total	160,885	226,977	562,700	696,210
Urban Fringe and Rural, Sub-Total	170,885	223,023	100,810	134,790
Maricopa County Total	331,770	450,000(3)	663,510	831,000

(1) Estimate by Maricopa County Planning and Zoning Department.
(2) Interpolation, 1950 to 1960 by Maricopa County Planning and Zoning Department
(3) Arizona Statistical Review, 1963, Valley National Bank, See Page 10.

Within the Phoenix Metropolitan Area, there has been made no attempt to separate domestic, commercial, industrial, public, institutional, military and other water uses. For the purposes of this report, all these uses have been included in the per capita consumption rate. In making the allocation of industrial water on a per capita basis, the assumption was made - and used as basis for extension - that expansion of industry would take place also on a per capita basis, following the existing trend. From 1955 until 1963, Table 11 points to the interesting fact that total nonagricultural water use has increased from 156,300 to 282,000 acre-feet, but also that at the same time the per capita water use (in gallons per capita per day, gpcd) has decreased from 325 to 309 gpcd.

A break down of the figures given last has been attempted in Chart 1. The per capita use rates for 1955 and 1963 are:

Type of Water Use	1955	1963
Domestic Use	170	192 gpcd
Commercial and Industrial Use	50	50 gpcd
Urban Irrigation Use	105	67 gpcd
Total Water Use	325	309 gpcd

These are estimates, since urban irrigation in this sense is only the quantity as reported by the Salt River Project and other agencies, that is used for surface irrigation. The Salt River Project delivered the following volumes of water for the irrigation of yards of private homes:*

1955	44,031 acre-feet
1958	41,551 acre-feet
1959	44,025 acre-feet
1960	43,907 acre-feet
1961	43,113 acre-feet
1962	45,034 acre-feet
1963	54,493 acre-feet

The urban irrigation quantities shown on Table 11 and Chart 1 include deliveries by the Arcadia Water Company and other irrigation districts, which total 61,200 acre-feet in 1963.

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*Information obtained by Salt River Project.

TABLE 11

NONAGRICULTURAL WATER USE
Phoenix Metropolitan Area

Year	1955	1963	
City of Phoenix	14,727,010,000	39,241,469,000	Gallons per year
Other Municipalities	8,474,000,000	11,470,792,000	Gallons per year
Private Water Companies	3,449,000,000	5,342,000,000	Gallons per year
Self-Supplied Commercial and Industrial	8,295,000,000	15,846,000,000	Gallons per year
Urban Irrigation	16,080,000,000	19,950,000,000	Gallons per year
Total Nonagricultural Use	51,025,000,000	91,850,000,000	Gallons per year
	156,300	282,000	Acre-feet per year
	325	309	Gallons per capita per day (gpcd)

FORECAST OF WATER REQUIREMENTS FOR ALL NON-AGRICULTURAL PURPOSES

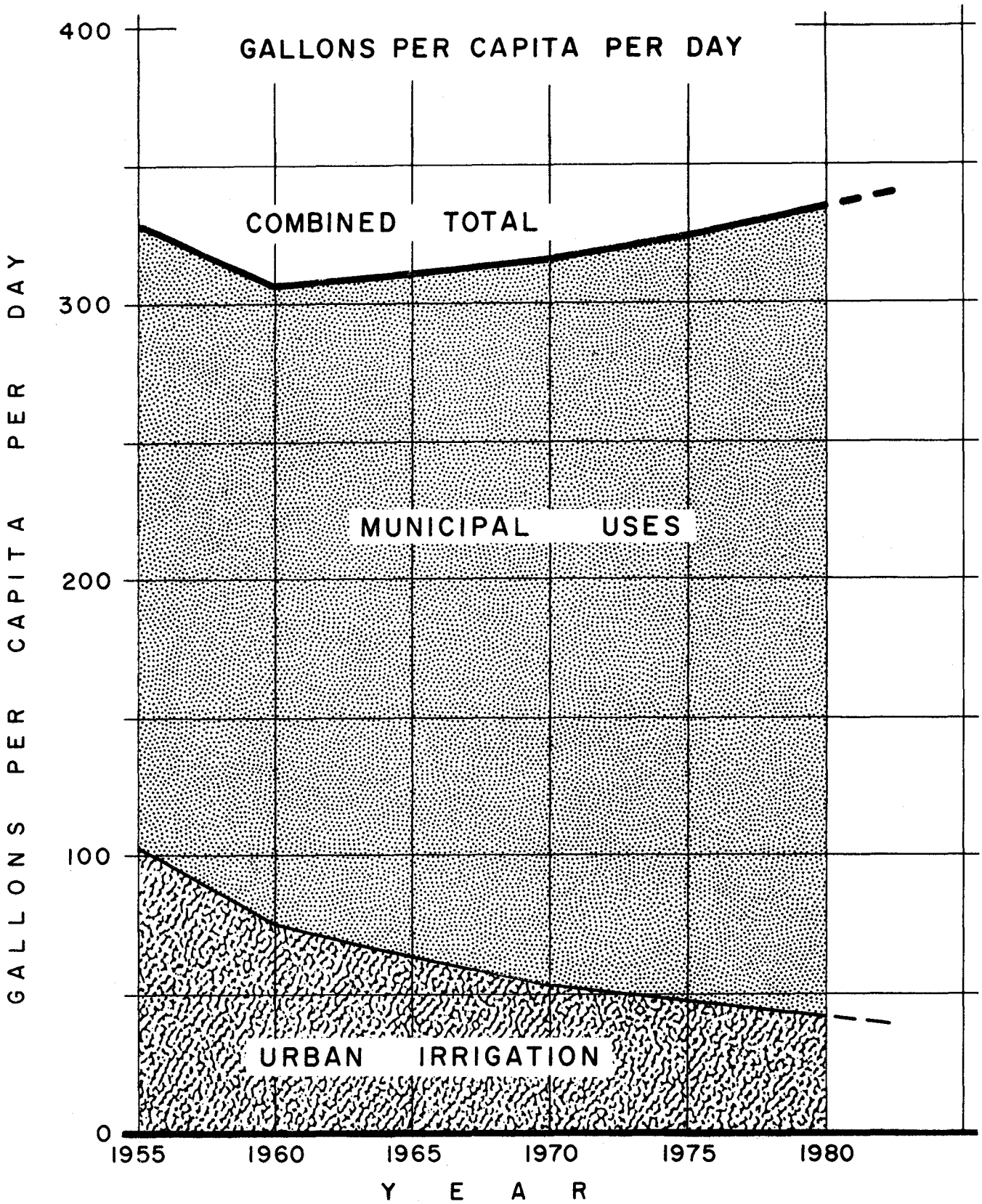

CHART I

The totals of municipalities and the private water companies contain unknown additional volumes delivered for sprinkler irrigation, the irrigation of golf courses and parks, etc. For this major reason, daily water deliveries by different water companies vary between 68.5 and 1780 gallons per house in the Phoenix Metropolitan Area. A gradual leveling off has been observed in the gpcd-use of urban irrigation water, because of the increase in multiple-dwelling areas and commercial districts, combined with higher population density which do not use irrigation water. However, a steady slight increase is expected in the total future urban irrigation use (acre-feet per year) as the Phoenix Metropolitan Area expands further into the existing agricultural districts. People often prefer to live in an oasis-like surrounding. This expected trend, as well as the observed annual domestic use-increase of 3 gpcd, will continue to give the total nonagricultural use an upward trend in the future (Chart 1).

Domestic Water Use

An annual increase of 3 gpcd of domestic water use has been observed. The respective 1955 and 1963 use figures are 170 and 192 gpcd. The upward trend has been constant for the past, and is expected to continue into the future. It is a mean of a cycle and, consequently, year to year variations must be expected as various factors affect the Phoenix Metropolitan Area to a greater or lesser degree. Multiple bathrooms, washing machines, dishwashers, garbage disposals and swimming pools have contributed to the rising trend in per capita consumption. Cities use water for sanitation and for recreational purposes such as playgrounds, swimming pools, the beautification of parks, street cleaning and fire protection. Records show a steady increase as new household conveniences are developed. There is nothing to indicate a reversal of these trends in the future.

Commercial and Industrial Water Use

Large quantities of water are used by commercial establishments such as laundries, motels and hotels. Industrial use is very high in steam-electric generating plants and ironworks, that use water almost entirely for cooling purposes. It is obvious that a city seeking new industries should scrutinize their water requirements. Such major industries are supplied directly by the City of Phoenix; others have their own water supply. Practically all industrial uses of water fall within one or more of the classifications listed in the following groups: a) cooling; b) processing; c) power generation; d) sanitary services; and f) fire protection. Steam-electric

generating plants use an average of about 60 gallons of water for each kilowatt-hour of electricity generated. The past trends show that commercial and industrial water use increases on a per capita basis. New heavy industries have not located in the Phoenix Metropolitan Area, with exception of the sugar refinery being built south of Chandler.

Water Use by Livestock

The County is well known for its extensive cattle raising and feeding operations. The water used by livestock is not directly measurable, but computations show that the total quantity is far larger than may be realized. Reported are water uses of 10 to 12 gallons per head per day, or about 1 acre-foot for each hundred head of cattle and horses per year. An additional 4 to 6 gallons per head and day has to be allocated because of necessary waste due to evaporation, sloshing of tanks, etc. The evaporation losses from stock tanks in the County are in the order of 6 to 7 acre-feet per acre of water surface, every year.

Water Use in Recreation

Water is an integral part of most recreational activities. For many parts of recreation - swimming, boating, fishing, water sports - water bodies are prerequisite. N. Wollman has calculated the value of water for recreational purposes, especially for sport-fishing, to be $264 per acre-feet. Picnicking, camping, hiking, and driving can be made more attractive along lake fronts and canal banks. County parks, campsites, and playgrounds need development of water facilities. The quantity of water withdrawn is small, limited to the amounts required for domestic uses at developed facilities. Water losses must be charged to recreation only there, where lakes or reservoirs are maintained exclusively for recreational use, which is rather the exception than the rule in Maricopa County.

TABLE 12

WATER REQUIREMENTS AND WATER SUPPLY 1963
Phoenix Metropolitan Area
(Quantity in Acre-Feet Per Year)

Water Requirements by Use (At Farm Head Gate and at Water System)		Percent of Total
Agricultural	2,081,000 acre feet	88.1%
Nonagricultural	282,000 acre feet	11.9%
TOTAL	2,363,000 acre feet	100%
Water Supply by Source (At Diversion Points and Well Sites)		
Ground Water	2,134,000 acre feet	72.0%
Surface Water	828,268 acre feet	28.0%
TOTAL	2,962,268 acre feet	100%
Actual Water Use by Source		
Surface Water and Ground Water Return Recharge	1,649,268 acre feet	55.6%
Depletion of Ground water Reserve	1,313,000 acre feet	44.4%
TOTAL	2,962,268 acre feet	100%

V. WATER SUPPLY SOURCES

Surface water and ground water are the sources of all water used for irrigation, public supply systems, industry, and for rural domestic and stockwatering needs.

1. The Phoenix Metropolitan Area

Table 12 refers to the water demands and supplies of the Phoenix Metropolitan Area, for the year 1963.

The requirements at farm head gates and at water systems totalled 2,363,000 acre-feet; 88.1 percent is used for agricultural purposes. This necessitated that 2,962,268 acre-feet be available at diversion points and well sites. The difference of 599,268 acre-feet was lost by seepage and evaporation between the points of diversion and the points of use. In addition a portion of the water applied to the agricultural areas was return-recharge to ground water. The total annual safe yield of surface water and ground water combined amounted to 1,649,260 acre-feet or 55.6 of all the water used; 1,313,000 acre-feet was the quantity of ground water "mined". In other words, 44.4 percent of the 1963 water supply or 1,313,000 acre-feet was depleted from ground water reserves.

Annual Safe Yield

The annual safe yield of a ground water reservoir is equal to the average annual recharge to that reservoir from all sources minus the amount that is depleted from the aquifer. This method evaluates additions to the ground water reservoir by infiltration from surface water sources (seepage from stream channels, canals, laterals and irrigated land) and by rainfall penetration. This is not an annual constant, for the following reasons: (1) Table 13 and Chart 2 exemplify annual variations in the volume of diverted surface water and in the percentage of ground water used, for the period 1953-1963; (2) the Salt River Project's long-range canal and lateral rehabilitation program, in progress since 1950, consists of concrete lining of canals, lining and tiling of laterals and other treatment methods to reduce seepage and evaporation losses. This water conservation program, and those of other irrigation districts,

TABLE 13

TOTAL WATER SUPPLY AT POINTS OF DIVERSION
Phoenix Metropolitan Area
(Gross Values in Acre-Feet Per Year)

Year	Pumped Values of Ground Water	Diverted Volumes of Surface-Water	Total Gross Water Supply
1953	2,300,000	856,658	3,156,658
1954	2,300,000	814,136	3,114,136
1955	2,200,000	749,262	2,949,262
1956	2,300,000	781,432	3,081,432
1957	2,300,000	655,534	2,855,534
1958	2,300,000	742,535	3,042,535
1959	2,200,000	712,088	2,912,088
1960	2,000,000	904,203	2,904,203
1961	2,200,000	722,453	2,922,453
1962	2,000,000	892,791	2,892,791
1963	2,134,000	828,268	2,962,268

TOTAL WATER SUPPLY
1953 — 1963
PHOENIX METROPOLITAN AREA

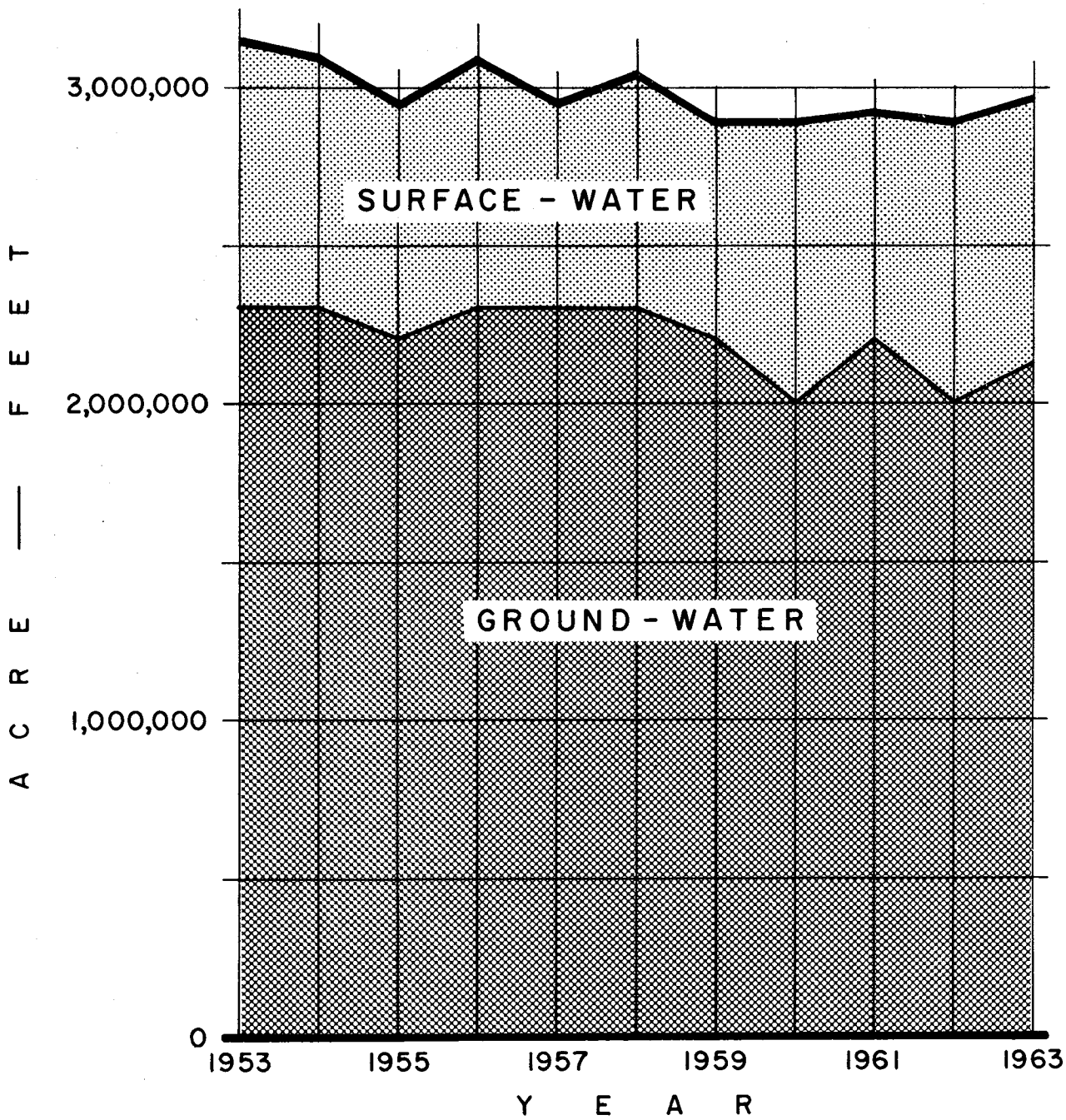

CHART 2

will slowly reduce seepage losses and herewith affect the annual safe yield; (3) irrigation practices might be changed by scientific irrigation procedures which would increase the irrigation efficiency and reduce considerably the annual safe yield. The "annual safe yield" is the ground water recharge from all sources per year.

The Salt River Project

During the year 1963, the Salt River Project produced 1,096,027 acre-feet of irrigation water. Gravity sources furnished 692,153 acre-feet of this total, while 403,874 acre-feet were provided by water pumped from wells. The city limits of Phoenix embrace over 140,000 acres, a large portion of which has been previously irrigated by the Salt River Project. Phoenix obtains part of its water supply by transferring Salt River Project water from irrigation to municipal use, as irrigated lands are subdivided. The City pays assessments on its urban developments within the Project area, where landowners do not and cannot use the Project water. Phoenix, however, is prohibited by contract from using this water outside Project boundaries.

In the year 1963, the City of Phoenix withdrew 105,331 acre-feet of surface water: 39,875 acre-feet Verde River water from its Verde Filter Plants; and 65,456 acre-feet of assessed irrigation water from the Salt River Project, a large percentage of which was processed through the City's Squaw Peak Filter Plant. Wells produced the difference of the City's water supply (see Table 11).

The Cities and Towns of Mesa, Tempe, Glendale, Gilbert and Peoria, also located within the Salt River Project, have or contemplate similar contracts on irrigation water use for urban developments. With continued population growth and urban development, an increasing percentage of Salt River Project water will be used for municipal requirements.

In 1963 the Salt River Project on its 126,223 Project-irrigated areas produced crops having a gross value of nearly $54 million, a gross value of $335 per acre and $55.5 per acre-foot of irrigated water used.

Surface Water Sources

Stream flow in Maricopa County has been recorded since 1889. The period before 1904 was a period of low stream flow, lower than any that has been experienced since that period.

The minimum water-year* on record (1899-1900) yielded 274,000 acre-feet. The period 1905 to 1920 appears in the records as a period of increased precipitation with a record high of 4,328,000 acre-feet runoff for the water-year 1904-05. The long-range aim of the Salt River Project is management and maintenance of its 13,000 square-mile watershed. Deterioration and physical changes have reduced the effective precipitation from 12 percent in the period 1910-1929 to 5.6 percent in 1963. In other words, 5.6 percent of the rain and snow falling on the watershed will reach runoff storage reservoirs with a storage capacity of 2,076,580 acre-feet (see Table 4). The only spill from the Salt and Verde Rivers system in the last 40 years occurred during the exceptionally wet water-year 1940-41.**

The U.S. Bureau of Reclamation in its "Supplemental Report of the Central Arizona Project, January 1963," found the average annual yield of the Salt-Verde River system to be 965,000 acre-feet, and of the Agua Fria River to be 52,000 acre-feet. The Bureau's estimate of the average annual yield of 100,000 acre-feet for the Gila River has been reduced in this study to an expected 33,000 acre-feet, because of the pending development of the Gila River Indian Reservation and its own water requirements. The calculated average annual surface-water yield, available for the Phoenix Metropolitan Area, has been determined at 1,050,000 acre-feet, which is used as a basis for forecast later in this report. The Bureau of Reclamation's estimate is 1,117,000 acre feet per year.

The primary source of water for Metropolitan Phoenix is surface water. However, the Metropolitan Area is most fortunate that it has additional large ground water reserves available to bridge periods when surface supplies are below normal. This is the main reason why the water-dependent economy of the area can and should be maintained at stable levels.

Ground Water Sources

The collection of essential basic data, scientific analysis of this data, and research to evaluate the best methods of ground water use and development are the fundamental steps in

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*The water year extends from October 1 until September 30.

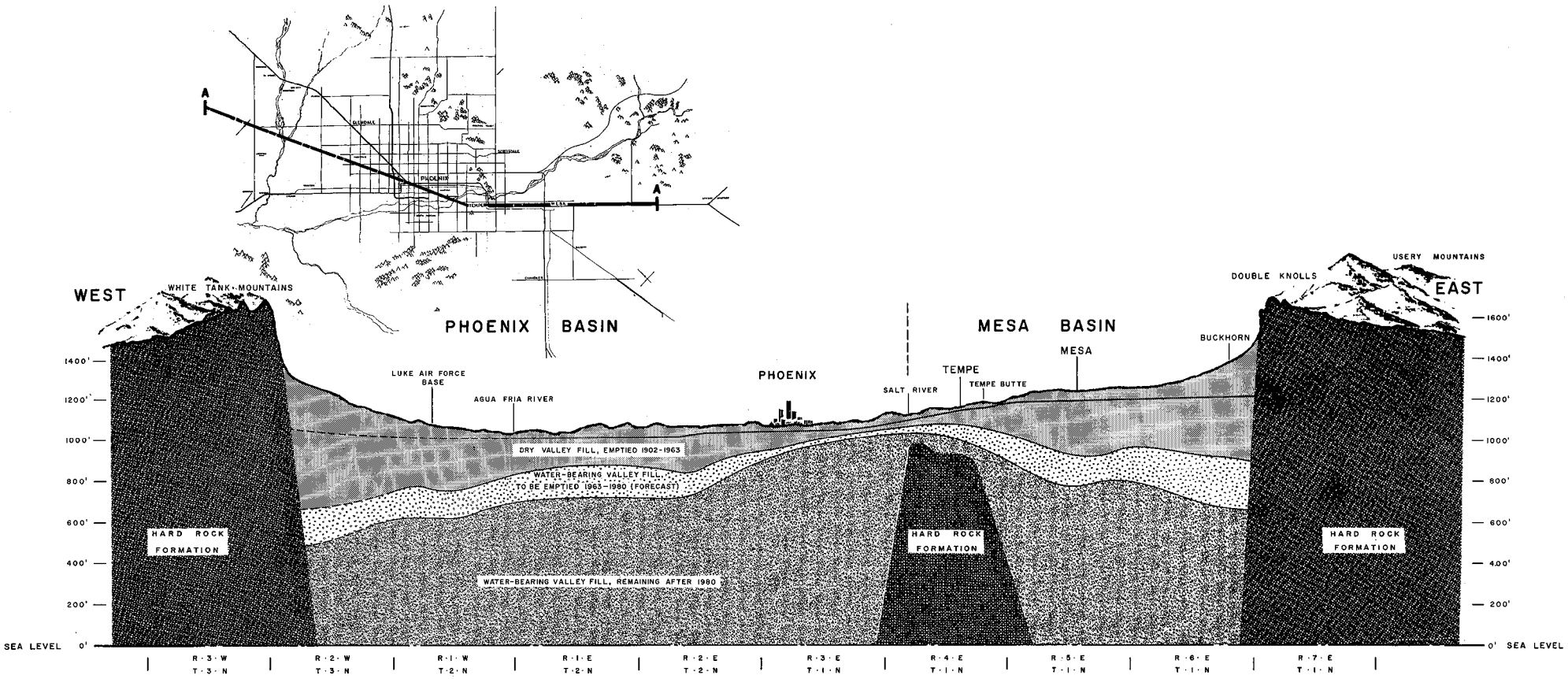
**After completion of manuscript for printing, Salt River was flowing again in Spring of 1965.

this present water resources research program. The limitations and the lack of essential data for specific projects have been mentioned before.

Analytical Approach to Quantitative Study. Mathematical control is indispensable for ultimate solution to the problem of prediction. To predict future withdrawals which may be possible, it is necessary to know how low water levels are permitted to fall. A cone of despression in a water table will be deepened by pumping water, and enlarged by diverting more water into wells. The cumulative effects of withdrawals over the years and changing aquifer conditions must be permitted to react within reasonable boundaries. Before starting with such an analysis, it is pertinent to determine the cumulative effects of the withdrawals that have been made in the past. The east-west cross-section of the ground water basins (Plate 4), intersecting the Mesa and Phoenix Basins of the Metropolitan Area, permits an understanding of the significance of this present research. Shown in this cross-section are the 1902 water-table; the falling water levels as of spring 1963; and the 1980 prediction assuming continuous past declining rates.

Water-Table Observations. Records show that the water table in many wells fluctuates in response to the changing amounts of water pumped in the surrounding well field during different periods of the year. In some basin areas, depletion of storage is seasonal rather than perennial, and the early spring readings are given a higher priority than the fall readings. This complicates quantitative studies. Water-table measurements are taken in the late winter months of each year, or in the early spring, by the U.S. Geological Survey; the U.S. Bureau of Reclamation; the Salt River Project; and by numerous other districts and private organizations. All the water level measurements since before 1950 to spring 1963 and later have been collected and evaluated for almost every observed well in the Mesa and Phoenix Basins, as well as in the other ground water basins of the County.

The procedure used for the present analytical approach is based on the average depletion trend for each single well, plotted since 1950 (Chart 3). This step automatically eliminates all water-table readings which fall out of line and establishes the necessary basis for further calculations. It is conservatively founded on the past trend, until the most recent observations, and it also allows for an estimate of future trends. Chart 3 indicated the method used for a few examples selected in various basin areas. The same procedure has been found the best



SOURCES:

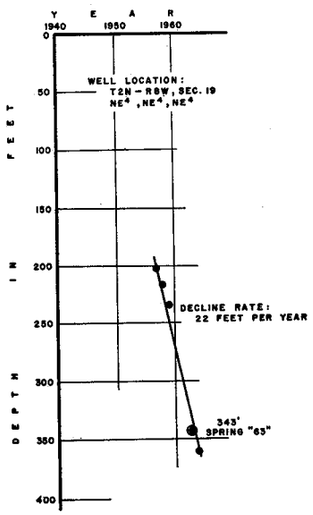
U. S. GEOLOGICAL SURVEY
U. S. BUREAU OF RECLAMATION
DR. H. J. THIELE, CONSULTING HYDROLOGIST.

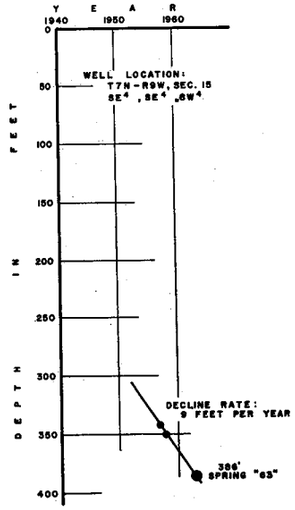
CROSS SECTION A-A

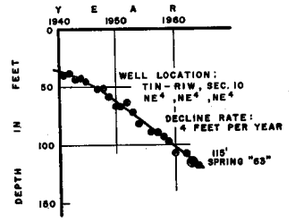
PHOENIX METROPOLITAN AREA

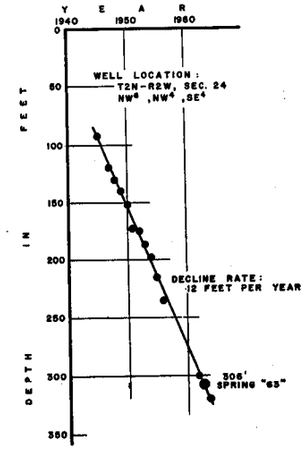
PLATE 4

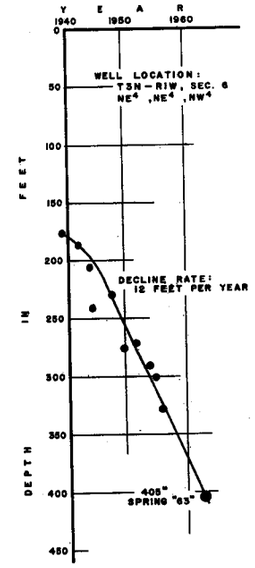
WATER-TABLE DECLINE PER ANNUM OF REPRESENTATIVE WELLS

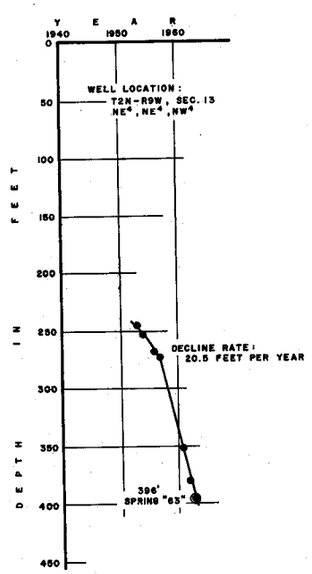


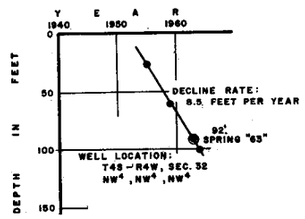


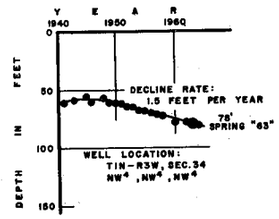


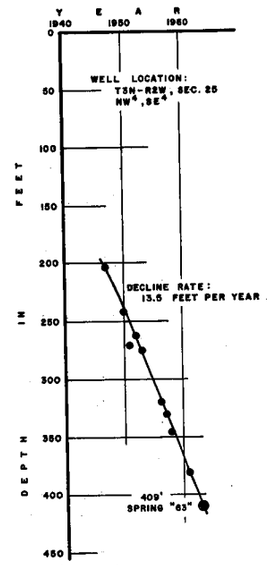


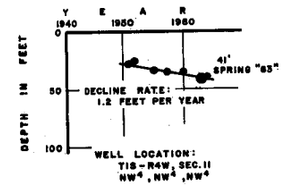












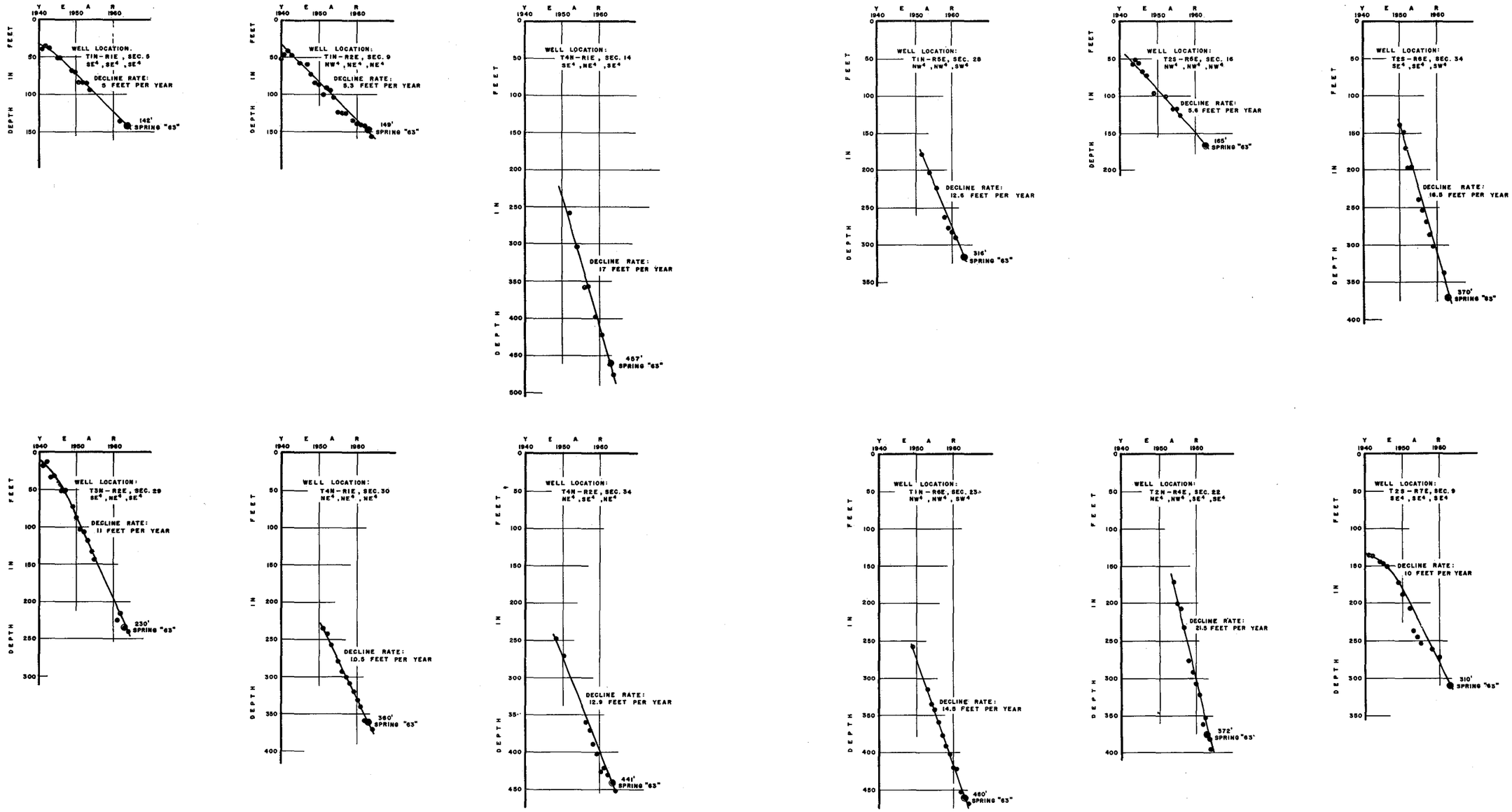
HARQUAHALA, McMULLEN, & GILA BEND BASINS

PHOENIX BASIN
WEST OF AGUA FRIA RIVER

CHART 3

SHEET 1 OF 2

WATER-TABLE DECLINE PER ANNUM OF REPRESENTATIVE WELLS

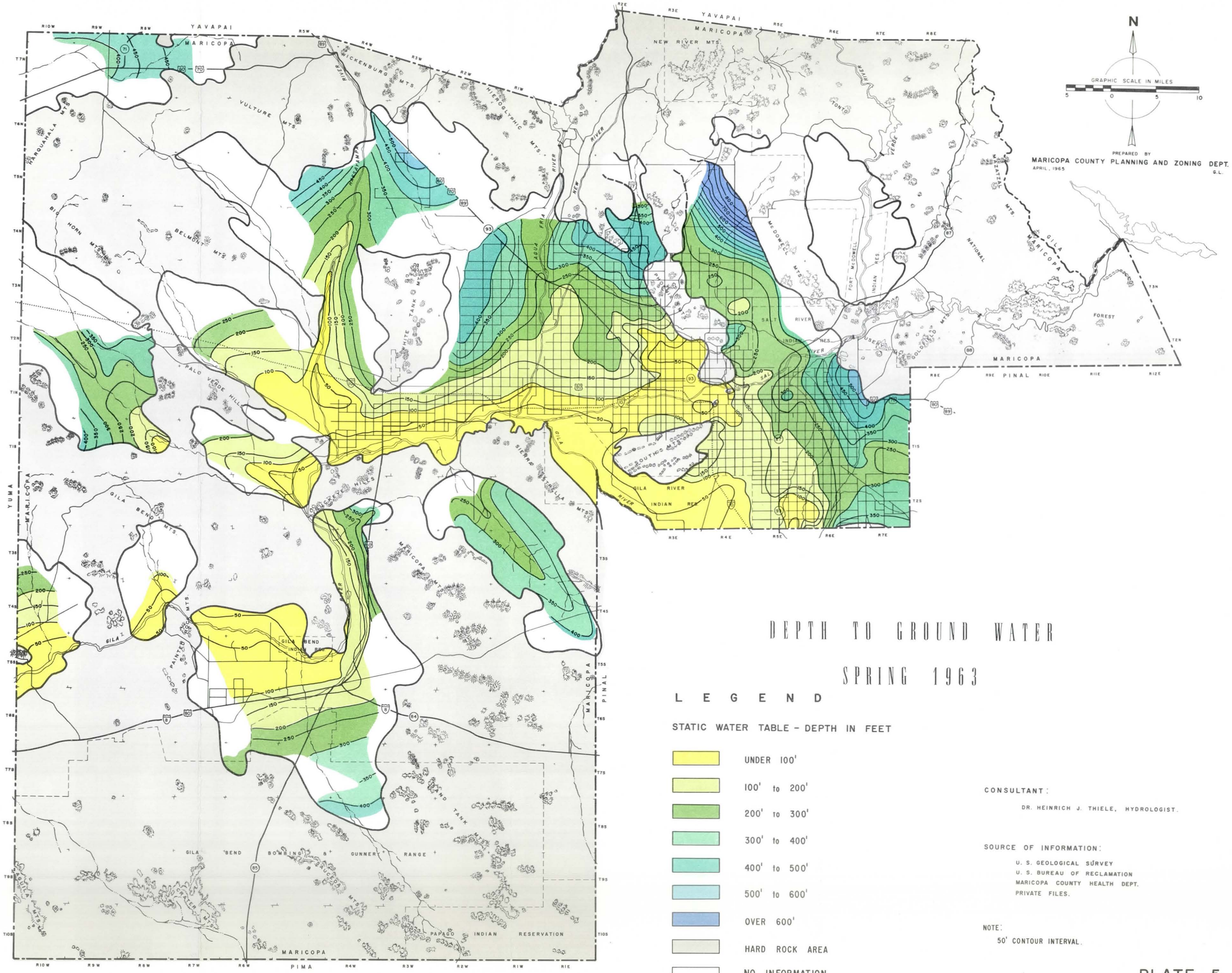


PHOENIX BASIN
EAST OF AGUA FRIA RIVER

MESA BASIN

CHART 3

SHEET 2 OF 2



DEPTH TO GROUND WATER

SPRING 1963

LEGEND

STATIC WATER TABLE - DEPTH IN FEET

- UNDER 100'
- 100' to 200'
- 200' to 300'
- 300' to 400'
- 400' to 500'
- 500' to 600'
- OVER 600'
- HARD ROCK AREA
- NO INFORMATION

CONSULTANT:

DR. HEINRICH J. THIELE, HYDROLOGIST.

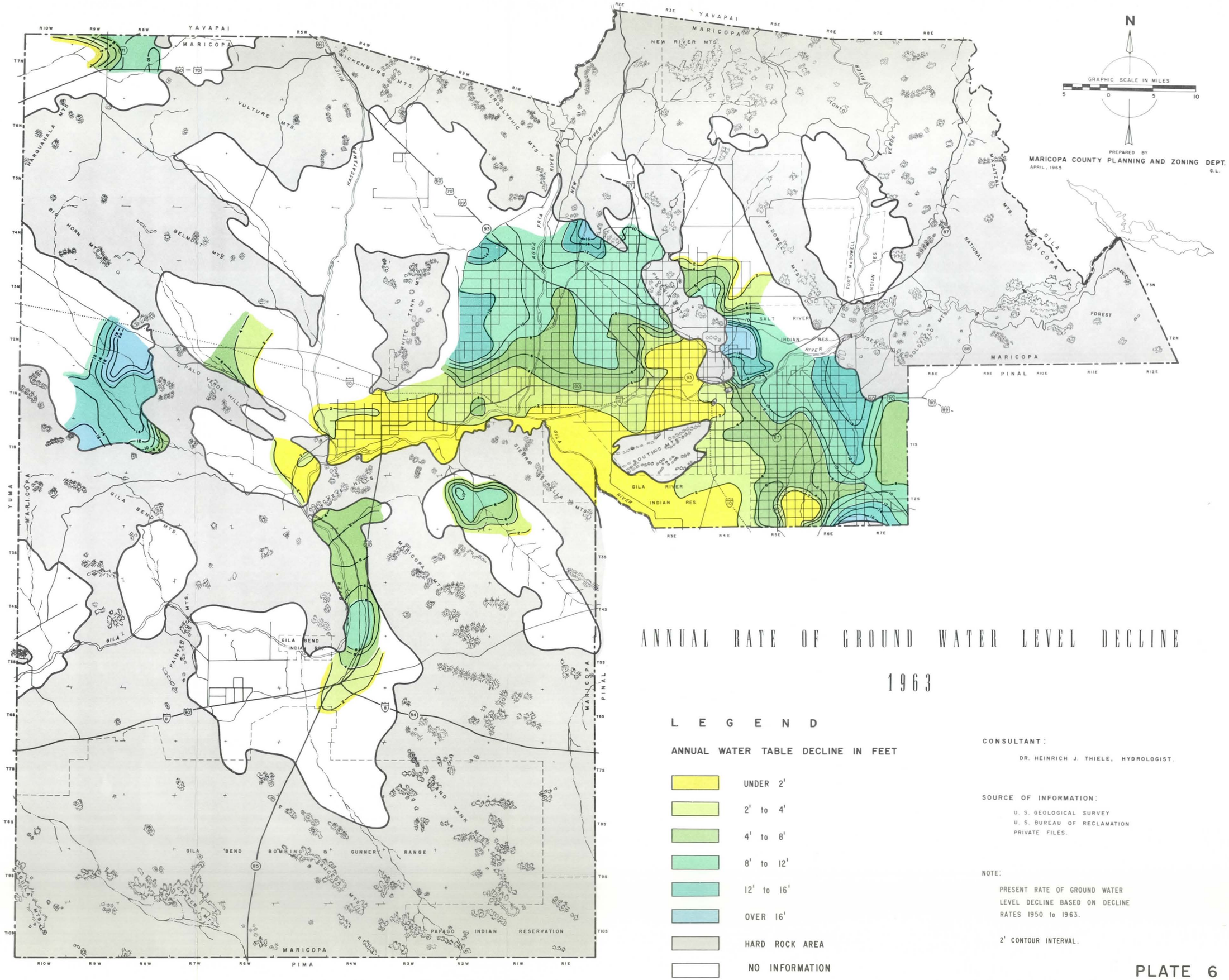
SOURCE OF INFORMATION:

U. S. GEOLOGICAL SURVEY
U. S. BUREAU OF RECLAMATION
MARICOPA COUNTY HEALTH DEPT.
PRIVATE FILES.

NOTE:

50' CONTOUR INTERVAL.

PLATE 5



ANNUAL RATE OF GROUND WATER LEVEL DECLINE

1963

L E G E N D

ANNUAL WATER TABLE DECLINE IN FEET

- UNDER 2'
- 2' to 4'
- 4' to 8'
- 8' to 12'
- 12' to 16'
- OVER 16'
- HARD ROCK AREA
- NO INFORMATION

CONSULTANT:

DR. HEINRICH J. THIELE, HYDROLOGIST.

SOURCE OF INFORMATION:

U. S. GEOLOGICAL SURVEY
U. S. BUREAU OF RECLAMATION
PRIVATE FILES.

NOTE:

PRESENT RATE OF GROUND WATER LEVEL DECLINE BASED ON DECLINE RATES 1950 to 1963.

2' CONTOUR INTERVAL.

PLATE 6

possible approach to establish future trends, by the U.S. Geological Survey in Water Resources Report No. 16: "Effects of Ground Water Withdrawals in Part of Central Arizona Projected to 1969". Readers may find that this present analysis of the water problem does not numerically agree in all phases with the U.S. Geological Survey analysis. This is a natural consequence of the complexity of the situation. There can never be enough observation material to map ground water table flunctuations and, for this present study, besides the information from the U.S. Geological Survey, additional material from the U.S. Bureau of Reclamation and other sources has been used in order to limit errors which cannot be avoided when using numerically restricted information.

The annual rates of water-table declines presented in Chart 3 range from 1.5 to 17.0 feet. Observed decline rates reach maximum values of 22 feet per year.

The historical ground water development was commenced by the earliest pumpers, whose enjoyment of the ground water source has been interfered with in the course of time by those who tapped the supply at a later period. This is demonstrated by Plates 5 and 6, maps which show the"Depth to Ground Water in Spring 1963" and the "Annual Rate of Ground Water Level Decline, 1963" in the County, respectively.

Along the mountain fronts depth to water augments caused by steeper ground-surface slopes toward foothills and mountains (Plate 5). In the Phoenix basin, water stands at relatively shallow depth in the Salt and Gila River Valleys, caused by irrigation return flows, low elevations, seepage losses from canals, and the fact that ground water pumpage underneath the central part of the City of Phoenix has declined with the rapid city development. The greatest depth to water is observed in Deer Valley (470 feet) and, northwest of the Luke Air Force Base (440 feet), together with annual decline rates of 15 and 17 feet, respectively. These and other extremes are displayed in Table 14.

In the Mesa Basin, the shallowest water table is situated west of Tempe, at about 60 feet depth. The greatest depths to water have been observed in Paradise Valley (870 feet) with a 1.0 decline per year; east of Mesa (501 feet) with a 15.4 foot decline per year; and near Chandler Heights (445 feet) with a 18.6 foot annual decline.

The water-table decline map points to the existence of two major cones of depression in the Phoenix Basin: (1) Along the northern basin boundary, north of Glendale and in Deer Valley, and (2) west of the Agua Fria River, along the east front of the White Tank Mountains.

TABLE 14

SPRING 1963 WATER TABLES
RATES OF ANNUAL DECLINE AND FORECASTS 1970 AND 1980
ASSUMING CONTINUOUS PAST DECLINE RATES
Phoenix Metropolitan Area

Area	Depth to Water Spring 1963 Feet	Rate of Annual Water Table Decline Feet	Depth to Water Forecast 1970 Feet	Depth to Water Forecast 1980 Feet
I PHOENIX BASIN				
West of Agua Fria River				
Gila River Valley	40-150	0- 4.0	50-180	60-220
Litchfield-Beardsley Area	150-440	4.0-15.0	180-530	220-680
East of Agua Fria River				
Salt River Valley	40-150	0- 4.0	50-180	60-220
Phoenix-Glendale-Deer Valley Area	150-470	4.0-17.0	180-570	220-740
II MESA BASIN				
Paradise Valley				
South of Indian Bend	60-315	10.5-17.5	200-420	200-580
North of Indian Bend	186-850	1.0- 9.2	240-860	300-880
Mesa-Chandler Area				
North of Baseline	60-513	1.4-15.4	70-615	84-745
South of Baseline	50-445	0-18.6	75-575	200-761
Queen Creek-Magma Area				
Maricopa County Area	230-501	6.0-13.5	279-527	350-637
Pinal County Area	245-412	6.0-13.0	287-457	350-633

Three decline areas exist in the Mesa Basin: the most important one lies east of Mesa and two minor ones are located near Chandler Heights and near Scottsdale.

The two ground water basins of the Phoenix Metropolitan Area are in almost every stage of development, from areas that are scarcely being depleted to those that are seriously over-developed. Wells are being deepened in all those districts which have heavy water-table declines, and steadily increasing pumping costs prevail.

Quantitative Estimates

The volumes of water that may be extracted from a ground water basin are determined by a quantitative ground water inventory. Normally capacity tables and curves are developed for surface water reservoirs. A gage will show the change in water level and with it the net increase or decrease in storage. When this storage method is applied to ground water reservoirs, several steps have to be taken:

(1) Determination of the basin boundaries;

(2) Contour maps have to be constructed showing the ground water reserves at successive dates;

(3) Calculation has to be made of the weighted average depth to water by using mathematical tools;

(4) Evaluation has to be made of the soil volume already depleted;

(5) Selection of a weighted average specific yield factor has to be made for the depleted part of the aquifer;

(6) Calculation has to be made of the volume of ground water dewatered;

(7) The volume of ground water dewatered has to be subtracted from the volume of ground water pumped, leaving the return recharge to the aquifer from all sources.

Chart 4 discloses the extent of the Phoenix and Mesa Basins underneath ground surface as well as the joint basin areas of the Phoenix Metropolitan Area. Selected for detailed evaluations is a period with relatively similar annual water table characteristics, spring 1956 to spring 1963. A water table map of spring 1956, not shown here, illustrates more in detail the information given in the last part of Table 15, as to basin extent and average depth to water. Similar evaluations for spring 1963 are based on data used for the construction of Plate 5, the Depth to Ground Water Map of Spring 1963.

AREA OF BASIN EXTENT UNDERNEATH GROUND SURFACE

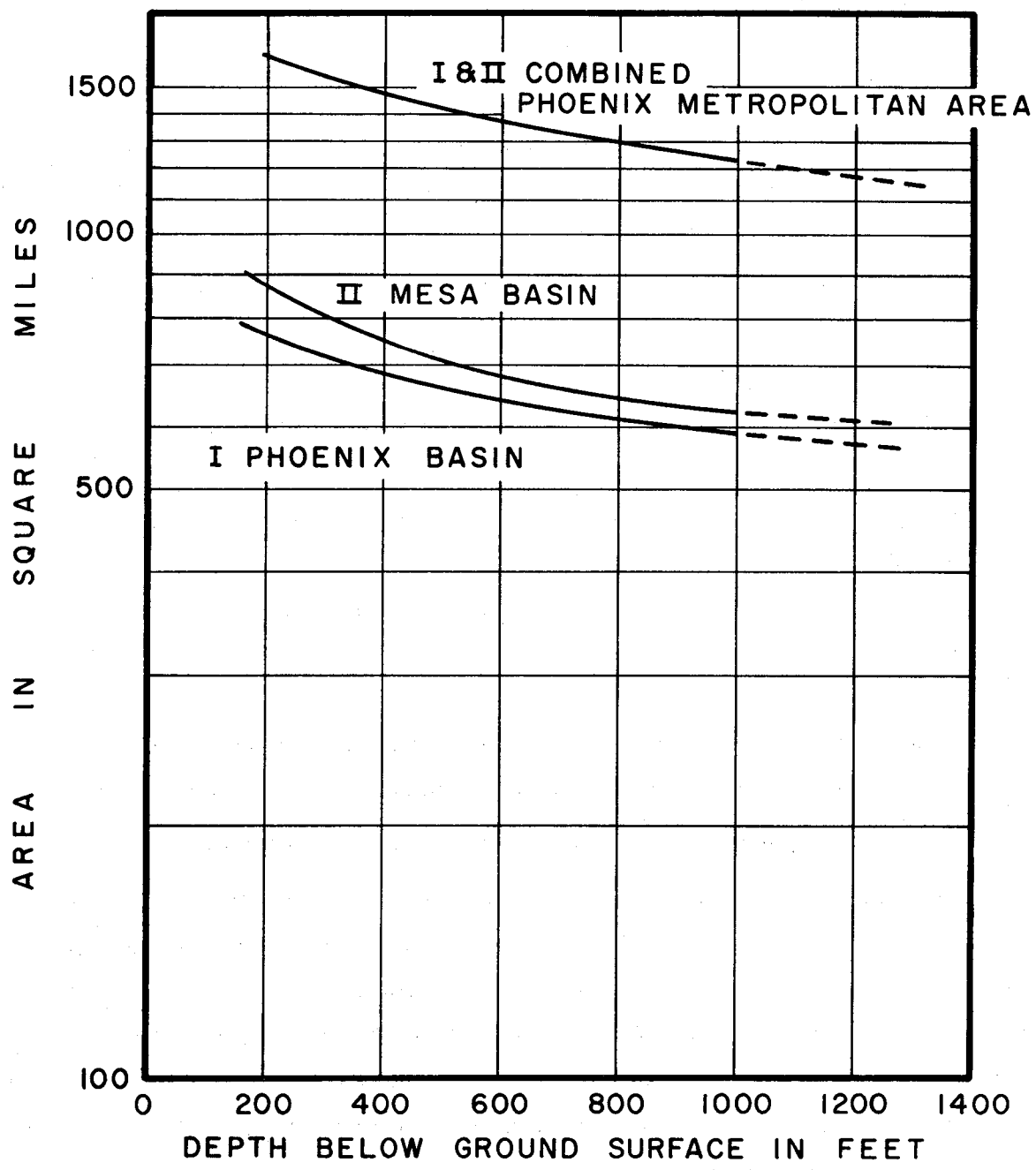


CHART 4

TABLE 15

BASIN EXTENT, AVERAGE DEPTH TO WATER, AVERAGE ANNUAL DECLINE RATES
1956, 1963 AND FORECASTS 1970 AND 1980
Phoenix Metropolitan Area

	1956			1963			1970			1980			Annual rate of water table decline
	Basin Extent		Depth to water	Basin Extent		Depth to water	Basin Extent		Depth to water	Basin Extent		Depth to water	
	sq.mi.	acres	in feet	sq.mi.	acres	in feet	sq.mi.	acres	in feet	sq.mi.	acres	in feet	
PHOENIX AREA I													
Area East of Agua Fria	441	282,000	131	435	278,000	170	420	269,000	209	396	253,000	265	5.6
Area West of Agua Fria	355	227,000	161	342	219,000	206	341	218,000	251	339	217,000	315	6.4
Sub Total	796	509,000	144	777	497,000	186	186	487,000	282	735	470,000	288	6.0
MESA AREA II													
Paradise Valley	230	147,200	318	220	141,000	360	210	134,500	402	205	131,300	462	6.0
Mesa-Chandler Area	313	200,200	173	307	196,500	225	304	194,500	277	297	190,000	351	7.4
Queen-Creek Magma Area	292	187,000	305	305	178,000	360	272	174,000	415	258	165,000	494	7.9
Sub Total	835	534,400	269	805	515,500	309	786	503,000	358	760	486,300	429	7.0
TOTAL (Phoenix Metropolitan Area (I & II)	1,631	1,043,400	203	1,582	1,012,500	248	1,547	990,000	293	1,495	956,300	358	6.48

TABLE 16

GROUND WATER PUMPAGE, RETURN-RECHARGE AND LOSS 1956 TO 1963

Phoenix Metropolitan Area
(Quantities in Acre-Feet)

	Spring 1956-Spring 1963	Average Per Year
Ground Water Pumped	15,300,000	2,185,000
Ground Water Recharge from all Sources	9,380,000	1,340,000
Loss from Ground Water Storage (at 20% specific yield)	5,920,000	845,000

According to the data in these tables, a soil volume of 46,900,000 acre-feet in the Phoenix and Mesa Basins has been dewatered in the 7-year period from the spring of 1956 to the spring of 1963.* The overall average water-table decline rate of 6.48 feet per year corresponds with M.M. Kelso's** overall figure for Arizona. Mr. Kelso states: "The ground water supplies will continue to decline at 6.5 feet per year as they have on the average since 1953, so long as withdrawals continue at the present rate volume."

Specific Yield. The specific yield is the volume of water as a percentage of the total soil volume that can be stored in it or withdrawn from it by pumpage. It changes from place to place because of changes in porosity and permeability. It also changes with increasing depth due to the higher compaction of the sediments and intervening layers of clay. The average specific yield value of the Phoenix and Mesa Basins is unknown (its determination would require many detailed studies of soil samples and numerous pumping tests of wells, which studies are not available). A weighted average specific yield value has to be projected. The U.S. Geological Survey analyzed the alluvial fill of the Humboldt River Valley in Nevada for specific yield. Specific yield values of the fine-grained deposits proved to be considerably higher than previously reported by earlier studies. The mean specific yield of all samples was 21.3 percent. (U.S. Geological Survey, Water Supply Paper 1669-M, 1963). In another publication and also shown in Table 22, the weighted average of the Waterman Wash Basin's specific yield has been given as 12.6 percent between 500 and 800 foot depth (U.S. Geological Survey Water Supply Paper 1669-F, 1963).

The present study discloses that the average specific yield of the dewatered part of the two basins of the Phoenix Metropolitan Area is between 20 percent and 21 percent, considerably higher than assumed in earlier papers published by the U.S. Geological Survey for this area.

An average specific yield of 20 percent was selected for an overall average depth to water of 248 feet. It further was assumed that the overall specific yield at 1,000 feet depth should be 10 percent and that the change in specific yield between 248 foot and 1,000 foot depth should be gradual following a straight line approach. The specific yield of 12.8 percent for 800 foot depth compares well with the 12.6 percent determined for the Waterman Wash Basin

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* See Table 16

**See M.M. Kelso, Arizona Academy, 1964

by the U.S. Geological Survey. If the specific yield values should actually average a larger decrease, then the following calculations would tend to yield an overestimate of the volume of ground water in storage. If specific yield values actually average a smaller decrease, then the following ground water volumes would be an underestimate of the volume of ground water that can actually be removed for a given weighted average water-table drop. The specific yield assumptions are shown in Chart 5.

Fundamental in the formulation of the basic ground water hydrologic equation is the concept that an entire ground water basin has to be considered as a unit in the analytical approach. It may be written in two parts:

(1) Depleted Basin Ground Water Volume = Basin Volume divided by weighted average specific yield

(2) Depleted Basin Ground Water Volume = Ground Water Loss by Discharge plus Ground Water Return Flow from all Sources

Annual Safe Yield. The expression "annual safe yield" will not be used further in this study, since it is not a constant factor. The annual ground water replenishment return flow from all sources, in this sense, is the same figure as the annual safe yield.

Table 17 and Chart 6 exhibit "Ground Water Storage Curves to 1,000 Feet Depth," based on a hypothesized set of conditions previously discussed herein. According to these exhibits the total remaining ground water storage to 1,000 feet depth in the spring of 1963 was as follows:

Phoenix Basin	53,971,000 acre-feet
Mesa Basin	46,337,000 acre-feet
Total Phoenix and Mesa Basins	100,308,000 acre-feet

Up to 1,000 feet depth, the Phoenix Basin contained more water than the Mesa Basin, since the average water table of the Mesa Basin stood at 309 feet in the spring of 1963, compared with the average Phoenix Basin water table at 186 feet. Although the exact volume of the ground water reserve is only estimated, changes can be projected by making certain assumptions in the correct order of magnitude. Even allowing for a considerable error, there can be no escaping the fact that the ground water reserves of the Phoenix Metropolitan Area

SPECIFIC YIELD ASSUMPTIONS

PHOENIX & MESA BASINS

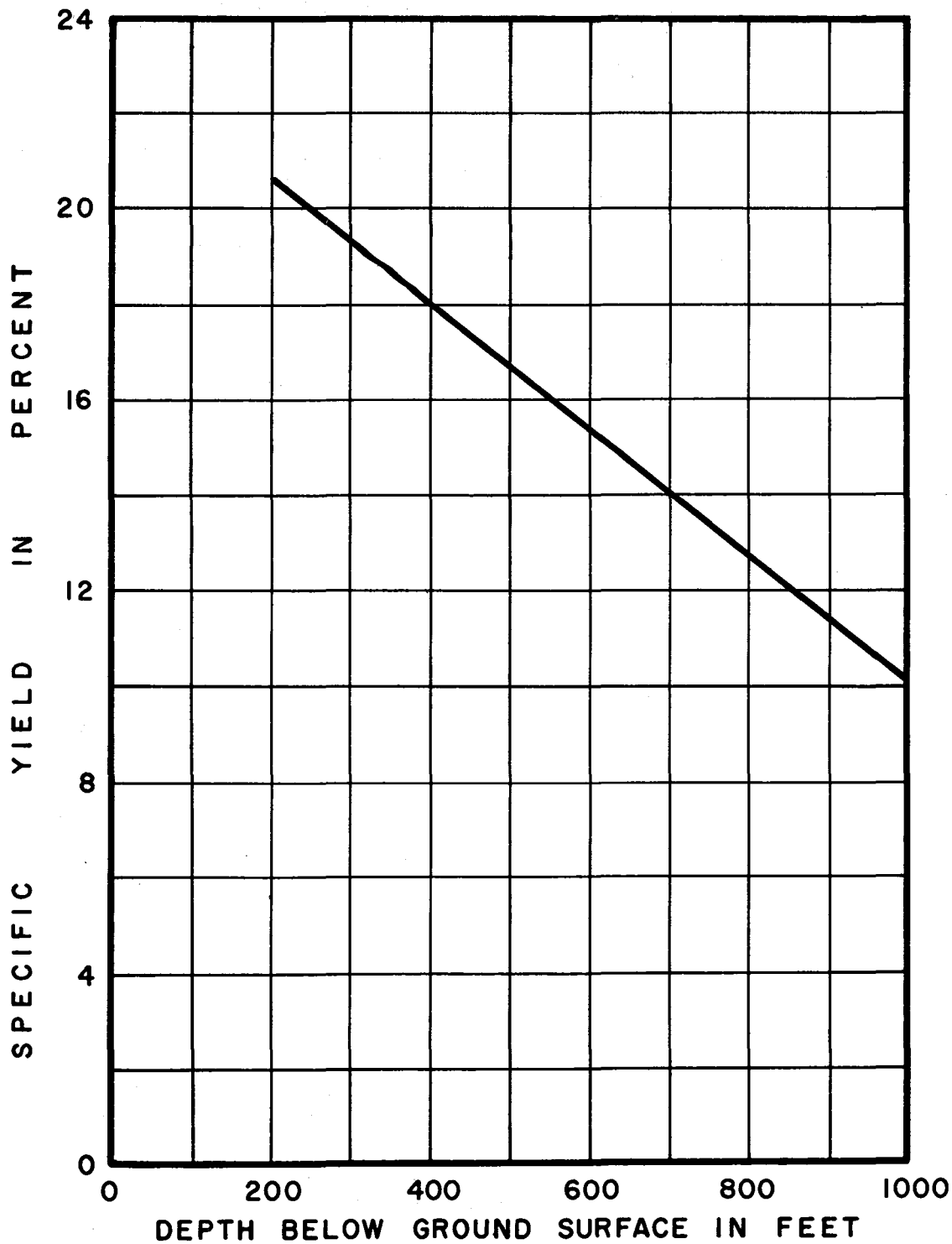


CHART 5

TABLE 17

GROUND WATER STORAGE TO 1,000 FOOT DEPTH, SPRING 1963
Phoenix Metropolitan Area

I PHOENIX BASIN		II MESA BASIN		I & II PHOENIX METROPOLITAN AREA	
Average Depth from Ground Surface in Feet	Ground Water Storage in Acre-Feet	Average Depth from Ground Surface in Feet	Ground Water Storage in Acre-Feet	Average Depth from Ground Surface in Feet	Ground Water Storage in Acre-Feet
186 - 200	2,460,000				
200 - 300	9,000,000			248 - 300	11,500,000
300 - 400	8,300,000	309 - 400	9,200,000	300 - 400	18,800,000
400 - 500	7,500,000	400 - 500	8,300,000	400 - 500	15,200,000
500 - 600	6,700,000	500 - 600	7,300,000	500 - 600	14,300,000
600 - 700	6,000,000	600 - 700	6,500,000	600 - 700	12,500,000
700 - 800	5,500,000	700 - 800	6,000,000	700 - 800	11,000,000
800 - 900	4,700,000	800 - 900	5,000,000	800 - 900	9,500,000
900 - 1000	3,800,000	900 - 1000	4,037,000	900 - 1000	7,508,000
Total 186 - 1000	53,971,000	309 - 1000	46,337,000	248 - 1000	100,308,000

GROUND WATER DEPLETION CURVES
to 1000 FOOT DEPTH
PHOENIX METROPOLITAN AREA

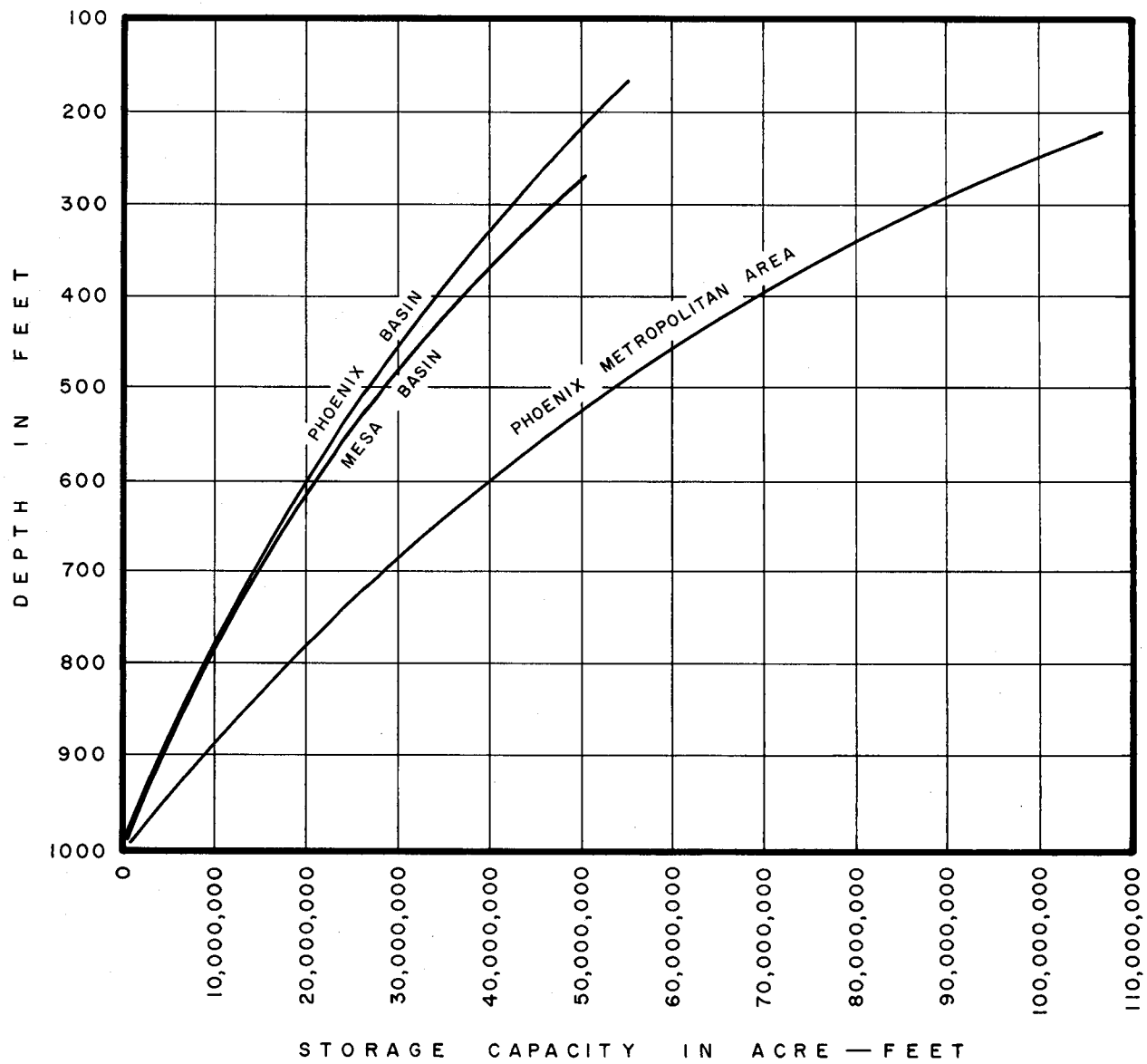


CHART 6

are depleting rapidly, even when taking into consideration that there are additional water-bearing strata in the deeper valley fill that are below 1,000 feet depth. The average specific yield below 1,000 feet depth is probably considerably less than 6 percent.

Some prediction as to water available is a dire necessity. So far, the problem of quantitative estimates has not been approached in the Phoenix Metropolitan Area. It is hoped that this report will lead to a continuing inventory of the quantity and quality of the water stored in the Area's two ground water basins.

Qualitative Estimates

The ground waters of the Phoenix Metropolitan Area are characterized by a wide range in type and concentration of chemical constituents. Water quality may appreciably affect water quantity. Larger bodies of highly mineralized water are surrounded by ground water of lower concentration.

The source of the brackish water is due partly to the storage of salt water and to salt layers in the lakebed deposits located in the deeper parts of the ground water basins. The deep salt-water sources have only occasionally influenced water quality in the younger formations. The steady increase in concentration of total dissolved solids to the southwest of Chandler, and in the Gila and Salt River Valleys, from the Salt River confluence area downstream to the County boundary in the west, has to be attributed mainly to the recirculation of ground water, since it is used for irrigation. A water outflow leaving the Mesa and Phoenix Basins, for practical purposes does not exist, to remove the salts of the tailend irrigation waters, and to maintain a salt balance in the ground water basins.

With all the collected qualitative information, it is now possible to determine location and horizontal extent of the saltwater bodies in the younger alluvial fill. Because of past trends, observed since 1942, it also is possible to predict, to a certain degree, the extent of volume-increase to be expected in future years. The Gila River saltwater body actually extends as a continuous flow around the south side of the South Mountains to the northeast into the Chandler area of the Mesa Basin. Twenty years ago, the Chandler and Buckeye saltwater bodies were smaller in size and more or less separated from one another. A simple calculation underlines the significance of these observations and the existing trends.

According to the preceding quantitative estimates, it can be concluded that a total of about 2.2 million acre-feet of surface water and ground water is used per year, while approximately 800,000 acre-feet are returned to ground water storage, from the grand total of about 3 million acre-feet needed at diversion points.

The overall total salt content of the water supply may be conservatively estimated at 600 parts per million (ppm). Therefore 2,200,000 acre-feet x 600 x 0.00137* = 1,800,000 tons of salt per year. In other words, 2.2 million acre-feet of water are used up, leaving in the two basins 1,800,000 tons of salt per year in the underground to be added slowly to the ground water reserve. In the 1953-1963 period, an estimated 18 million tons of salt added have increased substantially the concentration of the remaining ground water solution. The preceding discussion may be helpful to explain the salinity problem of the Phoenix Metropolitan Area.

Quality Criteria

The Federal Register of March 6, 1962, carried the latest revision of the generally accepted sanitary criteria for water for domestic purposes in the "Public Health Drinking Water Standards." This revised criteria is used by the Maricopa County Health Department in their review process for approval of proposed water supplies. The following limits are being suggested:

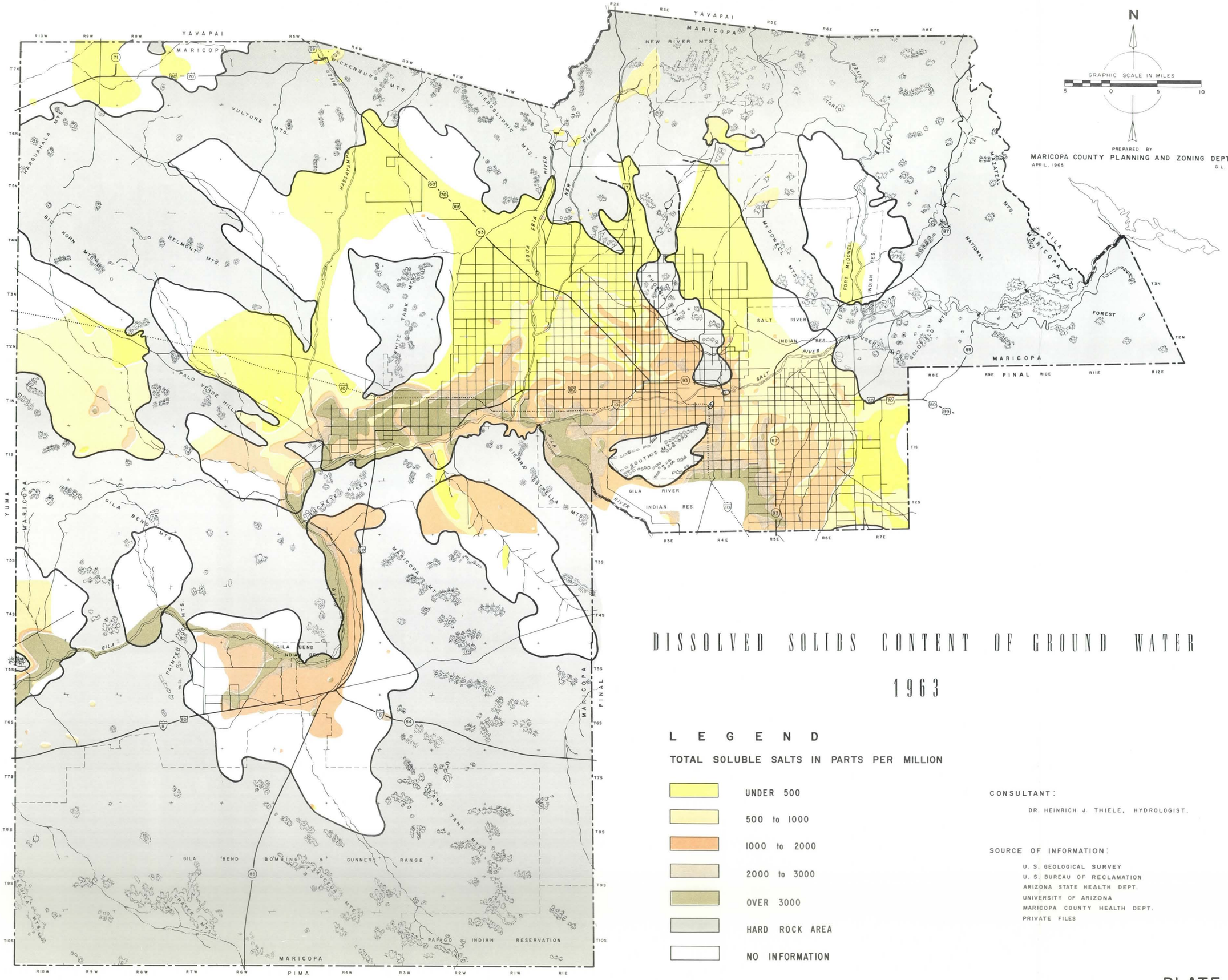
Suggested Upper Limits of Chemicals in Drinking Water

Constituent	Concentration in Parts Per Million (ppm)
Total Dissolved Solids	500
Total Hardness	170
Fluorides	1.4

Plates 7, 8 and 9 illustrate the following criteria: Total dissolved solids, total hardness, and fluorides. These components are discussed as follows:

Total Dissolved Solids. Dissolved matter is commonly the outstanding constituent in ground water, originating in the soluble material which is dissolved by water moving through

*See Footnote Page 7.



DISSOLVED SOLIDS CONTENT OF GROUND WATER

1963

L E G E N D

TOTAL SOLUBLE SALTS IN PARTS PER MILLION

- UNDER 500
- 500 to 1000
- 1000 to 2000
- 2000 to 3000
- OVER 3000
- HARD ROCK AREA
- NO INFORMATION

CONSULTANT:

DR. HEINRICH J. THIELE, HYDROLOGIST.

SOURCE OF INFORMATION:

U. S. GEOLOGICAL SURVEY
U. S. BUREAU OF RECLAMATION
ARIZONA STATE HEALTH DEPT.
UNIVERSITY OF ARIZONA
MARICOPA COUNTY HEALTH DEPT.
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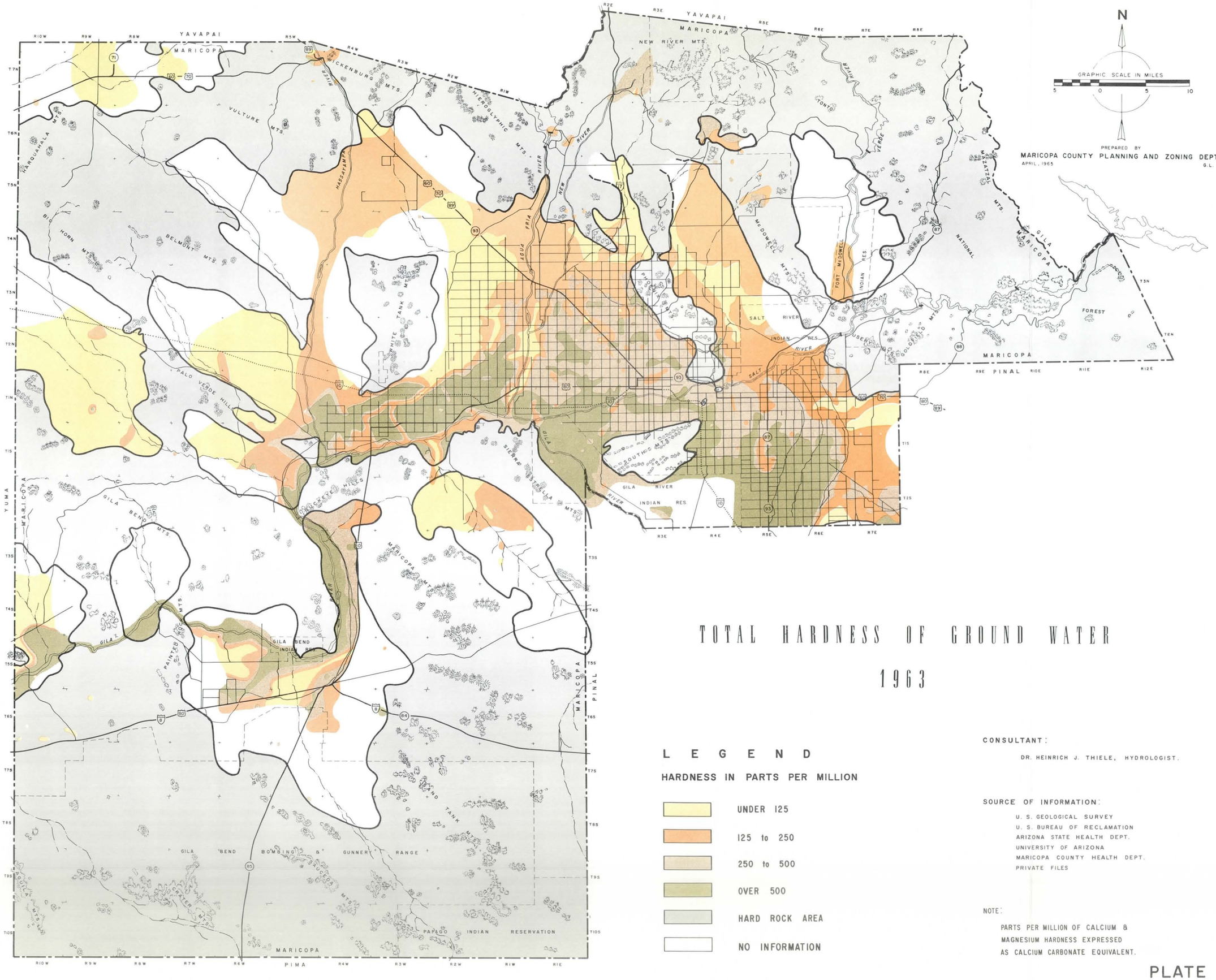
PLATE 7



TOTAL HARDNESS OF GROUND WATER

1963

LEGEND

HARDNESS IN PARTS PER MILLION

- UNDER 125
- 125 to 250
- 250 to 500
- OVER 500
- HARD ROCK AREA
- NO INFORMATION

CONSULTANT:

DR. HEINRICH J. THIELE, HYDROLOGIST.

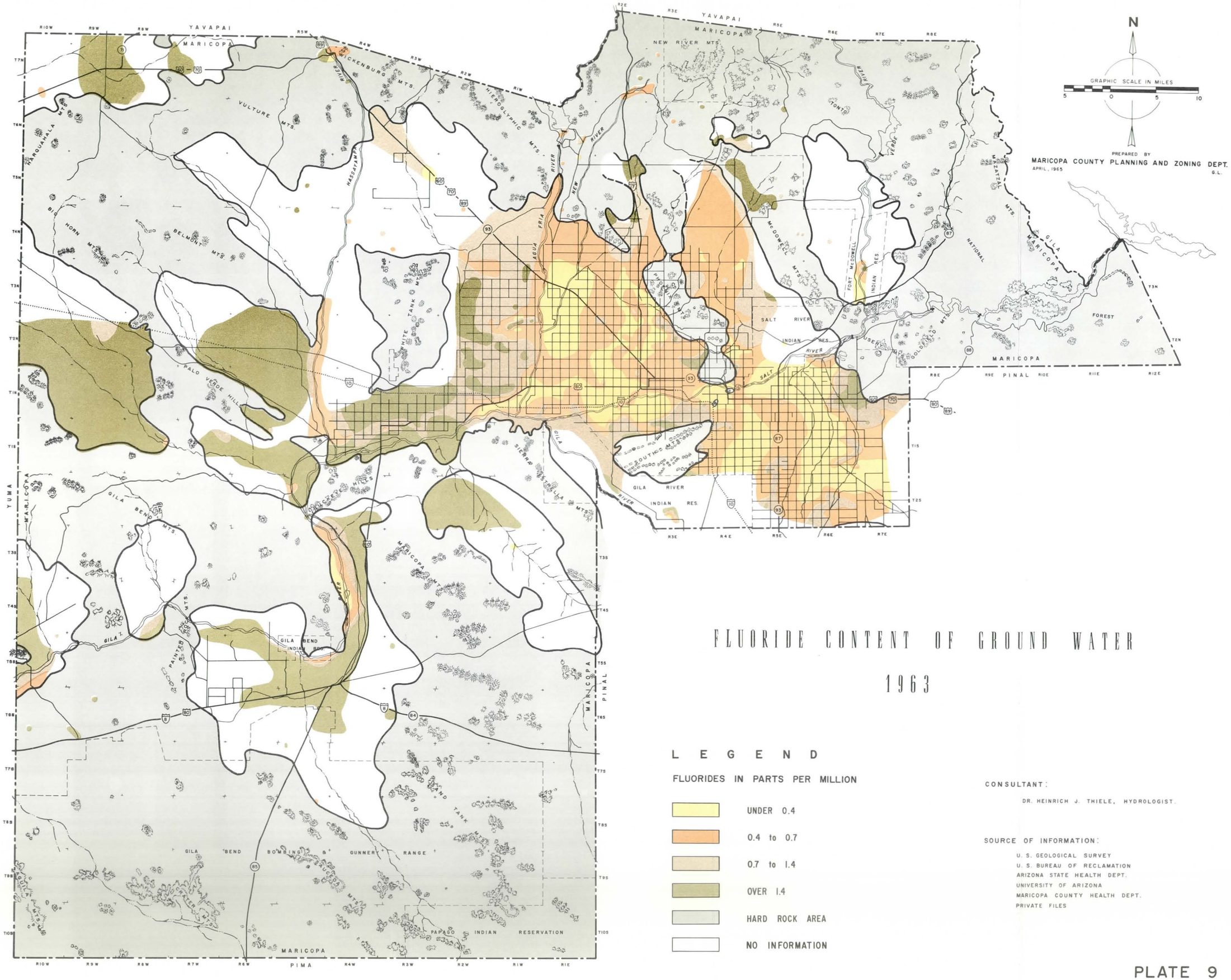
SOURCE OF INFORMATION:

U. S. GEOLOGICAL SURVEY
U. S. BUREAU OF RECLAMATION
ARIZONA STATE HEALTH DEPT.
UNIVERSITY OF ARIZONA
MARICOPA COUNTY HEALTH DEPT.
PRIVATE FILES

NOTE:

PARTS PER MILLION OF CALCIUM & MAGNESIUM HARDNESS EXPRESSED AS CALCIUM CARBONATE EQUIVALENT.

PLATE 8



FLUORIDE CONTENT OF GROUND WATER

1963

L E G E N D

FLUORIDES IN PARTS PER MILLION

- UNDER 0.4
- 0.4 to 0.7
- 0.7 to 1.4
- OVER 1.4
- HARD ROCK AREA
- NO INFORMATION

CONSULTANT:

DR. HEINRICH J. THIELE, HYDROLOGIST.

SOURCE OF INFORMATION:

U. S. GEOLOGICAL SURVEY
U. S. BUREAU OF RECLAMATION
ARIZONA STATE HEALTH DEPT.
UNIVERSITY OF ARIZONA
MARICOPA COUNTY HEALTH DEPT.
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PLATE 9

the alluvial fill and along bedrock formation boundaries. Plate 7 shows that the quantity of total dissolved solids may vary widely. As has been mentioned previously, chemical quality may be modified by use. This also holds true for irrigation return flows and for the sewage from municipalities. The used water generally has a higher proportion of dissolved solids than it had prior to the use, because of consumption, evaporation, and addition of chemicals.

The total dissolved solids content of water does not present an actual health hazard. The limit of 500 ppm is abritrary, but calls into notice a point where a few persons object to the taste of the water. Most of the drinking water used in Maricopa County has a total solids content between 500 and 1,000 ppm. The Phoenix Metropolitan Area is most fortunate in retaining considerable ground water reserves with a total salt content below 500 ppm: in the northern part of the Phoenix Basin; in Paradise Valley; and in the Queen Creek-Magma area. Table 18 displays the extremes and average values of the total dissolved solids; hardness, fluorides, and ground water temperature.

The total solids range from 168 ppm in the Litchfield-Beardsley area to 8,136 ppm south of Chandler. The content of total dissolved solids can be reduced effectively by demineralization, as demonstrated by the demineralization plant in Buckeye, where the salt content of brackish water is being diminished from above 2,000 ppm to below 500 ppm.

Total Hardness. Hardness of water is caused mainly by calcium and magnesium dissolved in ground water, and is a measure of the amount of soap required to form a lather. Hardness is calculated as follows: Calcium (ppm) x 2.5 + Magnesium (ppm) x 4.1 = total hardness (ppm), expressed as $CaCO_3$ equivalent. Plate 8 shows the total hardness of ground water in Maricopa County.

The significance of hardness lies in the field of aesthetics and economics rather than public health. The U.S. Public Health Service recommends less than 170 ppm for waters of good quality. The following classification of water hardness is arbitrary although commonly used:

0 - 60 ppm	soft
61 - 120 ppm	moderately hard
121 - 180 ppm	hard
More than 180 ppm	very hard

TABLE 18

QUALITY OF GROUND WATER 1963
Phoenix Metropolitan Area

Area	Total Dissolved Solids		Total Hardness		Fluorides		Temperature	
	Range ppm	Average ppm	Range ppm	Average ppm	Range ppm	Average ppm	Range ppm	Average ppm
A. PHOENIX BASIN								
West of Agua Fria River								
Gila River Valley	179-6560	2100	40-2360	600	0.2- 5.0	1.3	71-114	80
Litchfield-Beardsley Area	168-2014	280	26- 578	77	0.3- 5.0	1.4	72- 91	82
East of Agua Fria River								
Salt River Valley	544-6840	1900	52-2687	530	0.2-28.8	0.8	70- 84	77
Phoenix-Glendale-Deer Valley Area	192-2983	490	82- 791	250	0.2- 9.0	0.6	69-996	81
B. MESA BASIN								
Paradise Valley								
South of Indian Bend	253-1747	625	66- 780	225	0.3- 5.6	0.7	66- 94	83
North of Indian Bend	195- 454	305	48- 232	160	0.3- 1.4	0.7	83- 97	86
Black Mountain Foothills	280- 480	380	105- 378	230	1.0- 3.2	2.2	74- 75	75
McDowell Mountains Foothills	247-1063	580	118- 512	155	1.0- 6.0	3.5	-	-
Mesa-Chandler Area								
North of Baseline	318-4083	770	46-1593	270	0.1- 0.8	0.8	68-112	75
South of Baseline	463-8136	2100	85-3820	790	0.2- 2.4	0.6	74- 95	78
Maricopa County Area								
North of Apache Blvd.	835-1433	1130	130- 470	350	0.3- 2.8	1.8	84-106	95
South of Apache Blvd.	250-1072	440	21- 298	150	0.2- 0.9	0.7	76- 95	88
Pinal County Area	230- 690	550	161- 268	210	0.1- 1.0	0.6	74- 90	79

Table 18 gives the range of hardness for the Phoenix Metropolitan Area from 21 to 3,820 ppm. Soft waters are in the Litchfield-Beardsley area. Moderately hard and hard ground waters are found in Paradise Valley and the Queen Creek-Magma area. Very hard waters are in underground storage in all other parts of the Phoenix Metropolitan Area.

In the laundry industry it is generally accepted that water with more than 100 ppm of hardness should be softened, to produce better results in laundry operations. There is no set limit above which a home softening unit should be installed economically, although it is somewhere between 100 and 200 ppm total hardness. The demineralization of the Buckeye water reduces the total hardness from 354 ppm to 51 ppm, offset by an increase in sodium.

Fluorides. The solvent action of water on the minerals with which it comes in contact makes water a chemical solution of varying composition. This holds true especially for fluorides, as set forth by Plate 9. Ground water coming in contact with granitic rocks often is characterized by a higher fluoride content, as displayed in Table 18. The fluorides in the Phoenix Metropolitan Area range from 0.1 to 28.8 ppm. The average values above the recommended upper limits are found near and in the foothills to the north and east of Paradise Valley, east of Mesa, and north of the Queen Creek area, they also are higher than 1.4 ppm in parts of the Litchfield-Beardsley-Buckeye area.

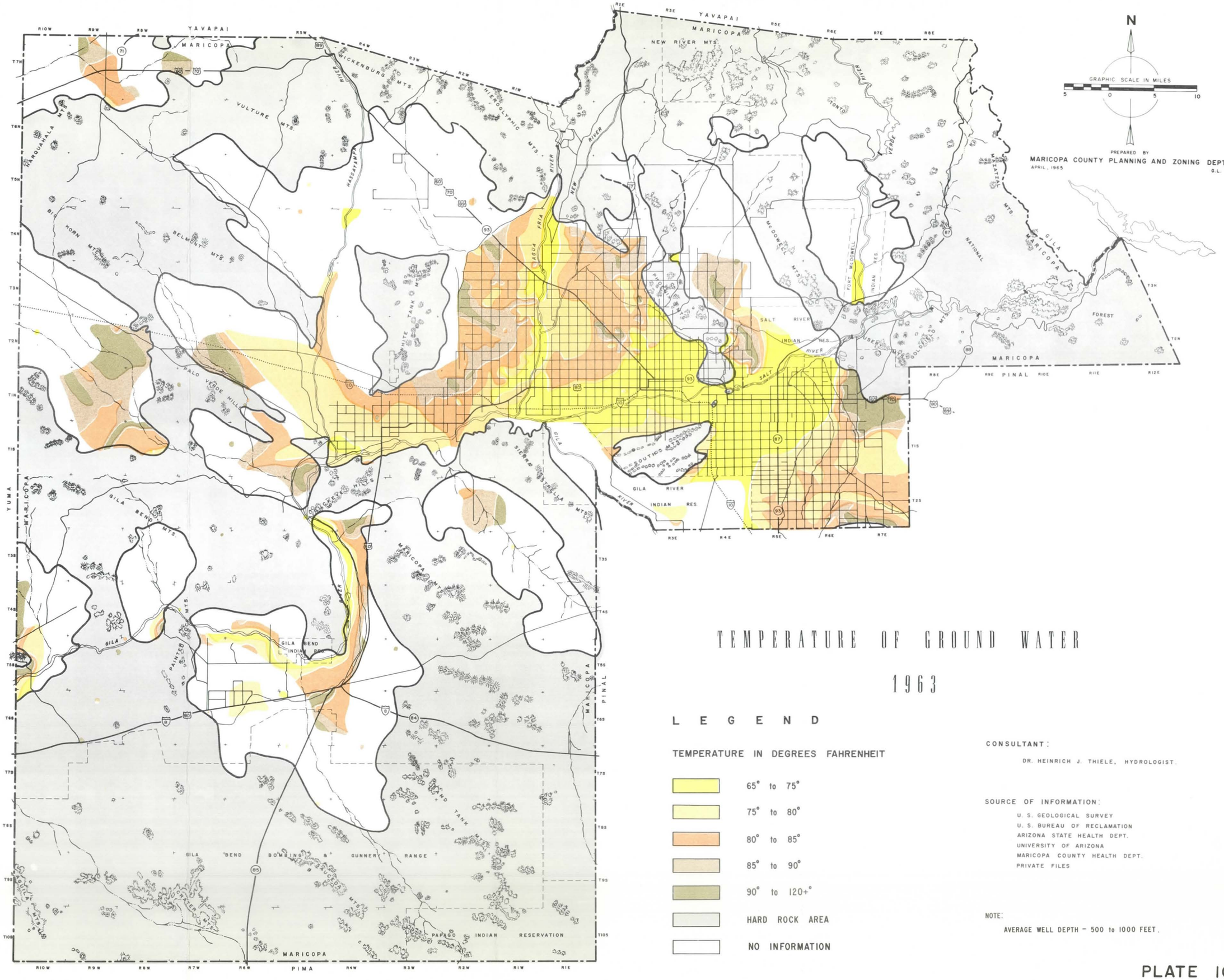
The recommended control limits of fluorides are related to average daily air temperatures (see Table 19.) Fluorides in concentrations greater than two times optimum constitute grounds for the rejection of the supply, for the following reasons: Young children during the period of formation of their permanent teeth, are greatly affected by the fluoride content of the water. Too little fluoride leads to a higher incidence of dental cavities. Too high a fluoride content leads to fluorosis, a condition in which the teeth become discolored, mottled or brittle. The greater the deviation from the optimum level, in either direction, the more pronounced is the effect. Mild-mottling will occur from 1.5-2.5 ppm of fluoride content; above 2.5, brown stains on the teeth are in evidence; and above 4.0 ppm deep pits will appear where the enamel surfaces have been virtually destroyed.

Some of the water supplies need fluoridation treatment, i.e., fluorides have to be added. Others need defluoridation.

TABLE 19

SUGGESTED UPPER LIMITS OF FLUORIDE IN DRINKING WATER

Annual Average of Maximum Daily Air Temperature °F	Recommended Control Limits Fluoride Concentrations in ppm		
	Lower	Optimum	Upper
50.0 - 53.7	0.9	1.2	1.7
53.8 - 58.3	0.8	1.1	1.5
58.4 - 63.8	0.8	1.0	1.3
63.9 - 70.6	0.7	0.9	1.2
70.7 - 79.2	0.7	0.8	1.0
79.3 - 90.5	0.6	0.7	0.8



TEMPERATURE OF GROUND WATER

1963

L E G E N D

TEMPERATURE IN DEGREES FAHRENHEIT

- 65° to 75°
- 75° to 80°
- 80° to 85°
- 85° to 90°
- 90° to 120+°
- HARD ROCK AREA
- NO INFORMATION

CONSULTANT:

DR. HEINRICH J. THIELE, HYDROLOGIST.

SOURCE OF INFORMATION:

U. S. GEOLOGICAL SURVEY
U. S. BUREAU OF RECLAMATION
ARIZONA STATE HEALTH DEPT.
UNIVERSITY OF ARIZONA
MARICOPA COUNTY HEALTH DEPT.
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NOTE:

AVERAGE WELL DEPTH – 500 to 1000 FEET.

PLATE 10

Not covered in this report are nitrates and nitrites which are rated among the poisonous ingredients dissolved in water. Excess contents of these constituents sometimes cause irritation of the mucous linings of the gastro intestinal tract and bladder. High sodium content in drinking water may be harmful to persons suffering from cardiac, renal, and circulatory diseases.

Ground Water Temperature

Ground water temperature reflects to a certain degree the micro-climate of an area, which has an effect on the severity of frosts. For this reason Plate 10 may be of interest to farmers and home owners; also industrial water users who are considering locating in the Phoenix Metropolitan Area may pay attention to this map. Table 18 shows the temperature range of the Phoenix and Mesa Basin from 66° to 114°F. The largest warm water zones exist east of Mesa, with temperatures from 90° to 112°F, supplying hot baths in the Buckhorn health resorts.

The temperatures of the ground waters shown in Plate 10 have been measured in the water pumped from various wells in the area, which are normally above 500 feet in depth. Because of the geothermal gradient, ground water temperature increases 1°F for each 64 feet of depth. Plate 10 does not represent a ground temperature in one certain depth; it offers a good approximation of temperature distribution in ground waters pumped from underground storage.

2. The Outlying Ground Water Basins

This section discusses the ground water conditions as of spring 1963 in the ground water basins located to the west of the Phoenix Metropolitan Area in the following sequence: Waterman Wash Basin; Gila Bend Basin; Dendora Valley; Palomas Plains; McMullen Valley; Harquahala Basin; Tonopah Valley; Arlington Valley; Lower Hassayampa Valley.

Information available from these basins is not very adequate, and various assumptions had to be made in order to construct their portion of Plates 5 to 10. For these basin areas, the data presented have to be considered as estimates.

Following the procedure used for the Phoenix Metropolitan Area, Tables 20 and 21 set forth the extremes of the observed water-table data, annual decline rates, and the range and averages of observed water-quality information.

Table 20 displays four major water-table decline areas: Waterman Wash Basin; the northern part of the Gila Bend Basin; the area east of McMullen Valley and the Harquahala Basin. The highest decline rates per annum have been recorded for the Harquahala Basin, which seems to have reached its peak of irrigation agriculture.

Table 21 shows dissolved solids contents below 1,000 ppm in the northern Palomas Plains; McMullen Valley; Harquahala Basin; Tonopah Valley; and Lower Hassayampa Valley. The average fluoride content is considerably above the maximum limit of 1.4 ppm in all of these ground water basins, with the exception of the Lower Hassayampa Valley (0.5 ppm).

Because of the irregular distribution and the relatively small number of wells in the basin areas, little information is available as to the hydrological character of the alluvial fill. No estimate is available as to the amount of water stored in the ground water reservoir, with the exception of the Waterman Wash Basin.

Waterman Wash Basin

During the year 1963, a total of 65,000 acre-feet of ground water was pumped, in order to irrigate 11,300 acres (1963 Agricultural Map of the University of Arizona), as shown in Plate 2. The depth to water in this agricultural area ranged from 215 to 356 feet, and the rates of annual water-table decline from 2 to 10 per year. The water quality is as follows:

Quality Criteria	Quality Range	Quality Average
Total Soluble Salts	598 - 2,100 ppm	1,100 ppm
Total Hardness	40 - 416 ppm	130 ppm
Fluorides	0.3 - 7.3 ppm	4.5 ppm
Ground Water Temperatures	81 - 96°F	89°F

Total soluble salts and fluorides mostly are above acceptable limits.

The U.S. Geological Survey (Water Study Paper 1669-F) has studied the Waterman Wash Basin and found that 15 percent of the pumpage used for irrigation is being recharged as return flow to ground water and that the total loss of ground water during the 11-year period 1952 through 1962 was 366,000 acre-feet while 480,000 acre-feet had been pumped. These figures take into account any possible annual recharge of the ground water basin from all sources. In the center of the irrigated area, the water table declined more than 120 feet in the period 1952-1962.

TABLE 20

GROUND WATER BASINS OUTSIDE THE PHOENIX METROPOLITAN AREA
Water Tables, Spring 1963, Rates of Annual Decline and Forecasts 1970 and 1980
(Assuming Continuous Past Decline Rates)

Area		Depth to Water Spring 1963 Feet	Rate of Annual Water Table Decline Feet	Depth to Water Forecast 1970 Feet	Depth to Water Forecast 1980 Feet
Waterman Wash Basin		215-356	2.0-10.0	277-385	365-454
Gila Bend Basin	(North	110-329	2.0- 9.7	140-364	204-414
	(South	24-252	0- 4.2	24-261	24-274
Dendora Valley		30- 60	0.7- 1.8	35- 65	40- 78
Palomas Plains	(North	76-244	0- 1.0	77-253	78-263
	(South	30- 76	0- 1.0	30- 77	30- 78
McMullen Valley		406-484	2.6- 9.0	424-547	450-637
Harquahala Basin		31-390	0.9-22.0	200-525	350-730
Tonopah Valley		64-245	0.3- 7.7	70-273	75-313
Arlington Valley		63-200	0.6- 3.0	88-215	120-235
Lower Hassayampa Valley		30-480	0- 1.3	30-490	30-500

TABLE 21

GROUND WATER BASINS OUTSIDE THE PHOENIX METROPOLITAN AREA
Quality of Ground Water 1963

Values Shown in Parts Per Million

Area	Total Dissolved Solids		Total Hardness		Fluorides		Temperatures	
	Range ppm	Average ppm	Range ppm	Average ppm	Range ppm	Average ppm	Range °F	Average °F
Waterman Wash Basin	528- 2,100	1100	40- 416	130	0.3- 7.3	4.5	81- 96	89
Gila Bend Basin	335-14,500	1900	96-4,860	490	0.2- 8.0	2.9	66-119	82
Dendora Valley	2,111- 7,235	3200	191-2,537	1,450	1.0- 6.8	3.9	79-95	85
Palomas Plains	526- 700	660	37- 60	56	1.1- 6.4	4.5	78-106	95
McMullen Valley	189- 420	300	48- 206	85	0.6-15.0	2.8	80- 95	86
Harquahala Basin	417- 864	600	45- 160	100	0.6-32.0	3.2	76-102	90
Tonopah Valley	253- 971	480	36- 138	65	2.4-10.0	6.0	79-129	96
Arlington Valley	343- 4,901	1200	60-1,635	130	0.4-10.0	2.3	73- 95	87
Lower Hassayampa Valley	198- 347	260	51- 160	140	0.2- 1.1	0.5	76- 82	78

Table 22 reveals a total ground water storage of 9,500,000 acre-feet to 1,000 feet depth in the Waterman Wash Basin.

The cone of depression formed by ground water pumpage obviously does not recover, since the formations have a relatively high silt content.

Gila Bend Basin

The present ground water withdrawals in the basin are considerably greater than recharge, and the deficiency is balanced by drawing from ground water storage. In 1953, the loss from ground water storage averaged 115,000 acre-feet per year, during which time 173,000 acre-feet were pumped to irrigate 32,000 acres. During the years 1959-1960, pumpage reached maximum values of 250,000 acre-feet per year, causing an annual ground water loss in the order of 190,000 acre-feet. The heavy water-table decline and the increasing ground water salinity caused a reduction of pumpage to 170,000 acre-feet in 1962. Of the 53,500 cultivated acres only about 42,000 were irrigated during the year 1963. One hundred twenty-five wells were in operation. A minor quantity of surface water is used for irrigation, averaging 10,000 to 12,000 acre-feet per year and originating in the Gila River. Depth to water in the spring of 1963 was as great as 329 feet in the northern part of the basin (Rainbow Valley). Practically all of the waters in the basin exceed the suggested limits for total solids, hardness and fluorides:

Quality Criteria	Quality Range	Quality Average
Total Soluble Salts	333 - 14,500 ppm	1,900 ppm
Total Hardness	191 - 4,860 ppm	490 ppm
Fluorides	0.2 - 8.0 ppm	2.9 ppm
Ground Water Temperatures	66 - 119°F	85°F

Dendora Valley

In 1963, 1,870 acres in Dendora Valley were cultivated. This is a relatively small basin, and past ground water pumpage has been in the order of 6,000-7,000 acre-feet per year. Water-table decline rates are below 2 feet per year, and the greatest depth to water was 60 feet in the spring of 1963. The water exceeds the suggested limits of chemicals in drinking water as set forth on page 32.

TABLE 22

COMPUTATION OF AVERAGE SPECIFIC YIELD AND VOLUME OF RECOVERABLE WATER
WATERMAN WASH BASIN

Depth Zone (feet)	Estimated Specific Yield (Percent)	Footage of Logs Examined	Percent of Total Footage	Weighted Average Specific Yield (Percent)	Average Thick-ness of Zone (feet)	Area (acres)	Total Volume of Sediments (acre-feet)	Volume of Recoverable Water (acre-feet)
300* to 500	15	2,390	69.3	10.4				
300* to 500	5	1,060	30.7	1.5				
		SUM 3,450	100.0	11.9	200	120,000	24,000,000	2,800,000
500 to 800	15	4,963	76.3	11.4				
500 to 800	5	1,547	23.7	1.2				
		SUM 6,510	100.0	12.6	300	120,000	36,000,000	4,500,000
800 to 1000	15	1,243	42.0	6.3				
800 to 1000	5	1,713	58.0	2.9				
		SUM 2,956	100.0	9.2	200	120,000	24,000,000	2,200,000
300 to 1000				11.3	700	120,000	84,000,000	9,500,000

Source: U.S. Geological Survey Water Supply Paper 1669-F, Table 7, 1963

* Water level is at 300 foot depth.

Quality Criteria	Quality Range	Quality Average
Total Soluble Salts	2,111 - 7,235 ppm	3,200 ppm
Total Hardness	191 - 2,537 ppm	1,450 ppm
Fluorides	1.0 - 6.8 ppm	3.9 ppm
Ground Water Temperatures	79 - 95 °F	85 °F

Palomas Plains Basin

This basin is located in western Maricopa and eastern Yuma Counties. The U.S. Geological Survey estimated the quantity of ground water in storage in the first hundred feet below the water table to be about 5 million acre-feet (Arizona Water Resources Report No. 4). During 1962, about 4,000 acres were irrigated with 15,000 acre-feet of ground water. Greatest depth to water was 244 feet and the highest water-table decline was 1 foot per year, in the spring of 1963. The valley has a total extent of 1,225 square miles.

In the southern part of the area, in the Gila River Valley, ground water is highly mineralized. Massive tuff deposits underlie the alluvial fill. Wells have been drilled successfully penetrating these deposits and they have found a deep-seated fresh-water aquifer in volcanic rocks at about 1,000 feet depth which extends in this depth to the north underneath the Palomas Plains.

North of the Gila River zone with highly mineralized waters, the water characteristics are:

Quality Criteria	Quality Range	Quality Average
Total Soluble Salts	543 - 700 ppm	660 ppm
Total Hardness	37 - 60 ppm	56 ppm
Fluorides	1.1 - 6.4 ppm	4.5 ppm
Ground Water Temperatures	78 - 106°F	95°F

Fluorides generally are exceeding the recommended limits.

The lava flows and volcanic conglomerates underlying valley fill and tuff layers contain freshwater locally of higher temperatures (106°F). The old health resort and spa of Agua Caliente originated here because of the warm water, observed first as a spring flow in the foothills of the Agua Caliente Mountains.

McMullen Valley

Located in the northwest corner of Maricopa and in Yavapai and Yuma Counties is McMullen Valley, 48 miles long and 15 miles wide. During 1953 about 6,000 acre-feet of ground water were pumped for irrigation. In 1957 the pumpage increased to 21,000 acre-feet, and in 1962 to 75,000, for the irrigation of 18,000 acres. The greatest depth to water was 484 feet near Aguila and the water-table decline rate 9.0 feet per year, in spring 1963. The water quality critieria are as follows:

Quality Criteria	Quality Range	Quality Average
Total Soluble Salts	189 - 400 ppm	300 ppm
Total Hardness	48 - 206 ppm	85 ppm
Fluorides	0.6 - 15.0 ppm	2.8 ppm
Ground Water Temperatures	80 - 93°F	86°F

Fluorides are too high for domestic use.

Harquahala Basin

About one-third of the basin is situated in Maricopa County, the remainder in Yuma County. The agricultural development, mostly within the southern part of the basin in Maricopa County started in 1952-1953, when numerous wells were drilled. Ground water pumpage increased from 20,000 acre-feet in 1953 to about 100,000 acre-feet in 1959 and 200,000 acre-feet in 1963, irrigating an estimated 33,000 acres from 105 irrigation wells.

The increasing rate of ground water withdrawal has caused ground water table declines of as much as 200 feet since 1954, and a depth to water up to 390 feet in the spring of 1963. The annual water-table decline rate of 22 feet per year, occurring underneath a relatively large area, probably will cause a reduction in agricultural acreage within a short span of years. An additional increase in decline-rates can be expected, since the water-yielding capacity of the alluvial fill decreases with depth. The water quality is good for agricultural purposes; for domestic use the high fluoride content is in most places detrimental:

Quality Criteria	Quality Range	Quality Average
Total Soluble Salts	417 - 864 ppm	600 ppm
Total Hardness	45 - 160 ppm	100 ppm
Fluorides	0.6 - 32.0 ppm	3.2 ppm
Ground Water Temperatures	76 - 102°F	90°F

Tonopah, Arlington and Lower Hassayampa Valleys

These three areas are connected with one another. According to information received from the University of Arizona, Department of Agricultural Economics, the following agricultural land was cultivated in 1963:

Tonopah Valley	6,920 acres
Arlington Valley	6,540 acres
Lower Hassayampa Valley	850 acres

The total water use in the Tonopah Valley was reported by the U.S. Geological Survey as 35,000 acre-feet in 1962. Water consumption rates in the other two basin areas have not been reported separately. Water use in the Tonopah Valley was as high as 55,000 acre-feet in 1960, and has decreased considerably, probably caused by falling water tables with a decline rate up to 7.0 feet per year and a depth to water of 245 feet in 1963. The comparable values of Arlington Valley are 200 feet depth to water and 3.0 feet decline for spring 1963.

The average water quality information of the three basin areas may be condensed as follows (also see Table 20):

Ground Water Basin	Chemical Constituents (ppm) Average Values			
	Total Soluble Salts	Total Hardness	Fluorides	Ground Water Temperature
Tonopah Valley	480	65	6.0	96°F
Arlington Valley	1,200	130	2.3	87
Lower Hassayampa Valley	260	140	0.5	78

The total salt content is very high in Arlington Valley; and fluorides are excessive in the Tonopah and Arlington Valleys.

Tonopah is one of the oldest spa and health resort areas in Arizona because of hot ground water resources with temperatures up to 129°F. It might be predicted that Tonopah has a good possibility of being revived as a health-resort after the projected Interstate Highway No. 10 has been constructed.

VI. FUTURE WATER NEEDS AND POPULATION POTENTIAL OF THE PHOENIX METROPOLITAN AREA

Availability of water is one of the major governing factors in urban land use in the Phoenix Metropolitan Area. So far it is obvious that there has never been an attempt to answer the question of how much water is available that can be used for future development. The present study sheds light on some of the pressing issues which are significant far beyond those of a water resources study only. Dependability of supply is the prime requisite for all water users, especially business and industry. The purpose of this part of the study is to determine the water resource utilization potential in relation to population growth and water requirements.

1. The Population Potential

E. Whittacker made a most interesting study in 1953: "The Theory of the Relationship of Resources Development to Economic Development." Based on earlier discussions of this phenomenon, he depicted a typical cycle of population increase in the West as a flattened "S". The curve supposes that some new development has expanded resources and therefore has stimulated a surge forward in population. But gradually the surge loses its momentum and in due course growth ceases. Whittacker points out that it seems apparent that the population-resource connection operates as cause and effect in both directions. The present population growth rate of the Phoenix Metropolitan Area is relatively high, so that lack of sufficient water might present a limitation. It cannot be denied from an economic standpoint that a certain maldistribution of water is in effect. Most likely, the need for water for all purposes will grow at a rate substantially faster than that of the population. This might be prevented, if the County would masterplan future land use, by analyzing area for area land utilization, water uses, water requirements and water availability. This concept might include the distribution of water utility companies within the County and their actual function. The aim is to define a future ultimate urban land use plan solidly based on dependable sources of water.

The extent of future expansion for each land use, the intensity of development and the direction and limits of growth influence water use, as well as recent trends in domestic consumption. Both are important and must be considered in determining the adequacy of any land use concept to meet future growth. A land development plan provides information on the amount of land that will be devoted to each purpose and how intensively it will be utilized through gradual development. From knowledge of how much water each individual use requires, the total consumed in the area can be computed.

Per Capita Water Use

Present water consumption and the continuous change in requirement during a certain period of the past have been studied (see Chapter IV: Trends in Water Consumption). However, it becomes evident that in order to study future demands today's standards of water usage are not entirely suitable for application to the expected growth in population and expansion of land uses in the Phoenix Metropolitan Area. With the information available it is difficult to make predictions as to the adequate changes that can be expected to take place in present day consumption figures. This should be kept in mind when using the forecasted per capita requirements for all nonagricultural purposes, presented in Table 23 and Chart 1.

It is anticipated, at this time, that the per capita water requirements will increase from 309 gpcd in 1963 to 335 gpcd in 1980.

Agricultural Water Use

It has been assumed that agricultural water use averages 4.84 acre-feet per acre and year. There do exist limits in water development. It might become obvious, after having studied this report, that expansion in water use can only come through transfer of water from one use to another, and not through development of additional uses which would increase the total water consumption.

Economic Limits in Water Development. There are cost limits to water development. Water is a limitation on irrigated crop production. M. M. Kelso has shown that, through its effects, it will have a significant impact on the County's economy (Arizona Academy 1964). A substantial percentage of the County's personal income still is created, directly and indirectly, through crop agriculture. The limiting water cost is a result of several factors: pumping

TABLE 23

WATER REQUIREMENTS FORECAST
Phoenix Metropolitan Area*

Year	Gallons Per Capita Per Day			Total
	Municipal Use	Urban Irrigation Use	All Other Nonagricultural Uses	
1963	192	67	50	309
1965	198	63	50	311
1970	213	53	50	316
1975	228	47	50	325
1980	243	42	50	335

*See also Chart 1.

cost per acre-foot; intensity of water application and crops grown; government acreage allotments; local water availability; and supply-demand-generated price relationships. There does not exist a fixed concept. It is a changing concept over time, depending on actual and anticipated cost-price technology relationships facing individual farmers and groups of farmers in a particular area of the County. However, the statement can be made that as the water table declines and the operating costs increase, the farming income will diminish and also that of farm-dependent business.

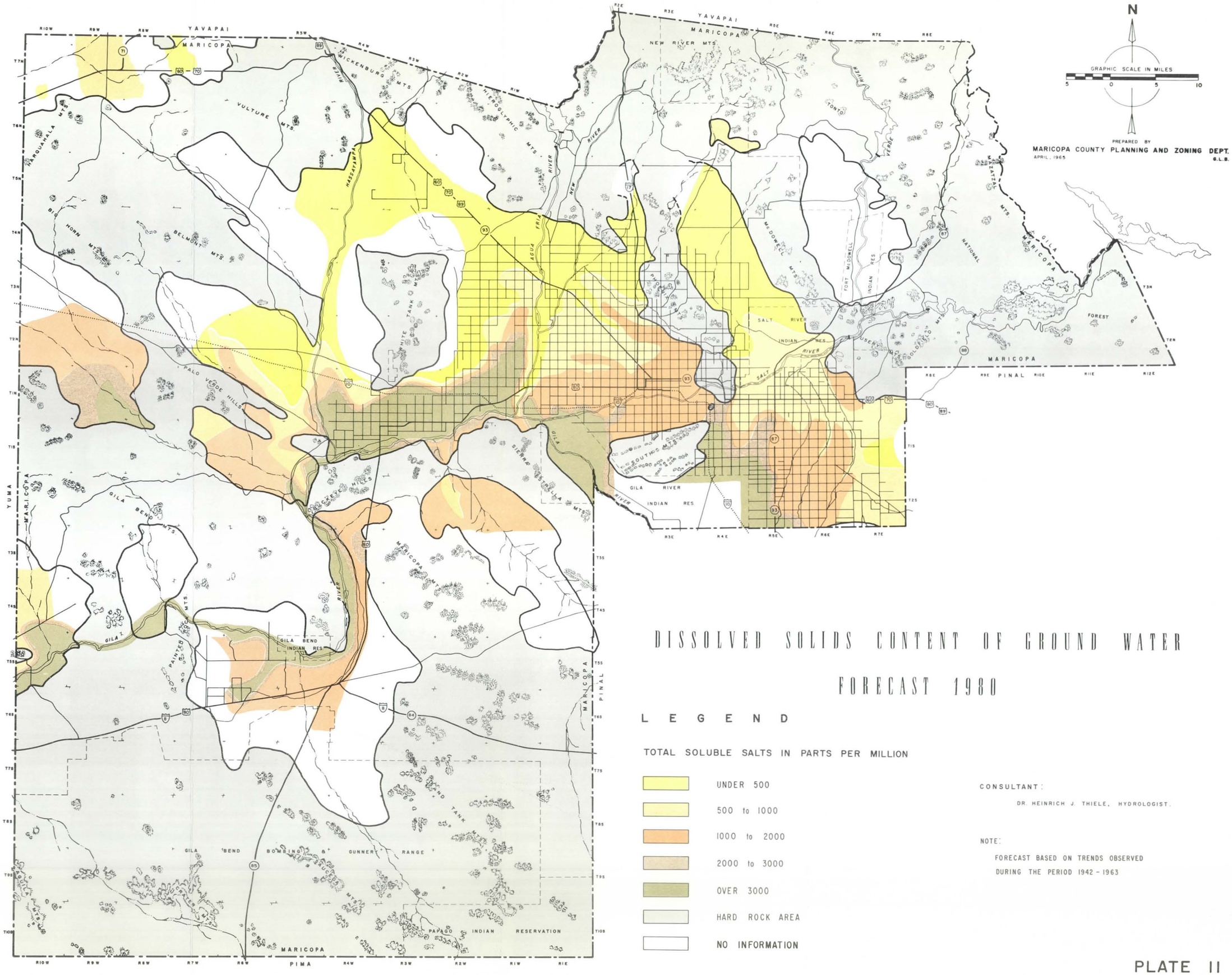
These consequences have not always been realized in farm investments in the past, neither by the farmer nor by the farm appraiser. At this time it still remains wishful thinking to raise the farm efficiency from 50 percent to an optimum of 70 percent - to offset the increasing production costs. This problem has not changed in its order of magnitude during the past 10 years, nor will it probably change in the next 15 years.

In Chapter IV it is shown that the economic limit of the used water resource is found in irrigation agriculture. Water used in any other sector of the County's economy other than agriculture, no matter whether the results are measured in dollars or employment, is vastly more productive. This limiting factor is mentioned to underline the fact that some estimate of the economic holding capacity of the land in the Phoenix Metropolitan Area is badly needed.

Manipulating Ground Water Storage for Maximum Utilization

It is obvious that people cannot be expected to change their life long habits without dire need, never minding the seriousness of the water problem. During the period 1953-1963, water tables have declined at a constant annual rate, and the total annual water use in the Phoenix Metropolitan Area was relatively constant. Accordingly, the principal objective in planning should be to manage the ground water reserve for long-range maximum utilization by keeping the decline rate of the past ten years constant, also in the future, at least for the coming ten years. This approach will give the necessary time to develop a balanced water-land use information program, based on a basin-wide concept.

In making projections of future water use it is essential to predict the areas where future water users are likely to be located. Questions arise as to the magnitude of the potential areas of water development, and as to the potential for effective utilization of the still remaining ground water reserves. Quality changes will set new area limits acceptable for



DISSOLVED SOLIDS CONTENT OF GROUND WATER

FORECAST 1980

LEGEND

TOTAL SOLUBLE SALTS IN PARTS PER MILLION

- UNDER 500
- 500 to 1000
- 1000 to 2000
- 2000 to 3000
- OVER 3000
- HARD ROCK AREA
- NO INFORMATION

CONSULTANT:

DR. HEINRICH J. THIELE, HYDROLOGIST.

NOTE:

FORECAST BASED ON TRENDS OBSERVED DURING THE PERIOD 1942 - 1963

PLATE II

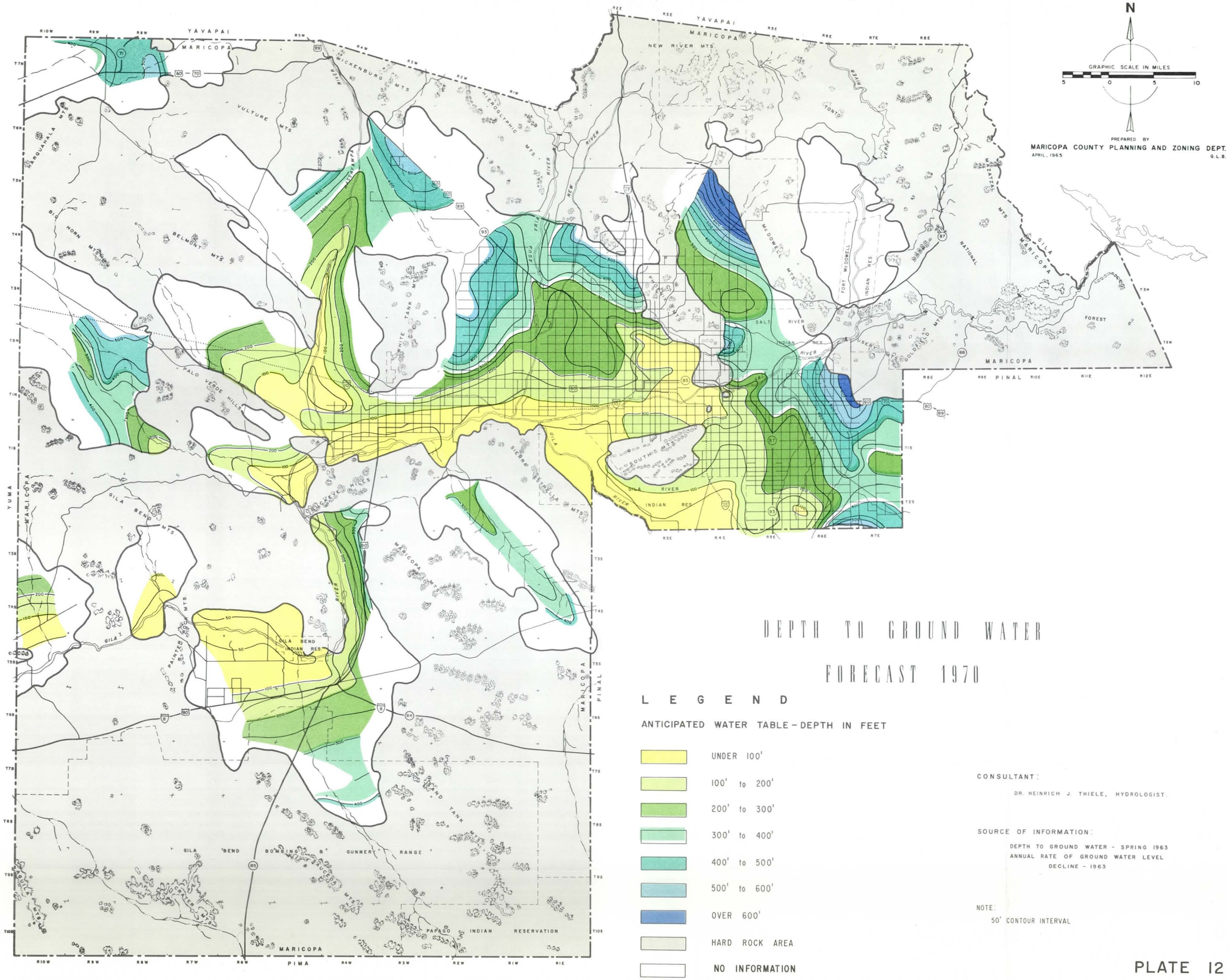
human consumption, as shown in Plate 11. Water supplies have to be allocated to certain areas assuring that water can be obtained there in the appropriate quantities and qualities, and for an acceptable price at the time when needed and for many years to come. It has been most revealing and unexpected that the water consumption of Buckeye was reduced to half that of the preceding year, after the water was demineralized and became more expensive (according to information obtained from the Town of Buckeye).

Time relations are surely of basic significance in ground water development forecasts. Depleting the remaining resources too far during the next ten years narrows and limits the opportunities to make adjustments that may be needed in the future. This means loss in flexibility. The same thinking holds true for the safety of long-term investments, or business operations, where water is directly or indirectly a critical limiting factor, such as agriculture, industry, power and gas lines or other business. In this sense, the present report is part of a reconnaissance survey.

Any plan should be flexible, so that it can be modified if future developments deviate from predictions which this present forecast indicates. A first essential is some forecast as to the future, because a plan to accommodate future demands for water must be founded upon some predictions, expressed or implied, as to future needs. It is the logical procedure to fit any future developments into the available water supply, by master planning the County's future development trends. Examples will be given later in this report.

Projections with Present Decline Rates Continued until 1980

The two depth-to-ground-water forecast maps for 1970 and 1980 (Plates 12 and 13) have been constructed and ground water fluctuation contours were drawn according to the average water table decline rate at each single point of observation. The areas enclosed by each contour were evaluated by planimeter and the computed average area between contours was multiplied by the contour interval to obtain the volume of change in the ground water reservoir between contours. The algebraic sum of the volumes between contours resulted in the total change in volume of the Phoenix and Mesa Basins, for each evaluated part of the two ground water reservoirs.



DEPTH TO GROUND WATER

FORECAST 1970

LEGEND

ANTICIPATED WATER TABLE - DEPTH IN FEET

- UNDER 100'
- 100' to 200'
- 200' to 300'
- 300' to 400'
- 400' to 500'
- 500' to 600'
- OVER 600'
- HARD ROCK AREA
- NO INFORMATION

CONSULTANT:

DR. HEINRICH J. THIELE, HYDROLOGIST.

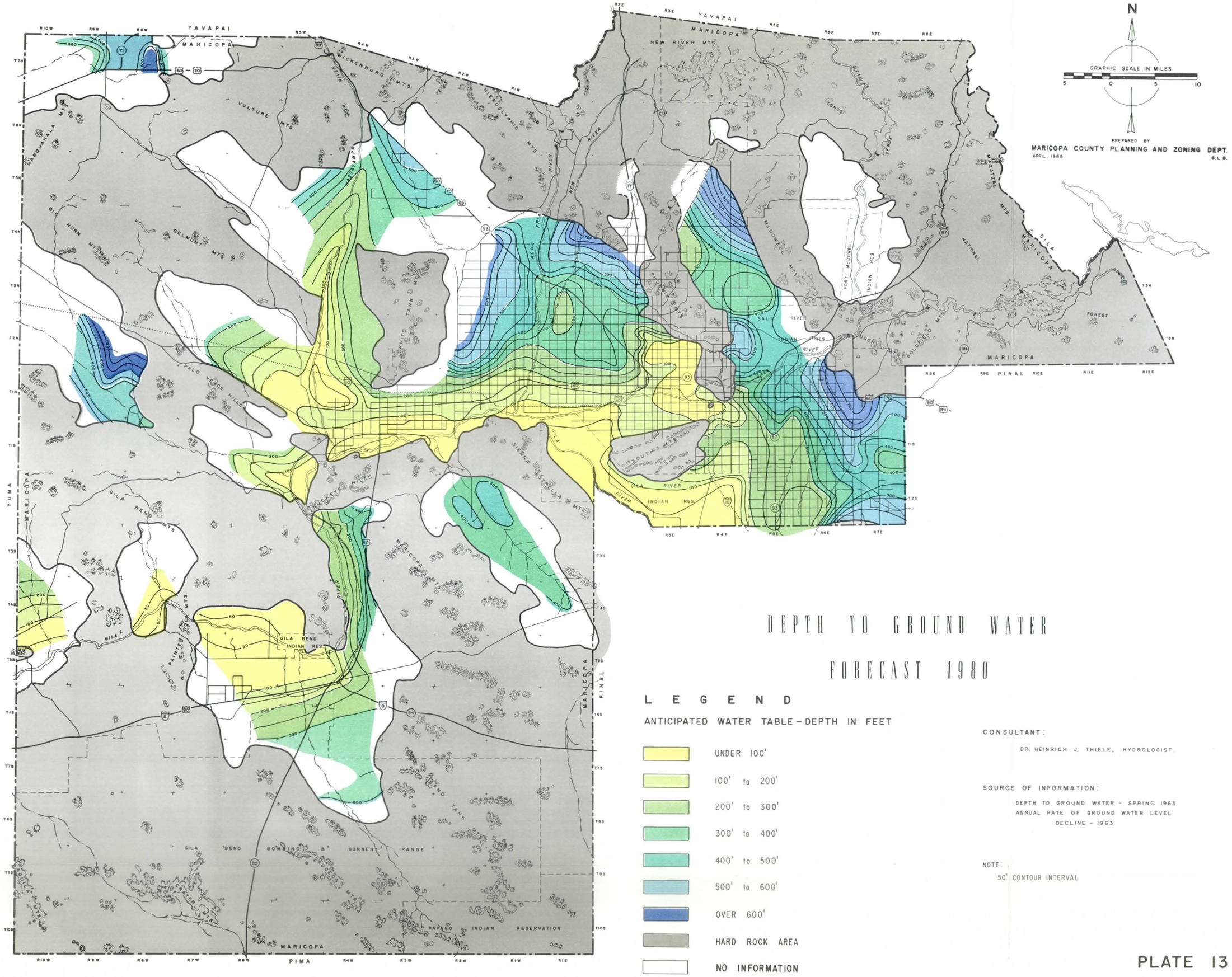
SOURCE OF INFORMATION:

DEPTH TO GROUND WATER - SPRING 1963
ANNUAL RATE OF GROUND WATER LEVEL DECLINE - 1963

NOTE:

50' CONTOUR INTERVAL

PLATE 12



DEPTH TO GROUND WATER

FORECAST 1980

LEGEND

ANTICIPATED WATER TABLE - DEPTH IN FEET

- UNDER 100'
- 100' to 200'
- 200' to 300'
- 300' to 400'
- 400' to 500'
- 500' to 600'
- OVER 600'
- HARD ROCK AREA
- NO INFORMATION

CONSULTANT:

DR. HEINRICH J. THIELE, HYDROLOGIST.

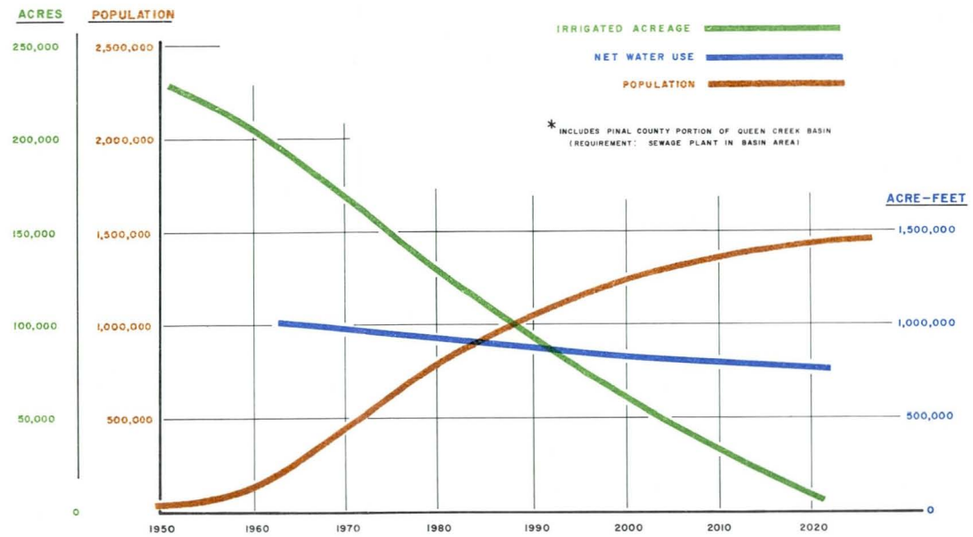
SOURCE OF INFORMATION:

DEPTH TO GROUND WATER - SPRING 1963
ANNUAL RATE OF GROUND WATER LEVEL DECLINE - 1963

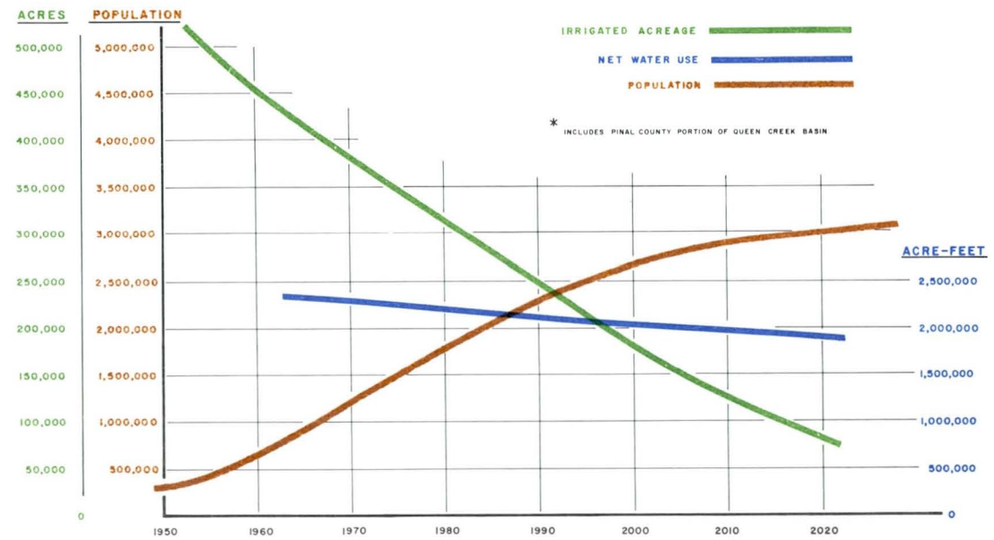
NOTE:

50' CONTOUR INTERVAL

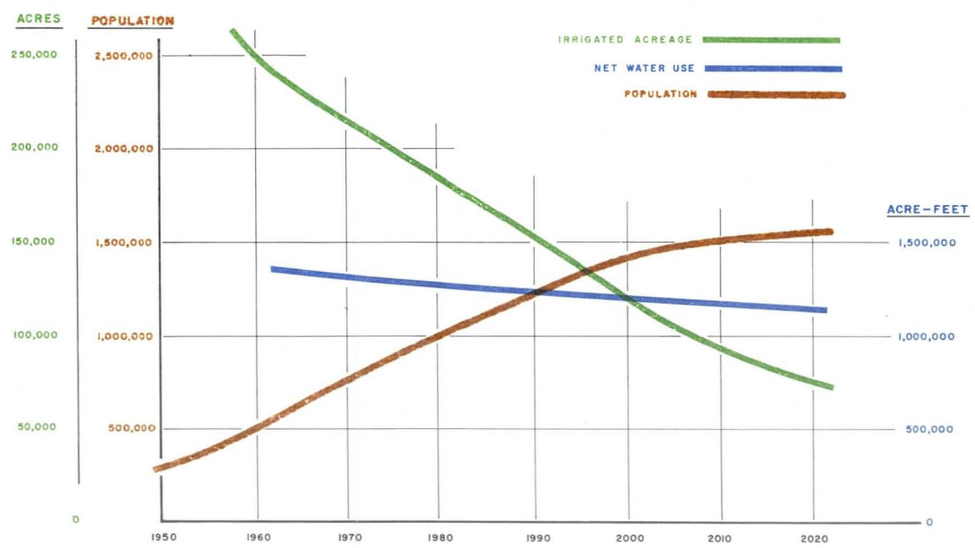
PLATE 13



MESA AREA (II)*



PHOENIX METROPOLITAN AREA (I & II)*



PHOENIX AREA (I)

GROWTH POTENTIAL OF THE PHOENIX METROPOLITAN AREA

CHART 7

Continuing discharge at a rate guaranteeing the further constant decline of the past years would empty the ground water reservoirs to 1,000 feet depth, under the assumptions made in Part V of this report in the following periods, starting in the spring of 1963:

Phoenix Basin	136 years
Mesa Basin	99 years

The detailed calculations are presented in Table 24. These theoretical assumptions have been made in order to provide some constructive operational planning basis.

Table 24 shows the quantity of ground water that can be depleted each year, in each one of the two basins, at continuous average water table decline rates of 6.0 feet in the Phoenix Basin and 7.0 feet in the Mesa Basin. An uninterrupted return-flow from all sources would be required, comparable to the 845,000 acre-feet per year of the period 1956-1963, or its replacement by importation of other water, to balance water supply and demand every year.

By 1980, the average depth to water in the Phoenix and Mesa Basins would be 288 feet and 429 feet, respectively. Under these assumptions, the quantity of water in storage would be progressively depleted.

The foregoing discussions are necessary steps for considering the utilization potential of the available water resources during the period 1963-1980, and beyond this period toward ultimate utilization. This enables the investigation of the two ground water reservoirs with flexible approaches. A possible one, an area-type study approach, is demonstrated in Chart 7.

Fundamental for the analytical approach is the concept that an entire ground water basin is to be considered as a unit, independent of the possibility that only certain portions of the basin might be operated. Discharge in acre-feet is plotted against time. The other two variables are the two consumers, agriculture and nonagriculture. The last two have to be balanced with the annual allowance. The summation of all water-using operations within the ground water reservoir or water supply area has to fit the basic assumptions, established for the concept of ultimate development. The projections of probable agricultural land uses and population growth rates depart from actual past trends observed during the period 1953-1963, if these are continued beyond 1980. Population forecasts have been made by Maricopa County Planning and Zoning Department, whose figures have been used. They are published in

TABLE 24

FORECAST OF WATER-TABLE DECLINE AND GROUND WATER DEPLETION 1963-1980
Phoenix Metropolitan Area

	I PHOENIX BASIN AREA						II MESA BASIN AREA						I & II PHOENIX METROPOLITAN AREA					
Year	Average Depth to Water	Basin Area Below Water Table (Acres)	Water Table Decline (Per Year)	Specific Yield (by Percent)	Ground Water Depletion Per Year (Acre-Feet)	Accumulative Depletion (Acre-Feet)	Average Depth to Water	Basin Area Below Water Table (Acres)	Water Table Decline (Per Year)	Specific Yield (by Percent)	Ground Water Depletion Per Year (Acre-Feet)	Accumulative Depletion (Acre-Feet)	Average Depth to Water	Basin Area Below Water Table (Acres)	Water Table Decline (Per Year)	Specific Yield (by Percent)	Ground Water Depletion Per Year (Acre-Feet)	Accumulative Depletion (Acre-Feet)
1963	186	497,000	6.0	0.2080	620,000	620,000	309	515,000	7.0	0.1920	693,000	693,000	248	1,012,000	6.48	0.2000	1,313,000	1,313,000
1964	192	495,580	6.0	0.2073	616,000	1,236,000	316	513,300	7.0	0.1911	687,000	1,380,000	254	1,008,880	6.48	0.1992	1,303,000	2,616,000
1965	198	494,150	6.0	0.2064	612,000	1,848,000	323	511,600	7.0	0.1902	681,000	2,061,000	261	1,005,750	6.48	0.1983	1,293,000	3,909,000
1966	204	492,720	6.0	0.2057	608,000	2,456,000	330	509,900	7.0	0.1893	676,000	2,737,000	267	1,002,620	6.48	0.1975	1,284,000	5,193,000
1967	210	491,290	6.0	0.2050	604,000	3,060,000	337	508,200	7.0	0.1884	671,000	3,408,000	274	999,490	6.48	0.1967	1,275,000	6,468,000
1968	216	489,860	6.0	0.2041	600,000	3,660,000	344	506,500	7.0	0.1877	666,000	4,074,000	280	996,360	6.48	0.1959	1,266,000	7,734,000
1969	222	488,430	6.0	0.2031	596,000	4,256,000	351	504,800	7.0	0.1869	661,000	4,735,000	287	993,230	6.48	0.1950	1,257,000	8,991,000
1970	228	487,000	6.0	0.2026	592,000	4,848,000	358	503,000	7.0	0.1858	656,000	5,391,000	293	990,000	6.48	0.1942	1,248,000	10,239,000
1971	234	485,300	6.0	0.2018	588,000	5,436,000	365	501,330	7.0	0.1850	650,000	6,041,000	300	986,630	6.48	0.1934	1,238,000	11,477,000
1972	240	483,600	6.0	0.2012	584,000	6,020,000	372	499,660	7.0	0.1840	644,000	6,685,000	306	983,260	6.48	0.1926	1,228,000	12,705,000
1973	246	481,900	6.0	0.2004	580,000	6,600,000	379	497,990	7.0	0.1830	638,000	7,323,000	313	979,890	6.48	0.1917	1,218,000	13,923,000
1974	252	480,200	6.0	0.1998	576,000	7,176,000	386	496,320	7.0	0.1820	632,000	7,955,000	319	976,520	6.48	0.1909	1,208,000	15,131,000
1975	258	478,500	6.0	0.1990	572,000	7,748,000	393	494,650	7.0	0.1812	627,000	8,582,000	326	973,150	6.48	0.1901	1,199,000	16,330,000
1976	264	476,800	6.0	0.1982	568,000	8,316,000	400	492,980	7.0	0.1804	622,000	9,204,000	332	969,780	6.48	0.1893	1,190,000	17,520,000
1977	270	475,100	6.0	0.1974	563,000	8,879,000	407	491,310	7.0	0.1795	617,000	9,821,000	339	966,410	6.48	0.1884	1,180,000	18,700,000
1978	276	473,400	6.0	0.1966	558,000	9,437,000	414	489,640	7.0	0.1786	612,000	10,433,000	345	963,040	6.48	0.1876	1,170,000	19,870,000
1979	282	471,700	6.0	0.1958	554,000	9,991,000	421	487,970	7.0	0.1778	607,000	11,040,000	352	959,670	6.48	0.1868	1,161,000	21,031,000
1980	288	470,000	6.0	0.1950	550,000	10,541,000	429	486,300	7.0	0.1770	602,000	11,642,000	358	956,300	6.48	0.1860	1,152,000	22,183,000
2000	408	441,000	6.0	0.1785	10,200,000	20,741,000	569	459,000	7.0	0.1585	11,110,000	22,752,000	488	900,000	6.48	0.1685	21,310,000	43,493,000
2020	528	422,000	6.0	0.1650	8,880,000	29,621,000	709	428,000	7.0	0.1410	9,305,000	32,057,000	617	850,000	6.48	0.1530	18,185,000	61,678,000
	1,000	359,000	6.0	0.1000	24,350,000	53,971,000	1,000	386,000	7.0	0.1000	14,280,000	46,337,000	1,000	745,000	6.48	0.1000	38,630,000	100,308,000

"A Part of the Comprehensive Plan for Maricopa County; Part II: Population Growth, Existing Land Use, Phoenix, 1964." In the long run, irrigation development and population growth are interdependent, one upon the other. Attention should be called to the fact that it is not so important to predict when the stage of initial full development (immediately before reaching ultimate development) will be reached, as it is to approximate the pattern of land use that is most likely to accompany that specific stage. It is essential however to note the changes in the different types of land utilization in terms of their percentages of the total area irrigated and in relation to the passage of time, at least approximately. Some assumptions, therefore, with respect to the rate of potential population growth are essential as a primary step in projecting the agricultural pattern.

Tables 25 and 26 disclose the details of the calculations which serve for the construction of Chart 7.

Tables and charts are based on the two basin areas, Phoenix and Mesa Basins. The summation of the comparable basin values establishes the water needs of the Phoenix Metropolitan Area as a whole.* If this area's population were to increase from 815,000 persons in 1963 to 1,800,000 in 1980, the irrigated acreage would have to decline from 430,055 to 315,000 acres to maintain the annual rate of decline. The total water quantity required at delivery points would be less in 1980 than in 1963: 2,202,000 compared to 2,363,000 acre-feet, since the storage capacity of the two basins for the same thickness of water-filled material declines with depth. Using consistent assumptions, the forecasts also unfold the initial full development stage of 3 million people around the year 2020 with declining agriculture, and the ultimate development stage of 3.2 million people using 1.8 million acre feet of water per year and practically no agriculture left in the Phoenix Metropolitan Area. Salt River Project and Central Arizona Project, together with return-flow of treated waste water, should be able to supply this volume of water indefinitely. The ground water reserve itself will be touched in times of great need only, for instance in years of surface water shortage. The ultimate development stage should establish the long-term planning goal.

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*See Table 27

TABLE 25

FORECAST OF URBAN AND ALL OTHER NONAGRICULTURAL WATER REQUIREMENTS
1963-1980

	I PHOENIX BASIN AREA			II MESA BASIN AREA			I & II PHOENIX METROPOLITAN AREA		
Year	Population	Total Use		Population	Total Use		Population	Total Use	
		gpcd*	Acre-feet/ Year		gpcd*	Acre-feet/ Year		gpcd*	Acre-feet/ Year
1963	590,000	309	204,000	225,000	309	78,000	815,000	309	282,000
1964	614,117	310	213,000	258,824	310	90,000	872,941	310	303,000
1965	638,235	311	222,000	292,647	311	102,000	930,882	311	324,000
1966	662,353	312	231,000	326,471	312	114,000	988,824	312	345,000
1967	686,471	313	240,000	360,294	313	126,000	1,046,765	313	366,000
1968	710,588	314	249,500	394,118	314	138,500	1,104,706	314	388,000
1969	734,706	315	259,000	427,941	315	151,000	1,162,647	315	410,000
1970	758,824	316	268,500	461,765	316	163,500	1,220,589	316	432,000
1971	782,941	317.5	278,000	495,588	317.5	176,000	1,278,529	317.5	454,000
1972	807,059	319	288,000	529,412	319	189,000	1,336,471	319	477,000
1973	831,177	321	298,500	563,235	321	202,500	1,394,412	321	501,000
1974	855,294	323	309,000	597,059	323	216,000	1,452,353	323	525,500
1975	879,412	325	320,000	630,882	325	229,500	1,510,294	325	549,000
1976	903,530	327	331,000	664,706	327	243,000	1,568,236	327	574,000
1977	927,647	329	342,000	698,529	329	257,000	1,626,176	329	599,000
1978	951,765	331	353,000	732,353	331	271,000	1,684,118	331	624,000
1979	975,883	333	364,000	766,176	333	285,500	1,742,059	333	649,000
1980	1,000,000	335	375,000	800,000	335	300,000	1,800,000	335	675,000
2000	1,420,000	338	617,000	1,240,000	388	539,000	2,660,000	388	1,156,000

* Gallons per capita per day.

TABLE 26

FORECAST OF AGRICULTURAL REQUIREMENTS
1963-1980

Year	I PHOENIX BASIN AREA		II MESA BASIN AREA		I & II PHOENIX METROPOLITAN AREA	
	Total Acreage	Agricultural[1] Water Use (Acre-Feet)	Total Acreage	Agricultural[1] Water Use (Acre-Feet)	Total Acreage	Agricultural[1] Water Use (Acre-Feet)
1963	235,790	1,140,500	194,265	940,500	430,055	2,081,000
1964	233,000	1,127,500	191,000	922,500	424,000	2,050,000
1965	230,000	1,114,500	187,000	904,500	417,000	2,019,000
1966	227,000	1,101,500	183,000	887,500	411,000	1,989,000
1967	225,000	1,088,500	180,000	870,500	405,000	1,959,000
1968	222,000	1,075,500	176,000	853,000	398,000	1,928,000
1969	219,000	1,061,500	173,000	835,500	392,000	1,897,000
1970	216,000	1,048,000	170,000	818,000	386,000	1,866,000
1971	213,000	1,034,500	166,000	800,500	379,000	1,835,000
1972	210,000	1,020,500	162,000	781,500	372,000	1,802,000
1973	207,000	1,006,000	158,000	762,000	365,000	1,768,000
1974	204,000	991,500	154,000	742,500	358,000	1,734,000
1975	201,000	976,500	150,000	723,000	351,000	1,699,500
1976	198,000	961,500	146,000	704,500	344,000	1,666,000
1977	195,000	945,500	142,000	685,500	337,000	1,631,000
1978	192,000	929,500	138,000	666,500	330,000	1,596,000
1979	189,000	914,500	133,000	647,000	322,000	1,561,500
1980	186,000	899,500	129,000	627,500	315,000	1,527,000
2000	120,500	583,000	69,800	293,000	181,000	876,000
2020	74,800	363,000	8,300	40,000	83,000	402,000

(1) Based on 4.84 acre-feet of water per year for each acre of irrigated agricultural land.

TABLE 27

FORECAST OF TOTAL WATER REQUIREMENTS

Year	I PHOENIX BASIN AREA				II MESA BASIN AREA				I & II PHOENIX METROPOLITAN AREA			
	Total Acreage	Agricultural[1] Water Use (Acre-Feet)	Nonagricultural Water Use (Acre-Feet)	Total Water Use (Acre-Feet)	Total Acreage	Agricultural[1] Water Use (Acre-Feet)	Nonagricultural Water Use (Acre-Feet)	Total Water Use (Acre-Feet)	Total Acreage	Agricultural[1] Water Use (Acre-Feet)	Nonagricultural Water Use (Acre-Feet)	Total Water Use (Acre-Feet)
1963	235,790	1,140,500	204,000	1,344,500	194,265	940,500	78,000	1,018,500	430,055	2,081,000	282,000	2,363,000
1964	233,000	1,127,500	213,000	1,340,500	191,000	922,500	90,000	1,012,500	424,000	2,050,000	303,000	2,353,000
1965	230,000	1,114,500	222,000	1,336,500	187,000	904,500	102,000	1,006,500	417,000	2,019,000	324,000	2,343,000
1966	227,000	1,101,500	231,000	1,332,500	183,000	887,500	114,000	1,001,500	411,000	1,989,000	345,000	2,334,000
1967	225,000	1,088,500	240,000	1,328,500	180,000	870,500	126,000	996,500	405,000	1,959,000	366,000	2,325,000
1968	222,000	1,075,500	249,000	1,324,500	176,000	853,000	138,500	991,500	398,000	1,928,000	388,000	2,316,000
1969	219,000	1,061,500	259,000	1,320,500	173,000	835,500	151,000	986,500	392,000	1,897,000	410,000	2,307,000
1970	216,000	1,048,000	268,500	1,316,500	170,000	818,000	163,500	981,500	386,000	1,866,000	432,000	2,298,000
1971	213,000	1,034,500	278,000	1,312,500	166,000	800,500	176,000	976,500	379,000	1,835,000	454,000	2,289,000
1972	210,000	1,020,500	288,000	1,308,500	162,000	781,500	189,000	970,500	372,000	1,802,000	477,000	2,279,000
1973	207,000	1,006,000	298,500	1,304,500	158,000	762,000	202,500	964,500	365,000	1,768,000	501,000	2,269,000
1974	204,000	991,500	309,000	1,300,500	154,000	742,500	216,000	958,500	358,000	1,734,000	525,000	2,259,000
1975	201,000	976,500	320,000	1,296,500	150,000	723,000	229,500	952,500	351,000	1,699,500	549,500	2,249,000
1976	198,000	961,500	331,000	1,292,500	146,000	704,500	243,000	947,500	344,000	1,666,000	574,000	2,240,000
1977	195,000	945,500	342,000	1,288,500	142,000	685,500	257,000	942,500	337,000	1,631,000	599,000	2,230,000
1978	192,000	929,500	353,000	1,282,500	138,000	666,500	271,000	937,500	330,000	1,596,000	624,000	2,220,000
1979	189,000	914,500	364,000	1,278,500	133,000	647,000	285,500	932,500	322,000	1,561,500	649,500	2,211,000
1980	186,000	899,500	375,000	1,274,500	129,000	627,500	300,000	927,500	315,000	1,527,000	675,000	2,202,000
2000	120,500	583,000	617,000	1,200,000	69,800	293,000	539,000	832,000	181,000	876,000	1,156,000	2,032,000
2020	74,800	363,000	780,000	1,142,000	8,300	40,000	720,000	760,000	83,000	402,000	1,500,000	1,902,000

(1) Based on 4.84 acre-feet of water per year for each acre of irrigated agricultural land.

2. Augmenting the Available Water Supply

The 2,202,000 acre-feet at points of diversion (1963 water use) will not be available from the present surface water sources alone by about 1980, when return flows from seepage and irrigation will have been drastically reduced. N. Wollman concludes that if the Southwest is to share in projected population and economic growth, one or more of the following adjustments in the projections for 1980 must take place:

(1) An increase in water supply by increase in precipitation, increase in importation or desalinization;

(2) An increase in efficiency of water use beyond that which is anticipated;

(3) A reduction in heavy water-depleting uses in order to allow fulfillment of other uses. (Senate Select Committee on National Water Resources, U.S. Congress, 1959-60).

Central Arizona Project

The Colorado River offers the most readily available source of water from which to augment the supply of the Phoenix Metropolitan Area. It is assumed that the average canal side delivery of Colorado River water via Central Arizona Project will be for:

Agricultural irrigation	814,000 acre-feet per year
Municipal and Industrial Supply	256,000 acre-feet per year

It is planned to deliver, from the quantity last mentioned, 100,000 acre-feet to the City of Tucson at the end of a 50-year period. This delivery plan covers all of the Central Arizona Project Area in Maricopa, Pinal and Pima Counties. However, subsequent modifications may be expected after later determinations are made on distribution to various areas of need. Water delivery can scarcely be expected before 1980.

Ground Water Recharge - Flood Waters

The Flood Control District of Maricopa County has under study proposed artificial ground water recharge from flood runoffs for various parts of Maricopa County. The proposed recharge facilities fall into 2 categories. The first group are facilities to handle controlled flood runoff from detention basins providing a means of disposing of flood water; for instance, recharge pits are considered in Southeastern Maricopa County at the following locations:

(a) Upper Queen Creek Recharge area, in Sec. 21, and E 1/3 of Sec. 20, T2S, R8E;

(b) Upper Salt River recharge area, a strip 300 feet wide and 2 miles long on the left bank of the Salt River;

(c) Lower Queen Creek recharge area, between Roosevelt Canal and Queen Creek in Secs. 10, 11, 15 and 22, T2S, R6E;

(d) Salt River Mountains recharge area, SW corner of Sec. 21, T2S, R3E.

The Whitlow Dam on Queen Creek is a first step in this direction to collect and store the flood runoff needed.

Ground Water Recharge - Treated Waste Water

The use of treated sewage effluent for recharge is feasible. A metropolitan area has large quantities of effluent available which, with proper treatment, can provide supplies for industry, parks, golf course, or ground water recharge. Sewage is nothing else but polluted water, H_2O. Undesirable matter can be technically removed so that the remaining product may have any desired degree of purity. The Maricopa County Flood Control District deliberates secondary proposed recharge facilities for handling treated waste water, such as domestic and industrail sewage effluent, irrigation tail end water and part of the undetained flood runoff, for instance at the following locations:

(a) Mesa recharge area
recharge pit at the north-central edge of Sec. 31, T1N, R5E;
recharge pit in the NE corner of NW 1/4 of Sec. 4, T1S, R5E;

(b) Chandler recharge area, recharge shafts west of Chandler.

While the idea of purifying sewage is downgraded from an aesthetic viewpoint, it provides too much promise as a future water resource to allow passing it up without a thorough examination. The 1980 population of the Phoenix Metropolitan area probably will require a total of 675,000 acre-feet of water. Fifty percent of the used water might be sewage effluent, i.e. 337,500 acre-feet. This emphasizes the magnitude of the availability of a resource which can be developed with little pumping and no long-distance transmission lines.

The City of Phoenix has long-range plans to care for the domestic and industrial water demands of the Phoenix Metropolitan Area through the year 2000. The 91st Avenue Sewage Treatment Plant will have a projected final future capacity of 240 million gallons a day or about 270,000 acre-feet a year. The plant is located in the Gila River Valley, toward Buckeye, and as planned would discharge all the treated sewage effluents at the lower end of the Phoenix Basin. So far, no plans have been made to return at least a part of this outflow to the aquifer.

At this point, it is necessary to go one step further toward ultimate water use for about 3,200,000 people, with an annual water consumption of 1,800,000 acre-feet. The expected sewage flow volume might be in the order of 900,000 acre-feet per year. By this time, the average water table in the Mesa Basin may be deeper than 800 feet and approach 1,000 feet, i.e., provided that the sewage effluent of 450,000 acre-feet per year from the Mesa Basin is allowed to leave the basin, and not to be returned after treatment to ground water storage. A treatment plant in the lower end of the Phoenix Basin does not help the ground water conservation within the Mesa Basin. This deserves to be studied in detail. The transportation of the sewage effluent out of the Mesa Basin might, on the long run, endanger the existence of its water source.

Economical factors probably are in favor of operating a central sewage plant. On the other hand, it might be more economical to recharge and store all the imported Colorado River water in underground storage of the Mesa Basin, instead of Maxwell Lake.

Undoubtedly, there are numerous factors which enter into a water-reuse program in addition to water need, which include advancement in treatment methods; quality of resources; regulatory principles conducive to sewage development; and above all the securing of the proper support necessary for effective legislation and financial support to make water reuse a planned overall program.

Reduction of Evaporation - Salt, Verde and Agua Fria Rivers Surface Water Reservoirs

Evaporation losses from open water surfaces are tremendous, in the order of 6 to 7 feet per year, i. e., 6 to 7 acre-feet per acre of water surface of reservoirs on the Salt, Verde and Agua Fria Rivers, and also on the open canals and ditches. Monomolecular layers added to water surfaces have saved, on smaller surface water storage areas, up to 40 percent of the previous losses by evaporation. It may be expected that chemical compounds creating more

resistent films will be developed which will help to save substantially the stored runoff from the watersheds in the surface-water reservoirs, and to augment surface water delivery to the Phoenix Metropolitan Area.

Better Watershed Management to Increase Yields from Precipitation

In 1964, an agreement was signed between the U.S. Forest Service and the Salt River Project to rehabilitate the Salt and Verde watersheds, some 6 million acres, during a period of 25 years, and to spend some $75,000,000 in federal and Project funds. It is hoped to restore or even to improve the original effective precipitation of 12 percent which has been decreased now to 5.6 percent. The first contracts have already been let.

Demineralization of Saline Waters

The water demineralization plant of Buckeye has been operating since September 8, 1962, without interruption, to produce an acceptable domestic supply from brackish water sources.

TABLE 28

BRACKISH WATER DEMINERALIZATION AT BUCKEYE
Phoenix Metropolitan Area

Chemical Component	The Feed Water ppm	The Product Water ppm
Sodium	630	142
Calcium	116	17.6
Magnesium	15	1.7
Total Hardness	354	51
Chlorides	1,054	220
Sulfates	155	60
Bicarbonates	78	27
Nitrates	9	-
Fluorides	2	-
Total Dissolved Solids	2,076	484
PH	8.1	7.1

It can be concluded that demineralization of brackish water by electrodialysis is economically feasible in locations where other sources of water requiring less costly treatment are not available. The treatment costs for the full installation load of 233,000,000 gallons per year are 33 cents per 1,000 gallons. The actual load is 48 percent of capacity with a price of 50.9 cents per 1,000 gallons. It can be foreseen that demineralization will play an increasing role in the water supply of the Phoenix Metropolitan Area, as the remaining ground water solution will be getting more and more concentrated in the future.

Demineralization of brackish waters within the basins of the Phoenix Metropolitan Area is not a means of water saving and augmenting the available supply, as it originates from the same common ground water source. It is a popular misconception to assume that brackish water originates from a different source. As the remaining basin ground water reserve is getting more concentrated, demineralization will have to be used also within the Phoenix and Mesa Basins.

Saline water conversion will eventually provide an important part to increase our local freshwater supplies. Arizona is close enough to the Gulf of California to bring desalted ocean water to the Phoenix Metropolitan Area, after its population has grown to such dimensions that it can support the expense involved. Arrangements might be made with Mexico, to build a desalinization plant either in Mexico or in the United States at the end of supply canals originating in the Gulf, and pump the demineralized ocean water to the Phoenix Metropolitan Area. The expenses per 1,000 gallons, appear at this time to be unsurmountable ($1.00 per 1,000 gallons, excluding transportation), but it might be accepted gladly in a time of dire need. Irrigated agriculture within the Phoenix Metropolitan Area might be maintained into the future, if demineralized ocean water in sufficient quantities for all nonagriculture uses would reach this area before the end of this century. The same concept holds true if additional surface water would be imported in large quantities from the Pacific Northwest.

Since the annual return-recharge to ground water is being reduced by canal lining, higher irrigation efficiency, and other methods, one of several approaches might be used successfully to supplement the Phoenix Metropolitan Area's available water supply.

3. Water Resources Management and its Effects Upon Planning in Maricopa County

Every problem of regional growth involves a problem of land and water use. In essence, each building permit affects water resources management. Extending this thought far into the future leads to the perplexing question: "What will be the situation 30 years from now? Which measures will have to be taken?"

Water resources management should be coordinated with regional planning. Water availability sets the limits to the possible social and economic regional development. So far, Maricopa County has sponsored two basic studies: 1) "The Economy of Maricopa County, 1965-1980", by Western Management Consultants, published in 1965, which reviews past and present economy, and forecasts development trends for one specific economic model up to the year 1980; 2) This present water resources study which assesses present water supplies and demands, and for a generalized model, projects future water demands up to and beyond 1980.

An objective still to be accomplished is to coordinate and to interpret the economic and water resource data in terms of water requirements for the future, and to translate these requirements into a broad water resources management program. In order to reason logically from the present economic and water situation to a plan best suited for the year 2000, it is possible to use a basic methodology applied by Battelle Memorial Institute to the three Michigan Counties of Clinton, Eaton and Ingham.*

Alternative Long-Range Plans for the Tri-County Region, Michigan

The Michigan study parallels a situation as it exists in Maricopa County: Water availability limits regional growth and the task of the aforementioned research effort was to provide a technical-economic report that would serve as a guide or base for broad policy decisions relating to three alternate patterns of regional development and their implications on water resources management. The Michigan study involved the following major steps:

1. Review of the past and present economy of the region;

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* Battelle Memorial Institute: Alternative Long Range Water Use Plans for the Tri-County Region, Michigan - A Technical-Economic Report to Tri-County Regional Planning Commission, August 1963.

2. Assessment of present water supplies and demands of the region;

3. Selection of an economic goal on which subsequent water plans might be based;

4. Projection of future water demands to the year 2000;

5. Identification of three alternative economic development goals for the region to the year 2000.

6. Consideration of three alternative geographic patterns of future economic development as they may dictate future geographic patterns for water requirements;

7. Development of specific plans for water resources management and water-related facilities for each of the three alternative geographic patterns of economic growth;

8. Evaluation of the alternative plans and selection of the pattern presenting the best approach.

The three alternative physical approaches were: (a) Planned sprawl patterns of growth; (b) Satellite cities patterns; (c) Corridor patterns of growth. The aforementioned were based on: (1) An optimistic growth rate of population and industrial growth; (2) Limitations of their water resources.

The Planning Commission, in cooperation with the consultants, prepared "first-estimate" land-use maps according to the three postulated patterns of growth, following generally accepted urban-development concepts. The economic development goals were projected to the years 1970, 1980 and 2000, representing reasonable alternative economic growth patterns for each of the three approaches. These were later translated into water requirements to the year 2000 for residential, industrial, commercial, agricultural and public use purposes, for each one of the three selected models. The projected water requirements then formed the basis for projected water and sewage treatment facilities and their estimated costs.

For the benefit of the public, a committee analyzed, evaluated and interpreted the three alternative plans. It was found that a selected program has a far-reaching effect on the sequence of precedence of construction and other measures of importance. The Tri-County report concludes:

"(1) There are significant differences in the costs for developing water, sewage and other water-related facilities, depending on the geographic pattern of growth in the region;

"(2) Use of water resources of the region will require close coordination among the political units of the region. The planning and subsequent operation of water and sewage facilities will become increasingly interrelated, as the region develops;

"(3) The best understanding of water and sewage problems and alternative solutions can be obtained by continuous efforts of the County Planning Commission;

"(4) The establishment of a Metropolitan or Regional Water Authority may be required to implement the plan for water and water-related facilities and to manage the water resources;

"(5) There appear to exist legal precedents for implementing any or all portions of the selected plan."

The sequence of thought presented in the preceding program is not new. It confirms the author's knowledge and experience in this field and stresses the fact that regional, social and economic, improvement programs cannot be pursued without a far-reaching management program of the regional water resources. The Tri-County Regional Study was conducted without a preceding ground water evaluation, such as the subject report of Maricopa County. The U.S. Geological Survey states, in Water Supply Paper 1800, page 421: "Ground water information is adequate for only a few small areas. Much additional information is needed to encourage development in unpumped areas and to serve as a firm basis for maximum development in currently pumped areas." (Michigan, Lower Peninsula, Southwestern Part)

The cost of the technical-economic study of the three Michigan Counties is trivial when compared with the benefits that, without any doubt, can be derived from its results. Conditions indicate that it would be beneficial for Maricopa County to undertake a similar study. Programming the best possible solution of regional, social, and economic development would assure industry that it would be advantageous to locate in the Phoenix Metropolitan Area.

The Salt River Project in cooperation with the U.S. Bureau of Reclamation, both mentioned previously, have always worked on region-wide planning aspects. Without their efforts and operations the Phoenix Metropolitan Area probably would not have advanced to its present degree of development. An even closer coordination of water resources management with the physical planning process of various geographical areas in the county appears highly advisable in the future.

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