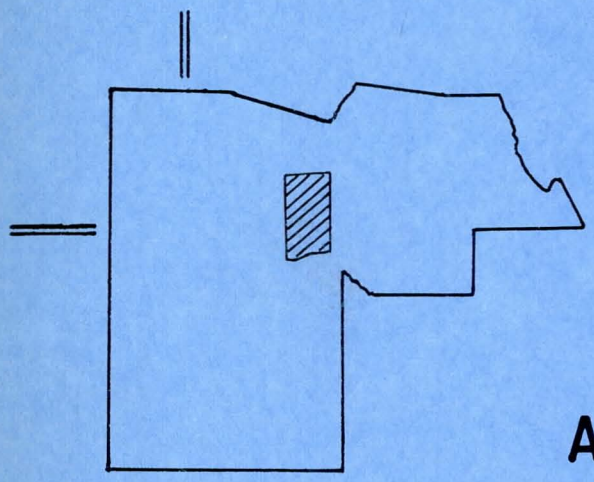

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A REPORT UPON
WEST CENTRAL MARICOPA COUNTY, ARIZONA

Volume I

A Study of Physical Environmental Factors as a Basis for Land Use Planning

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A REPORT UPON

WEST CENTRAL MARICOPA COUNTY, ARIZONA

Volume I

A Study of Physical Environmental Factors

as a Basis for Land Use Planning

Prepared by

THE MARICOPA COUNTY PLANNING AND ZONING DEPARTMENT
111 South Third Avenue
Phoenix, Arizona 85003

October 1971

Price: Two Dollars & Fifty Cents

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Lester J. Ringenberg, Planner
Harold Buell, Chief Cartographer
Catherine Morrow, Cartographer
Cleo Patterson, Secretary

"Conservation is getting nowhere because it is incompatible with our Abrahamic concept of land. We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect. There is no other way for land to survive the impact of mechanized man, nor for us to reap from it the esthetic harvest it is capable, under science, or contributing to culture."

- Aldo Leopold, "A Sand County Almanac," 1948

* * * * * * *

"The basic causes of our environmental troubles are complex and deeply imbedded. They include: our past tendency to emphasize quantitative growth at the expense of qualitative growth; the failure of our economy to provide full accounting for the social costs of environmental pollution; the failure to take environmental factors into account as a normal and necessary part of our planning and decision-making; the inadequacy of our institutions for dealing with problems that cut across traditional political boundaries; our dependence on conveniences, without regard for their impact on the environment; and more fundamentally, our failure to perceive the environment as a totality and to understand and to recognize the fundamental interdependence of all its parts, including man himself."

- Richard Nixon, "President's Message to the Congress of the United States," August, 1970.

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PREFACE

On October 1, 1970, the Maricopa County Planning and Zoning Commission by unanimous vote approved a resolution for a planning study to be prepared by the Planning and Zoning Department for a western portion of Maricopa County. It was agreed that the area of study should be bounded generally by the Beardsley Canal on the north, 91st Avenue on the east, the Salt and Gila Rivers on the south and the White Tank Mountains on the west.

As a basis for the land use planning, which is discussed in Volume II, this report is concerned with various physical environmental conditions and elements such as geology, climate, vegetation, soils and water resources. As in many areas of the Southwest, the quantity and quality of present and future water resources are of such importance as to merit extensive and continuing study; for this reason a major portion of this report is devoted to water resources.

This study, Volume I, was prepared by Lester J. Ringenberg of the Advance Planning staff. Mr. Ringenberg has a bachelors degree from the University of Nebraska with a major in Geology, and has done graduate study in Political Science at Arizona State University. Resource material was drawn from various governmental and private agencies as listed in the Bibliography. In addition, preliminary drafts of this report were reviewed by many persons and agencies and we herewith acknowledge the review and very helpful suggestions contributed by the following: Bert W. Thomsen, U.S. Geological Survey; Milo S. James and Chris P. Williams, U.S. Department of Agriculture, Soil Conservation Service; Wesley E. Steiner and Phillip Briggs, Arizona Water Commission; C.A. Pugh, U.S. Department of the Interior, Bureau of Reclamation; Joseph J. Weinstein, Maricopa County Health Department; H. Shipley and Dick Juetten, Salt River Project; and Henry Raymond and Dick Yancy, Maricopa County Municipal Water Conservation District Number 1.

Mr. Ringenberg is responsible for the technical analyses and conclusions contained in this report.

Donald W. Hutton

WEST CENTRAL MARICOPA COUNTY, ARIZONA

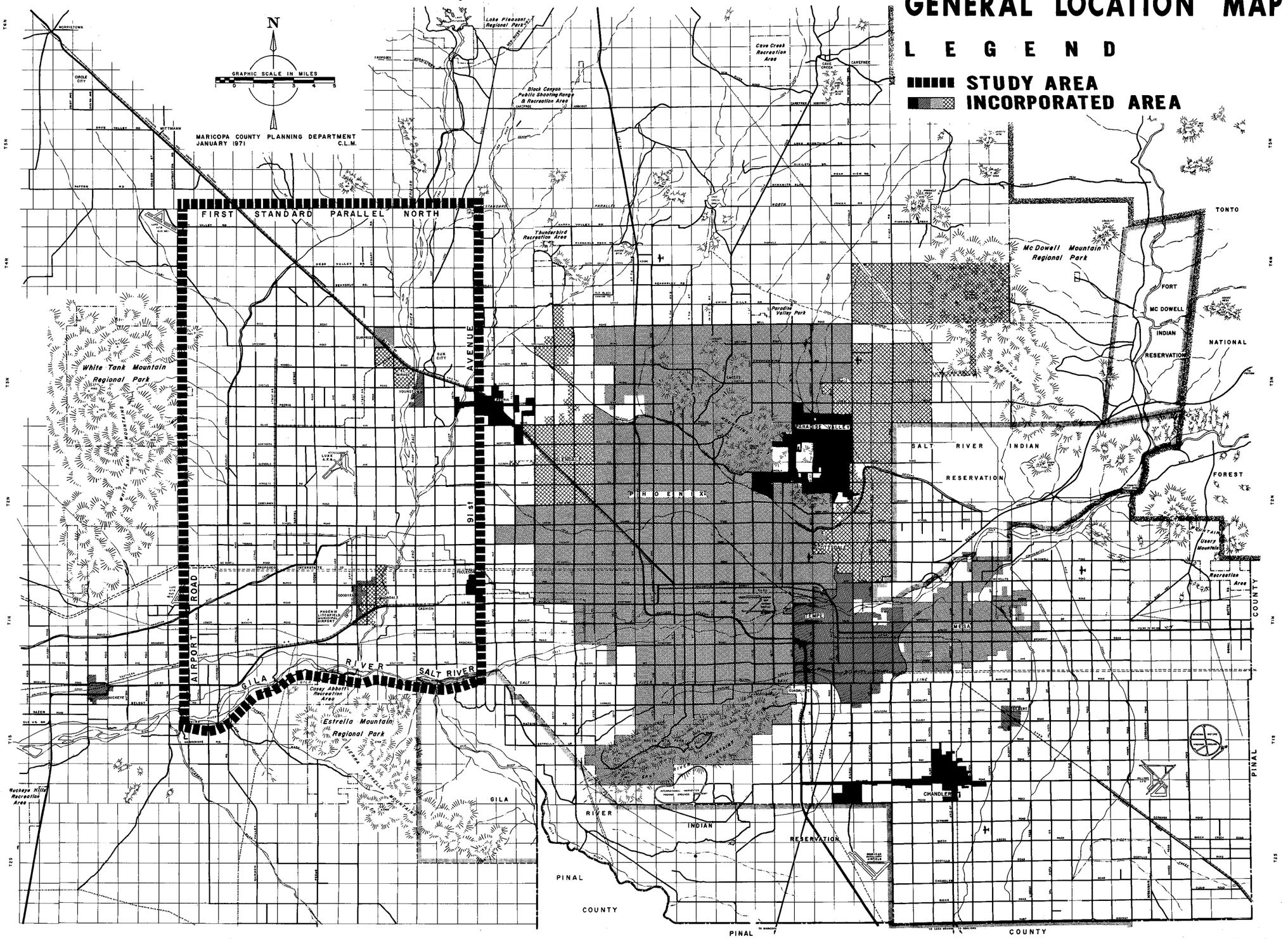


PLATE 1

CHAPTER I

INTRODUCTION

This report is a systematic evaluation of the physical environmental conditions that affect or influence land use planning for the geographical area "West Central Maricopa County, Arizona" shown on Plate 1. There are a total of 342 square miles or approximately 220,000 acres within the total Study Area.

Following sections contain brief comments on the present-day importance of environmental planning, an evaluation of the geology, climate, topography and soils and, since water resources are of such a critical nature in the Study Area as well as in the entire Southwest, separate chapters are devoted to various aspects of this particular problem. Included are discussions and analyses of the following: 1. Surface water; including drainage areas, flooding and flood control. 2. Subsurface or groundwater resources. 3. Other water sources including irrigation imports and irrigation recharge. 4. Potential future water sources from the Central Arizona Project and wastewater effluents. 5. Groundwater and surface water quality.

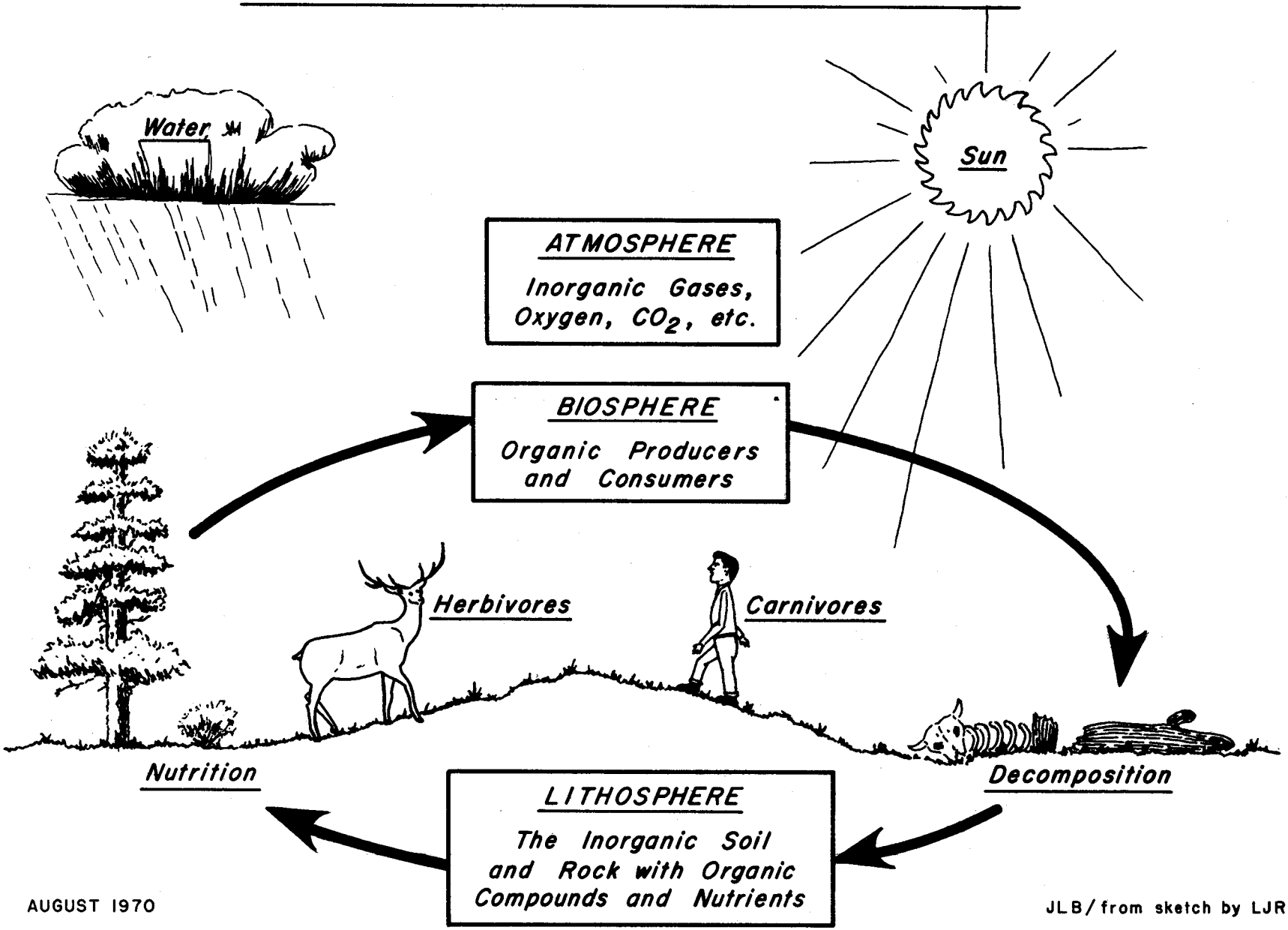
Finally, the entire physical setting and total natural resources are summarized and some suggestions for present and future improvements of the local environment are proposed herein and in Volume II.

Considerable latitude has been taken in using material from secondary sources. It should become obvious, however, that a great deal of additional investigation and research is needed in some phases of the physical conditions of the Study Area and the surrounding environs.

Since a good deal of the material in this report is of a scientific nature, a glossary of terms is included in the Appendix.

PLATE 2

"AN ECOSYSTEM"



AUGUST 1970

JLB/from sketch by LJR

CHAPTER II

ENVIRONMENTAL PLANNING

Planning, simply defined, is a process wherein (1) data are analyzed and explained and, (2) a program is formulated to bring about a desired result. A study of environmental conditions has always been an important basis for land use planning. However, increasing pollution and desecration of our natural resources have created a general public concern with these matters that has had its impact upon national, state and local legislatures throughout the country. There are now federal requirements that ecological studies be made in conjunction with federal grant applications for various types of public improvements. For example, the Corps of Engineers has recently been directed to consider the effects of any proposed project in terms of "navigation, fish and wildlife, water quality, economics, conservation, esthetics, recreation, water supply, flood damage prevention, ecosystems and the needs and welfare of the people".

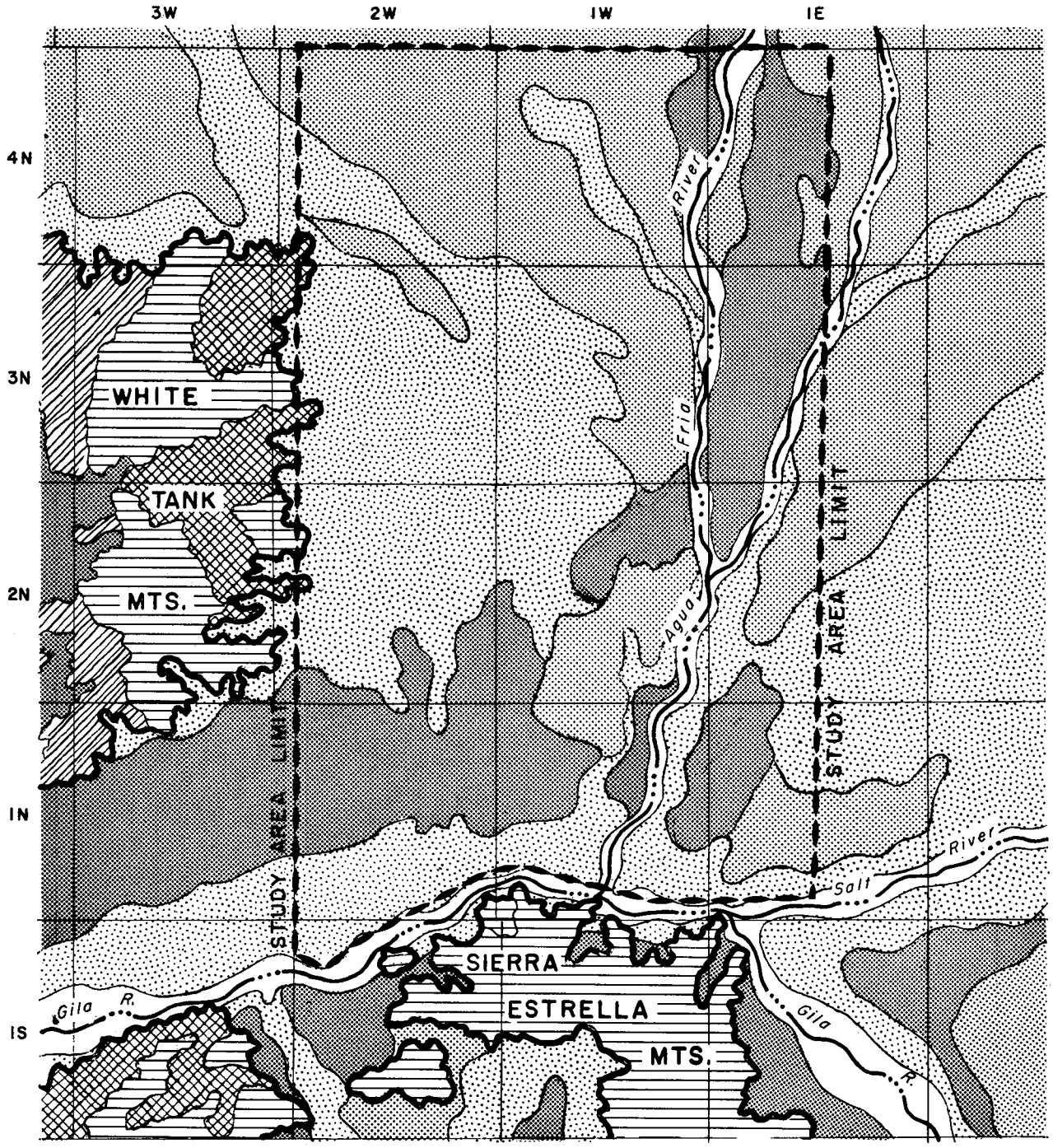
It has been proposed that we are passing from the "Age of Space" to the "Dawn of the Age of Ecology". From the academic point of view, the study of ecology is an old and respected subject. The word itself is derived from the Greek combining forms of oikos, meaning house and logos meaning study. Ecology, according to Websters Dictionary, is a branch of science "dealing with the interrelationships of organisms and their environments". To better understand ecology, however, an attempt must be made to understand what the specialist means by his concept of an "ecosystem". Simply defined, an ecosystem is the sum total of all of the living (organic) and non-living (inorganic) parts that support a chain or cycle of life within a given area. Plate 2 illustrates graphically the relationship of the essential parts in a typical cycle.

All the processes in the cycle, although illustrated simply, are actually quite complex. Interruptions in the cycle, either natural or man-made, cause the degeneration of our environment. Two illustrations of the relationship of man as an organism to the ecosystem might serve to point out problems common to metropolitan areas. Animals in order to live, water in order to be pure, and factories in order to operate, all consume oxygen. In turn, all the above emit carbon dioxide which, again in turn, is used by plants in the process of photosynthesis. As more open land is used by people and by factories, more oxygen is required, while, at the same time, more vegetation is being removed thereby reducing the amount of oxygen produced.

A second illustration concerns water. The topsoil, where properly maintained, acts as a giant sponge in the absorption of rainwater. Not only is the water stored in the upper layers for the use of plants but some quantities may reach lower layers to recharge subsurface aquifers. An increase in paving and rooftops not only reduces the amount of area available for absorption but it also increases the amount of quick runoff. Although flood control structures may limit upstream flows, sheet-flooding of local areas remains a critical problem.

It is obvious, then, that our environment depends upon the "natural things" that are present: the rocks and soils that make up the land, the variations in climate and the amounts and effects of water. An analysis of these factors as specifically affecting the study area is contained in the following chapters.

WEST CENTRAL MARICOPA COUNTY, ARIZONA



GEOLOGY AND SOILS

ADAPTED FROM: GEOLOGIC MAPS OF ARIZONA BUREAU OF MINES (1959) AND GENERAL SOIL MAP, MARICOPA COUNTY (SCS, 1969)

LEGEND

GEOLOGICAL OUTCROPS

- POST-LARAMIDE GRANITE AND RELATED CRYSTALLINE ROCKS
- PRECAMBRIAN GRANITE GNEISS
- PRECAMBRIAN GRANITE AND RELATED CRYSTALLINE ROCKS

SOILS

- A-DEEP SANDY LOAM AND LOAMY SOILS
- B-SOIL WITH LIMY CLAY LOAM SUBSOILS
- C-LIMY LOAMY SOILS AND LIMY GRAVELLY SOILS

PLATE 3

CHAPTER III

THE PHYSICAL SETTING

Geology

The sum total of the geology of an area depends upon the age and types of rocks; the intensity of alteration and deformation; and the effects of erosion and sedimentation. Throughout geologic time, stresses within the earth's crust have caused structural movement resulting in the folding, faulting and fracturing of great masses of rock. The study area is representative of these processes and is part of what is described as the desert region of the Basin and Range Province. As the name of the province suggests, intense structural activity has resulted in numerous relatively elevated and depressed blocks resulting in mountain masses rising rather abruptly from the broad plains or dry stream valleys that lie between them.

Reference to Plate 3, Geology and Soils, will show that two such mountain masses, the White Tank and the Sierra Estrella, border on the Study Area. In addition, similar blocks are represented by the Hieroglyphic Mountains to the north and the Phoenix Mountains to the east. In contrast to an average elevation of approximately 1,150 feet in the valley floor, the White Tank Mountains reach peaks of over 4,000 feet and the Sierra Estrella Mountains to the south rise to over 4,500 feet.

The mountain masses on Plate 3 have been depicted by type and age of surface geological outcrop. These are typical "hard rocks" and similar types make up the "basement" rocks beneath the sedimentary fill of the valley plain. Although similar in nature, rocks of oldest geological age (Precambrian) and recent age

TABLE 1

DATA ON CLIMATIC CONDITIONS

Means and Extremes for Period 1918-1957 - Litchfield Park Weather Station

Month	Temperature (F)							Precipitation Totals (Inches)			Estimated Mean Relative Humidity (Percent)	
	Means			Extremes								
	Daily Maximum	Daily Minimum	Monthly	Record Highest	Year	Record Lowest	Year	Mean	Greatest Daily	Year	6 A.M. (MST)	6 P.M. (MST)
January	66.1	34.9	50.5	87	1923	16	1950	0.93	1.79	1954	66	32
February	71.1	38.6	54.9	93	1930	22	1948	0.83	1.21	1931	66	28
March	76.9	42.6	59.7	97	1955	28	1956	0.72	1.56	1941	59	19
April	85.7	49.1	67.4	105	1936	27	1938	0.35	1.00	1926	48	14
May	94.4	56.8	75.7	113	1951	38	1921	0.15	1.24	1930	41	9
June	103.1	65.2	84.3	117	1940	49	1955	0.11	0.67	1925	36	10
July	105.9	75.2	90.6	118	1943	57	1943	0.76	1.73	1919	53	20
August	103.2	73.2	88.4	116	1918	57	1957	1.40	2.36	1951	59	24
September	100.0	66.3	83.2	115	1950	44	1920	0.75	2.71	1925	55	22
October	88.5	52.8	70.7	106	1955	33	1928	0.38	1.08	1957	58	27
November	76.1	40.6	58.4	98	1921	23	1931	0.63	2.65	1923	60	31
December	67.8	36.2	52.0	89	1950	20	1930	1.00	1.74	1940	67	37
Year	86.6	52.6	69.6	118	July 1943	16	Jan. 1950	8.01	2.71	Sept. 1925	56	23

Source: "Arizona Climate" by the Institute of Atmospheric Physics, The University of Arizona, Tucson, Arizona (January, 1960)

(Post-Laramide) are represented in a complex structural arrangement. Both the granites and the granitic gneisses are of similar mineral composition - essentially quartz, feldspar and mica. It is from these rocks, through the process of decomposition, erosion and sedimentation, that the valley fill and finally the soils have been derived. It should also be pointed out that the hardness and resultant resistance to erosion accounts for the "ruggedness" of the mountains in the Basin and Range Province.

Physiographic Processes

Soils are derived from the basic geological materials of a particular area. However, erosion and sedimentation, although decidedly influenced by rock types and structural forms, are conditioned by other interrelated factors such as climate and vegetation. Therefore, these elements will be reviewed first in terms of their effect in the study area.

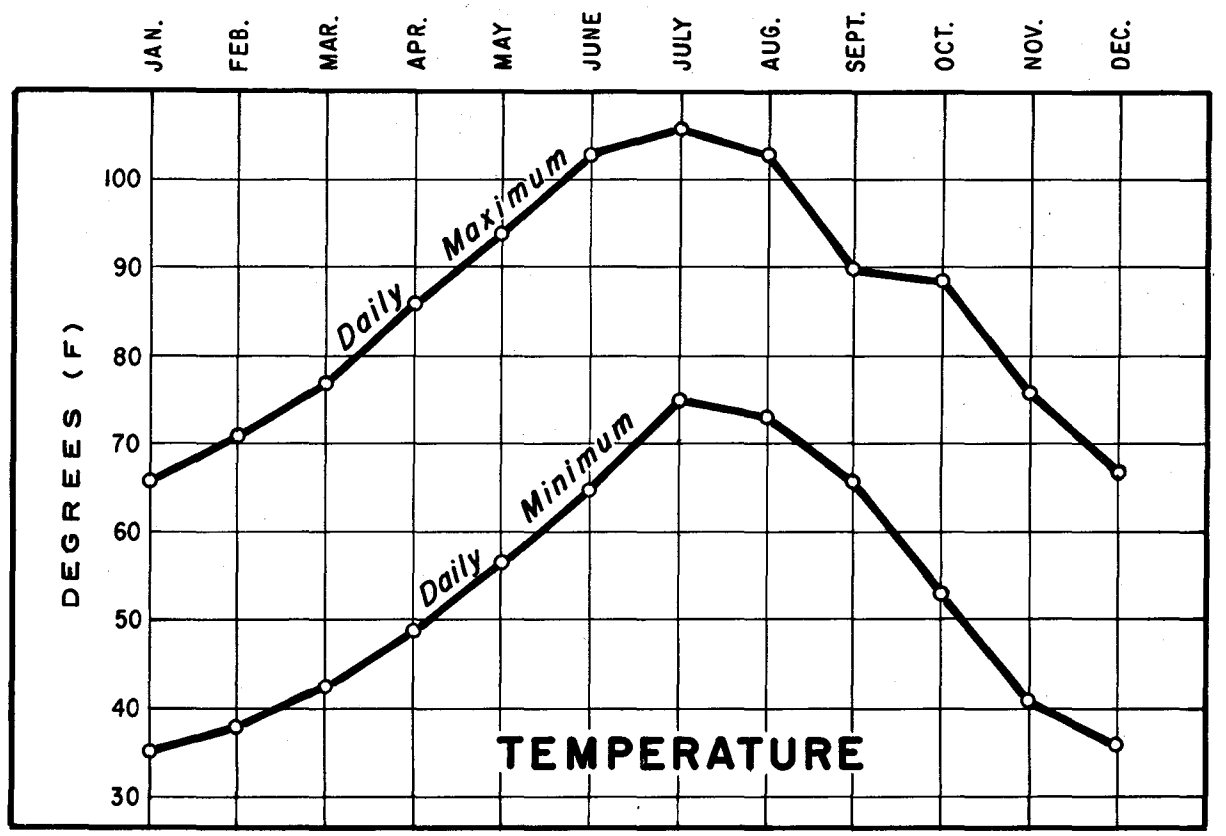
Climate

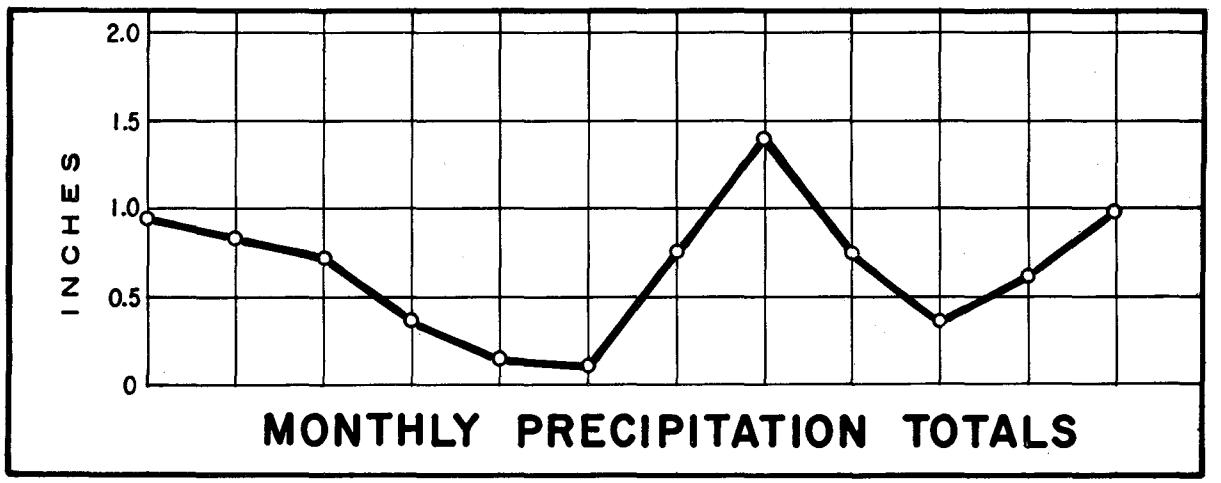
Climate is the average course or condition of the weather at a particular place over a period of time and includes such factors as temperature, precipitation, humidity and wind velocity. There are two U.S. Weather Bureau observation stations within the Study Area: one in Litchfield Park and one in Youngtown (formerly Marinette). Since the Litchfield Park station has complete records from the year 1918 and is also located near the center of the Study Area, a summary of data from this station is presented in Table 1. In addition, selected data from Table 1 is graphically presented on Plate 4.

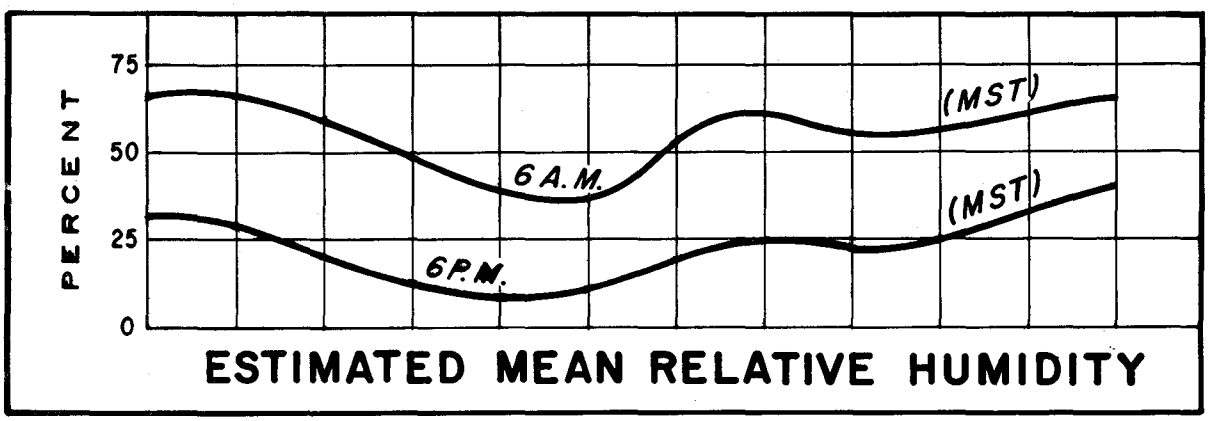
Temperature: The average yearly temperature in the area is 69.6 degrees. Reference to Plate 4, however, will show that there is considerable variation throughout the year. The summer climate is warm and from June through the middle of September, average daily temperatures exceed 80 degrees. During this same period, afternoon temperatures often exceed 100 degrees and a record high of 119 degrees was recorded on July 11, 1958.

SUMMARY OF CLIMATE

Litchfield Park Weather Station Means for Period 1918-1957







SOURCE: "ARIZONA CLIMATE" BY THE INSTITUTE OF ATMOSPHERIC PHYSICS, THE UNIVERSITY OF ARIZONA, TUSCON, ARIZ. (JAN. 1960)

From the first of October through the end of May, the climate of the area is very pleasant. In midwinter, average daily temperatures exceed 50 degrees, varying from the middle thirties near sunrise to 65 to 75 degrees in the afternoon. Freezing temperatures normally do not occur after the end of February or before the last week in November. A record low of 16 degrees was recorded in January, 1950. However, readings of 20 degrees or less occur on the average in only one winter out of every five.

Precipitation: The planning area has a dry climate, averaging slightly over eight inches of precipitation in most years. Reference to the previously-mentioned Plate 4 will show that the driest period occurs in the late spring. The most consistent and reliable rains occur in the midsummar and July is the only month of the year that has never been completely dry in the study area.

The warm season rains usually occur as localized afternoon and evening thunderstorms. In the winter months, the study area occasionally receives considerable moisture, but the amounts vary greatly from year to year. The least amount of total annual rainfall - 2.57 inches - was recorded in the area in 1950; and the higher extreme of 18.12 inches was recorded in 1941.

As noted above, most of the precipitation in the area occurs as thunderstorms. Quite often, a large amount of rain falls within a short period of time resulting in local sheet flooding. The greatest amount of rain to fall in one day - 2.71 inches - was recorded in September, 1925.

Humidity: The study area, like most of southern Arizona, is known for its low average relative humidity. These low values result from a combination of clear skies, low annual rainfall and high daytime temperatures.

Relative humidity readings have not been taken at the Litchfield Park station. The values shown in Table A and depicted on Plate 4 were estimated by a method devised at the Institute of Atmospheric Physics at the University of Arizona.

Calculations were made for 6 a.m. and 6 p.m., Mountain Standard Time (MST). Morning humidities range from an average of 36 percent in June to 67 percent in December. Evening humidities range from an average of only 9 percent in May to 37 percent in December.

Wind Velocity: Wind speeds have not been systematically recorded in the Study Area but they are usually of such low magnitude that they do not constitute an important element of the average climate. Occasionally, due to unusual barometric conditions, wind gusts over 50 miles per hour have been recorded. These conditions quite often occur just prior to thunderstorms, resulting in dust storms and blowing sand.

Vegetation

The type of vegetation found in a particular area is usually considered to be product of the environment, depending upon a number of variable and interacting factors. Most of the Study Area is either urbanized or is under irrigation for agriculture. The native vegetation in the few non-irrigated sections in the area consists mainly of creosote bush and annual grasses on the desert floor, mesquite and Salt Cedar along the Gila River bottoms, and palo verde and cacti with native perennial grasses on the nearby desert mountain slopes.

Recently, the Soil Conservation Service made a study of soil-plant relationships in the central Maricopa County area. Individual species of plants were identified and were in turn placed in vegetative groups. A summary of this data is presented below:

> Group A - Salt Cedar: This vegetative group occurs in and along rivers and major streams. The soil surface is 10 to 60 percent covered by perennial vegetation. The dominant plant species are salt cedar, mesquite, creosote bush and arrow-weed.

Group B - Creosote bush: This vegetative group occurs on valley plains, nearly level alluvial fans and a few stream terraces. 4 to 10 percent of the soil surface is covered by perennial vegetation. The dominant vegetation is creosote bush and bur-sage with palo verde trees and mesquite trees growing along washes.

Group C - Bur-Sage: This vegetative group occurs along the base of mountains. 5-15 percent of the surface is covered by vegetation. The plant makeup is dominated by bur-sage with minor percentages of cholla cactus, ocotillo, saguaro and barrel cactus. Ironwood and palo verde trees grow along washes along with coffee bush and other shrubs.

Group D - Saltbush: This vegetative group occurs along the lower ends of old alluvial fans and stream terraces which parallel major streams. The surface is 4 to 25 percent covered by perennial vegetation. The dominant plant is desert salt bush with scattered mesquite and palo verde trees along the washes.

Group E - Gayetta grass: This vegetative group occurs in swale positions along the margins of very old stream terraces. The surface is 10 to 50 percent covered with perennial vegetation. The dominant plants are big galleta grass along with scattered mesquite and palo verde trees.

Because of general sparceness and shallow root systems, plants life contributes little to the break-down of rocks to form soils in the Study Area. Likewise, native vegetation does not contribute a significant amount of humus to the desert soils.

Topography

Topography is the configuration of a land surface including its relief and the position of its natural and man-made features. Primarily, topography or "slope of the land" is dependent upon the types of rocks and their physical attitude. In turn, the rocks are altered by climatic processes and the effects of the vegetative cover. Due to general aridity, weathering and erosion in the Study Area are predominantly mechanical rather than chemical. The principal erosive process is the downward headcutting in mountain valleys and eventual movement of materials by flowing streams or flood waters to be deposited on the valley slopes and floor.

In contrast to the mountain masses, most of the Study Area is essentially a flat desert valley. From an elevation of approximately 1,250 feet at the northern boundary, the terrain slopes gradually downward to the south where at the confluence of the Agua Fria and Gila Rivers the elevation is 920 feet. This is an average slope of 15 feet per mile and only a few scattered "hills" alter the uniform and gentle land surface. Topography is depicted by contour lines adapted from U. S. Geological Survey topographic maps on following Plates 6 through 10.

Soils

The end product of physical, biological and chemical processes working upon the original rock of a given area results in the soils. To the soil scientist, however, this surface material must contain living matter and be capable of supporting plant life. For this reason, a distinction between "hard rocks" and kinds of soils has been made on Plate 3.

In June, 1969, the U. S. Department of Agriculture Soil Conservation Service (SCS) in cooperation with the Soil Conservation Districts in Maricopa County published a "General Soil Map" covering the entire county[20]. The areal extent of the kinds of soils shown on Plate 3 has been adapted from this map. As stated in the text accompanying this soil map, the determinations of soil groups are of a general nature only and, although useful for general planning purposes, local variations are likely to occur. More detailed surveys can be prepared by the Soil Conservation Service but, under some circumstances, financial assistance from the local community must be expected.

Soils are usually described in terms of the "soil profile". This is the sequence of the "horizons" or layers of different texture, structure, lime content, or other recognizable characteristics that the soil possesses. Different horizons

are the result of the original soil material and the kind and length of weathering to which it has been subjected.

The A horizon is the topsoil into which water penetrates, in which plants grow, and is the layer in which the most active weathering, both chemical and mechanical, takes place. The B horizon is the subsoil into which clay particles and other materials have moved from the topsoil. Depending on the age, drainage, and original material, this horizon may, in this area, contain large amounts of lime in the lower part. The C or third horizon may also include large amounts of lime or "caliche" in the upper part. With increasing depth, however, the character of the material grades back to the original texture of the sedimentary deposits from which the soil was formed.

There are three main kinds of soils in the Study Area as shown on Plate 3. A brief description of each is presented in the following paragraphs.

A - Deep Sandy Loams and Loamy Soils

These are the younger soils that have been deposited by flowing water in relatively recent time. They have not weathered sufficiently to have formed distinct horizons so still retain the erratic layers of different textured soil materials that were in the original deposition. They are not hard or sticky, are fairly porous, and plant roots can penetrate deeply where water is available. Topographically, these soils are on level to gently sloping valley plains and low terraces. Most of these soils have some degree of hazard to flooding. For agricultural use these soils have few limitations and are suited to the growth of a wide range of plants. They are deep, generally well drained, and are easily cultivated. Locally, they may contain excessive amounts of salts. When cultivated, they need only ordinary management practices to maintain soil fertility and tilth.

B - Soils with Limy Clay Loam Subsoils

These are older soils that have distinct horizons and are found on level to gently sloping alluvial fans and valley slopes that have not received deposition for a long time. Generally, they have a sandy loam to clay loam surface, or A horizon. The B horizon, or subsoil, contains enough clay to cause the soils to be sticky when wet and hard when dry. This horizon is usually reddish in color. The lower part of this horizon usually contains considerable lime.

At depths ranging between 20 and 36 inches the clay content decreases and the lime increases to a maximum . Below 3 to 5 feet the effects of weathering diminish and the material grades to the sandy and often gravelly unweathered material as originally washed down from the mountains.

Because of the higher clay and lime content, soils of this group require careful management when cultivated to prevent deterioration in the soil-water-air relationship. Some of these soils present problems when used for foundations of buildings or for septic tank filter fields. Detailed studies to determine the degree of limitations and methods of treatment are advisable before such uses are made.

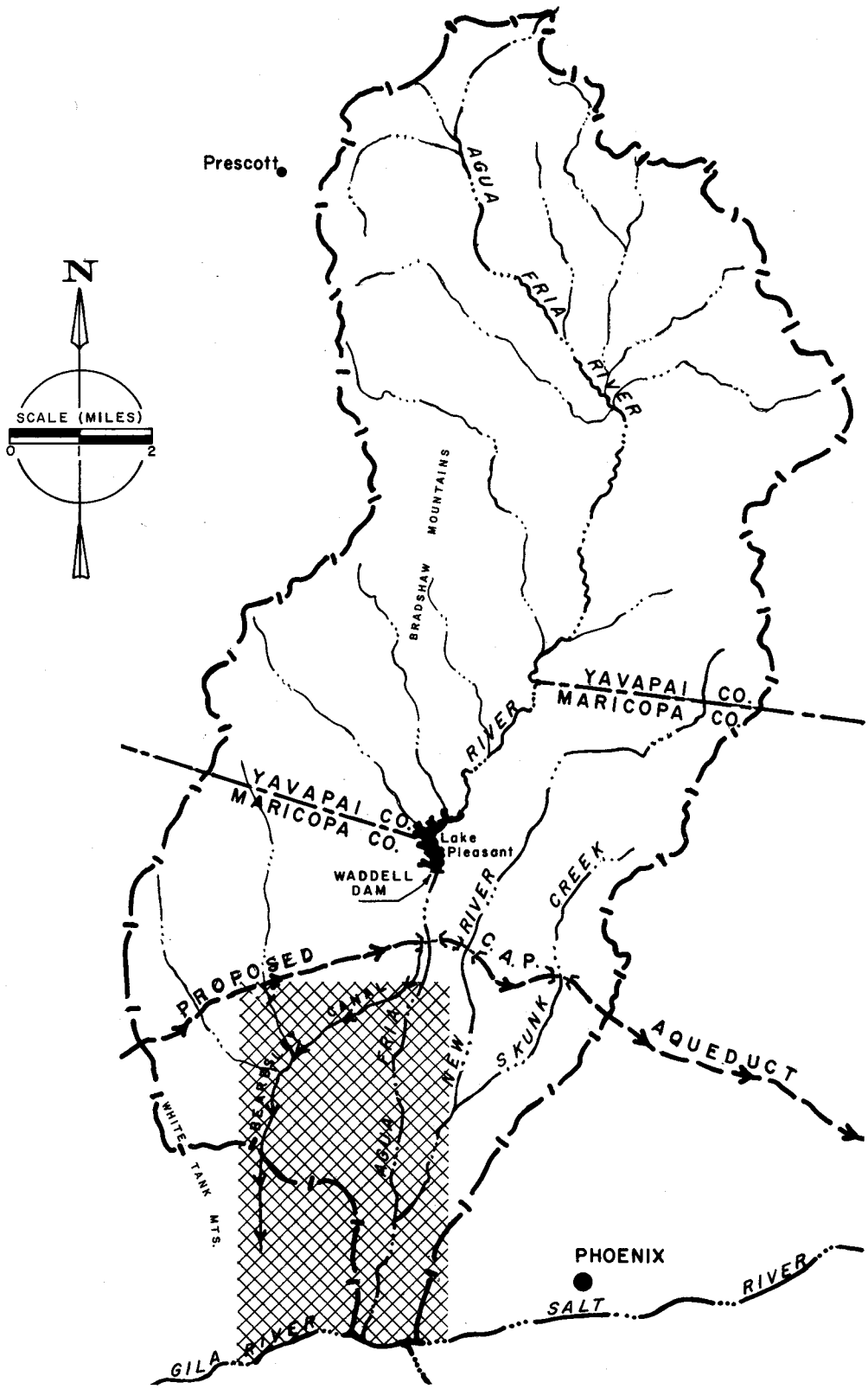
C - Limy Loamy Soils and Limy Gravelly Soils

All of these soils contain large amounts of lime. The soils on nearly level to gently sloping plains have a surface or A horizon of limy loam. At depths of from 12 to 24 inches this grades into a very limy C horizon that contains many modules of lime.

Because of the high lime and/or gravel content, these soils have some limitations for use for cultivated crops, and conservation practices are more difficult to apply and maintain. Local areas are excessively salty. Detailed studies to determine problems or limitations are recommended before septic tank filter fields or underground installations of metal or concrete are placed in these soils.

In recent years, the Soil Conservation Service has developed detailed criteria for interpretations of soils for many different uses. In addition to land capability classifications for cultivation, criteria have been established for, as examples, engineering, corrosivity, hydrology and shrink-swell behavior. In addition, soil limitation ratings have been developed for such uses as dikes and levees, foundations for low buildings, road locations, septic tank filter fields and recreational areas. For local planning and development, these interpretations are invaluable and should be used extensively.

WEST CENTRAL MARICOPA COUNTY, ARIZONA



LEGEND

STUDY AREA

AGUA FRIA RIVER WATERSHED

SOURCE: U.S. GEOLOGICAL SURVEY

CHAPTER IV

SURFACE WATER

In an arid or desert region, water is the prime resource since even the best of soils cannot support life without adequate moisture. Physically, socially, economically and even politically, people living in such areas become "water-oriented". The popularity of the lakes, reservoirs and flowing streams in Arizona demonstrates that people have become water-oriented "recreationally" also.

Even if the people are oriented to water, it is easy to ignore the fact that water is a scarce commodity in Arizona, as in all semi-arid lands. It is imperative that plans be made to develop both the land and water resources to be sure that they are adequate for the essential economic functions which they will be called upon to perform.

Water, as a resource, includes a number of related aspects. The amounts of water received in the area from rain have been discussed previously. In addition drainage, flooding, ground water reservoirs and finally usage and conservation are all part of the water resource system.

Drainage

Agua Fria River Watershed

The approximate southwest quarter of the study area drains directly south into the Gila River. The remainder of the area lies within the southern portion of the Agua Fria River Watershed, the general extent of which is shown on Plate 5. The headwaters of the river originate in the Prescott National Forest in central

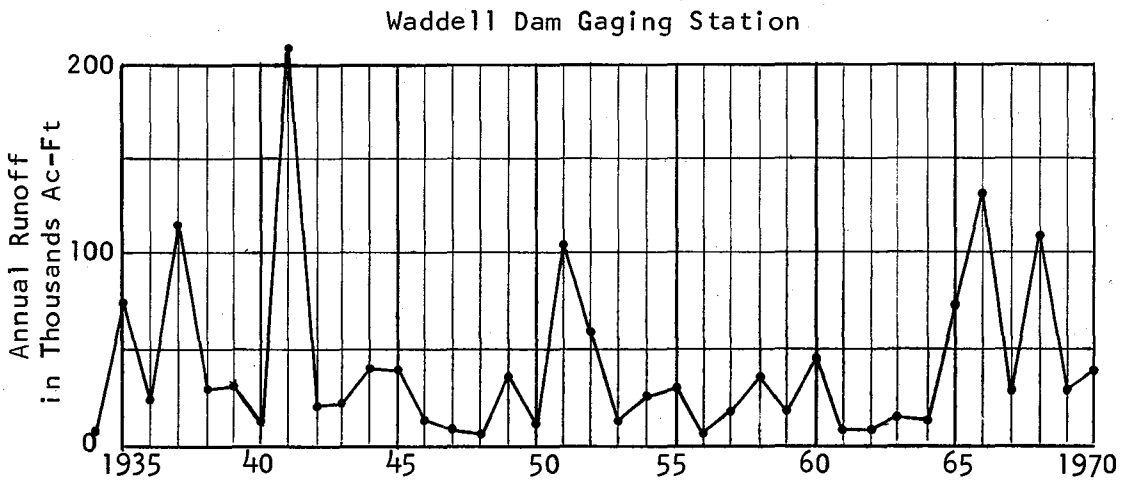
Arizona at an elevation of about 7,000 feet. The course of the stream is generally southward and is about equidistant between two parallel mountain ranges that form the boundaries of the drainage area. At its confluence with the Gila River, the water course has a total length of 130 miles and an average fall of 59 feet per mile. One major tributary, New River, flows generally southward for about 40 miles from its source to its confluence with the Agua Fria River in the eastern portion of the study area. The total watershed contains an area of 2,340 square miles.[36]

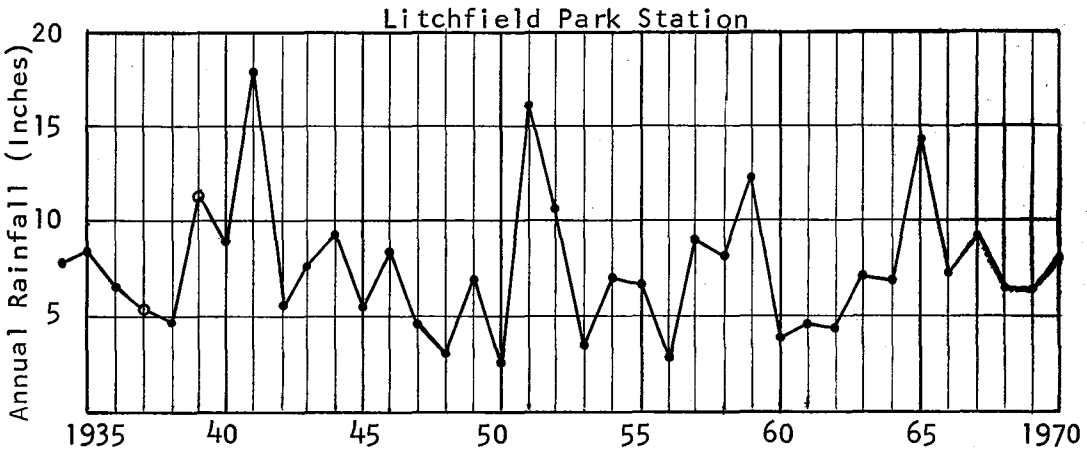
Private interests after solving numerous problems in a struggle that lasted several years, organized the Maricopa County Municipal Water Conservation District No. 1. Within this framework, the Waddell Dam on the Agua Fria River was completed in 1928 and, subsequently, a diversion dam forming a lower lake, and the Beardsley service canal, were constructed. The waters impounded by the dam form Lake Pleasant which now furnishes part of the irrigation water for approximately 35,000 acres in the Conservation District located in the northwest portion of the study area.

Waddell Dam is 175 feet in height, has a total storage capacity of 157,600 acre-feet and a surface area of 3,585 acres when full. Runoff is obtained from an area of 1,459 square miles and at Waddell Dam, where inflow to Lake Pleasant is measured, unit runoff is 42 acre-feet per square mile, resulting in an average annual runoff of approximately 61,000 acre-feet.[45]

The past use of averages in analyzing surface water supplies and flows in the desert Southwest is neither a valid nor reasonable approach. The relatively short-term records for watersheds in southern Arizona reveal great fluctuations from year to year indicating periods of storms and periods of near-disastrous droughts. Reliable records for the Agua Fria watershed are available for only a 36-year period, yet, even during this time, great extremes are evident. The

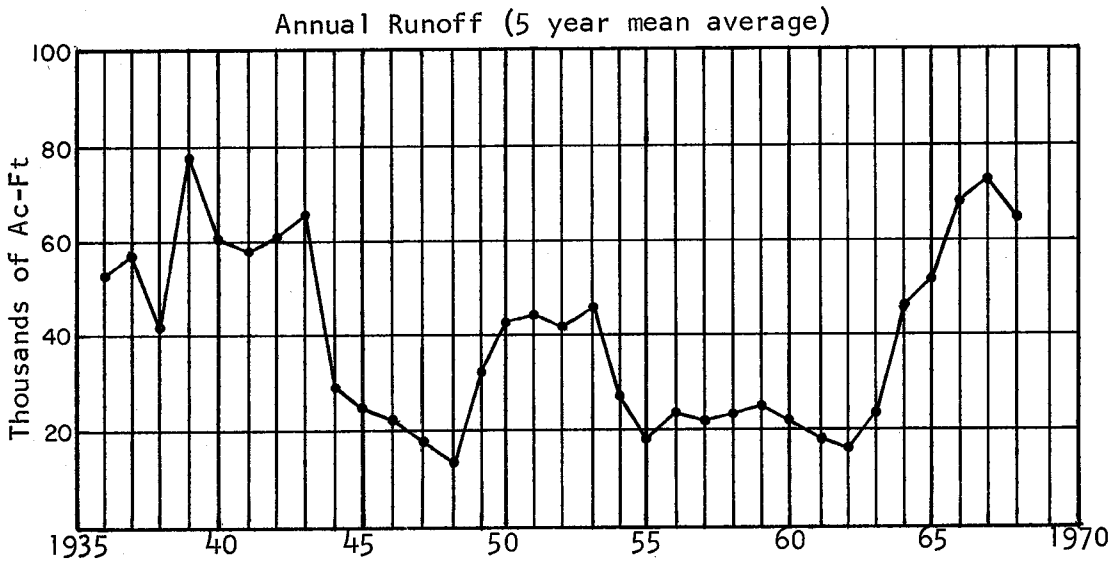
following graph shows yearly runoff as computed at the gaging station at the left upstream end of Waddell Dam.[41,43] In addition, average annual rainfall as recorded at the Litchfield Park station has been plotted.





It is evident that the periods of highest and lowest runoffs coincide with the amounts of rainfall in the general area. It must be remembered, however, that the Litchfield Park weather station (the closest station with nearly complete records) is some distance south of the drainage area of Lake Pleasant. The mountain areas probably have a higher annual rainfall than the desert valley.

A peak runoff of 209,200 acre-feet was reached in 1941 while the low of 5,210 acre-feet occurred in 1948. In order to evaluate reservoir storage in terms of the annual minimum constant supply available for use in the Conservation District, it was found that a five-year mean average was more useful than data by single years. The following graph shows the average annual runoff for the two years preceding, the two years following, and the subject year.



The highest mean average year was 1939 with an accumulation of 78,556 acre-feet for a five-year total of 392,780 acre-feet. The lowest mean average year was 1948 with an accumulation of 13,868 acre-feet for a five-year total of 69,340 acre-feet.

John Carollo Engineers, in a water works report for the Valley Metropolitan Area, calculated that a reserve volume equal to 24 percent of the full capacity of a storage reservoir would be required as protection during the worst drought.[30] For Lake Pleasant this would require a reserve of 38,000 acre-feet (24% times 157,600 acre-feet capacity). In addition, consideration must be given to annual loss by evaporation and seepage, and various methods have been used to calculate these losses. Carollo calculated a round value of 11 percent of total storage capacity as loss, which would equal approximately 17,000 acre-feet. On the high side, the U. S. Geological Survey determined from studies at Lake Mead during 1957 that evaporation loss rate was about 90 inches (7.5 feet) per year from the reservoir surface.[28] With Lake Pleasant at full capacity, this would amount to an annual loss of approximately 27,000 acre-feet (3,585 surface acres times 7.5 feet). Supported by other sources[34], it has been determined that an average annual loss of approximately 22,000 acre-feet can reasonably be expected. It should be remembered, however, that such losses are based upon full capacity of the reservoir with a maximum surface area exposed. Losses would be proportionately lower as the amount of water in storage was reduced.

Subtracting the amounts of storage capacity needed for reserve (38,000 acre-feet) and losses (22,000 acre-feet) nearly 100,000 acre-feet of capacity remains for inflow-outflow calculations. In five-year cycles, this would mean that an inflow of 20,000 acre-feet per year could be diverted to Conservation District use. The graph on page 14 reveals that runoff was less than 20,000 acre-feet in only four years during the recorded 36-year interval (i.e. 1948, 1955, 1961 and 1962). As previously pointed out, the lowest runoff in a five-year period was approximately 70,000 acre-feet. With a reserve of 38,000 acre feet, the annual minimum supply would still have been slightly over 20,000 acre-feet.

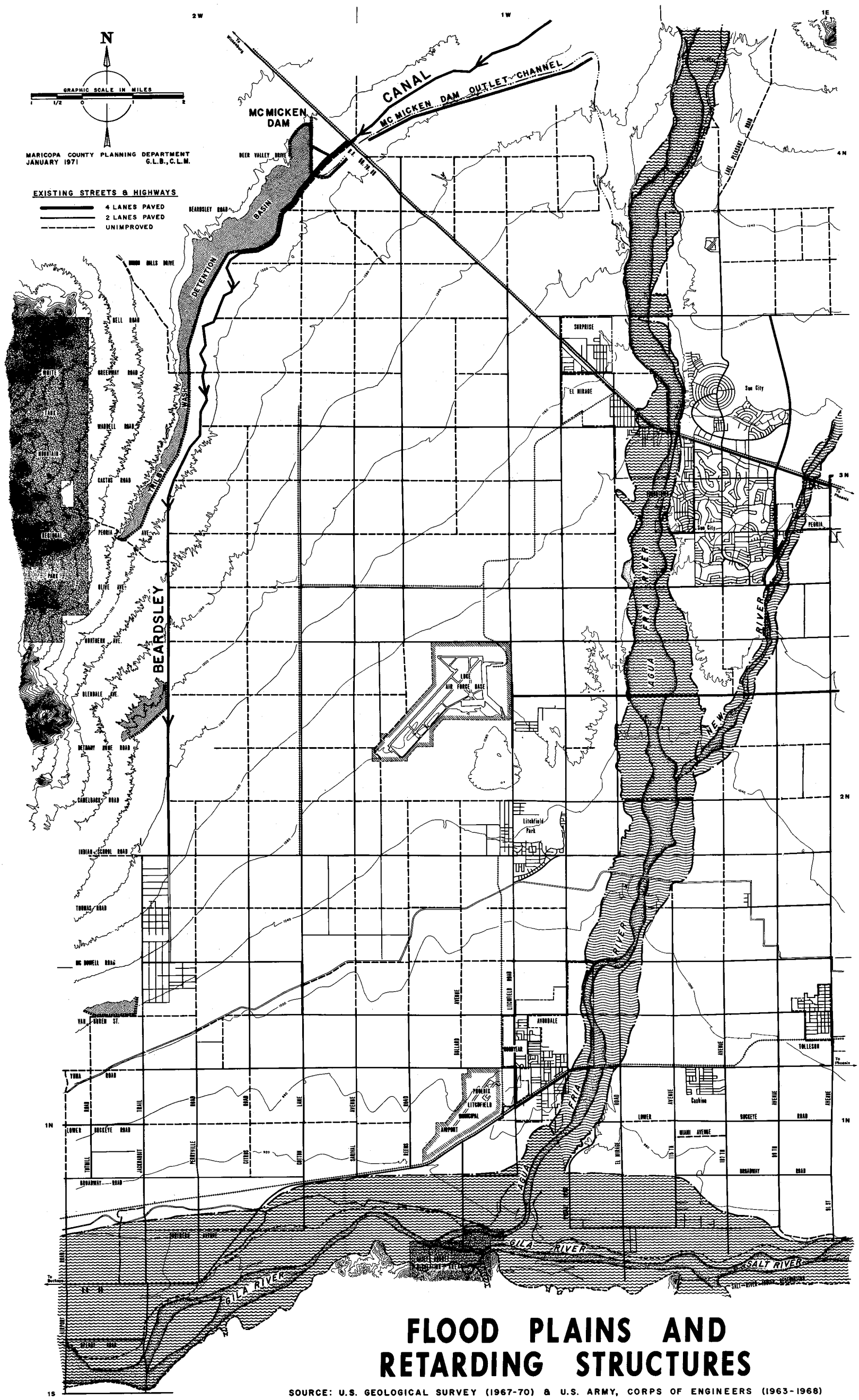
For the determination of potential future water resources for the study area, it will be assumed that 20,000 acre-feet per year will be available for Lake Pleasant diversions. It should be pointed out that Carollo calculated that the annual minimum historic water supply from the Agua Fria River would appear to be 15,000 acre-feet. In October, 1970, however, the Maricopa County Municipal Water District #1 in a report submitted to and compiled by the Arizona Interstate Stream Commission indicated that from 1980 to 2030 "surface water usage" would be 23,000 acre-feet.[24]

White Tank Drainage Area

The eastern slopes of the White Tank Mountains drain into the study area and during times of severe thunderstorms considerable damage has been inflicted upon the irrigated lands and growing communities within the area. Prior to World War II, the Soil Conservation Service conducted studies on watershed problems of land management, soil and moisture conservation, and flood prevention in the general area. Studies continued after the organization of the Agua Fria Soil Conservation District in 1945. Investigation turned to action when, in August 1951, flood damage from a single storm amounted to over $3 million. Crops, roads and railroad tracks were washed out; Luke Air Force Base was inundated (at the time, combat pilots were being trained for Korea); and homes in the Litchfield Park, Goodyear and Avondale areas were severely damaged.[35]

After obtaining funds from several sources, the Soil Conservation Service (SCS) directed the construction of a dam 4 miles long and 23 feet high in the Trilby Wash area as shown on Plate 6. The dam was completed in 1954 and became the Nation's first small-watershed project, effectively controlling nine subsequent floods. In the same year, the SCS supervised the construction of the two smaller White Tank structures to the south of the original dam. Since there had been considerable flood water damage to defense installations, Maricopa County called upon the Corps of Engineers for additional help in controlling the

WEST CENTRAL MARICOPA COUNTY, ARIZONA



FLOOD PLAINS AND RETARDING STRUCTURES

SOURCE: U.S. GEOLOGICAL SURVEY (1967-70) & U.S. ARMY, CORPS OF ENGINEERS (1963-1968)

L E G E N D

- STANDARD PROJECT FLOOD AREA
- FLOOD PRONE AREA
- TOP OF BANK
- RETARDING STRUCTURES
- DETENTION BASINS

PLATE 6

watershed. In 1956, the Corps had completed the nine-mile-long Trilby Wash Detention structure (incorporating the SCS structure), McMicken Dam and an outlet channel which provides for the release of water from the dam to the Agua Fria River water-course.

These small flood control structures are not designed to be reservoirs but they do effectively contain the flash stream-flows and release it slowly to help recharge downstream groundwater basins. The amount of recharge from the structures in the study area is difficult to determine since there are many unknown factors such as porosity and permeability of the sediments beneath the basins, their connection with subsurface aquifers and the ease of lateral movement within the aquifers. The Soil Conservation Service has estimated that more than 40,000 acre-feet of runoff are retained by the above-described structures each year. The U.S. Geological Survey has estimated that approximately 5 percent of the precipitation in the desert mountainous areas is recharge to groundwater reservoirs at the mountain fronts[45]. Since the water back of detention basins has a longer period in which to percolate, it is reasonable to assume that at least 10% of the annual volume would become ground water recharge. On this basis approximately 4000 acre-feet would be available for pumpage in the Study Area each year.

Other Drainage Areas

The drainage area south of Lake Pleasant, including the entire study area consists of approximately 965 square miles. From the rolling hills to the north, the land slopes gradually to the flat plains of the valley floor. The whole area is drained by a system of washes which connect to the Agua Fria and Gila River channels. During normal rains, the water is usually absorbed directly into the soil and there is little flow in the washes and channels. During severe thunderstorms, however, sheet-flooding may occur and the channels and flood plains may become innundated. Since most of the washes and channels that traverse the valley floor contain coarse-grained material, downward seepage is quite rapid.

The combination of evaporation from the soil and transpiration from plants is called "evapotranspiration" and is the method of the return of water from the earth to the atmosphere. In the southern portion of Arizona, the combination of high temperature and low humidity causes an extremely high rate of evapotranspiration. The U. S. Geological Survey has calculated that only about 1.0 percent of the annual precipitation becomes available from recharge to groundwater reservoirs.[45] Based upon an average annual rainfall of 8 inches, there is a recharge of approximately 4000 acre-feet in the southern portion of the Agua Fria River Watershed.

Flooding and Flood Control

Although the dams and detention basins, shown on Plate 6, within the watershed have effectively controlled some of the flooding, the natural system of washes and stream channels are still subject to local inundations. This type of flooding occurs in one of two ways: 1. A high intensity thunderstorm wherein a large volume of rain falls within a relatively short period of time. In this case, the surface materials are unable to absorb the water fast enough to prevent runoff, or 2. A rather normal rain that lasts over a period of several days. Under these circumstances, the "surface sponge" becomes saturated during the early time of precipitation and runoff follows.

As recently as September, 1970, there was considerable flood damage in the study area, including the washout of the Olive Avenue crossing of the New River adjacent to Sun City. A complexity of meteorological events produced an unusually heavy precipitation during a three-day period.[21] At the Litchfield Park Weather Station, recorded rainfall was as follows: September 4, 0.48 inches; September 5, 1.00 inches; September 6, 2.42 inches.

In the Scottsdale area, where there was severe flood damage, 3.57 inches of rain fell on September 6th - nearly half of the average annual precipitation for the area.

In addition to the erratic nature of the storms in the valley, urban development, especially since World War II, has disrupted the natural drainage system, thereby adding to flooding hazards. In many cases, streets, roads, subdivisions and industrial buildings, have been constructed with little regard for this system. The disruption of the natural channels and the increase of run-off resulting from the "covering" of soils of high absorbability, has resulted in new flooding and storm drainage problems, especially in some local areas.

Flood control in the study area is under the administration of the Maricopa County Flood Control District which was established in 1959. A publication entitled "Comprehensive Flood Control Program Report" was prepared by the District in 1962 and was adopted and approved by the Board of Directors of the Flood Control District of Maricopa County on November 20, 1963.[27] In cooperation with the U. S. Army Corps of Engineers, a number of flood control studies have been conducted for certain drainage areas within the County and other studies are being undertaken. The reports that affect the study area will be reviewed in following paragraphs.

One of the recommended projects and plans included in the above mentioned comprehensive report covers the Salt and Gila River Channels. From basic data furnished by the Corps of Engineers, flood boundaries and profiles were drawn by the District. Plate 6 shows the "Standard Project Flood" area for these channels and the top of the bank. As defined by the District, the Standard Project Flood is that which:

> "...may be expected from the most severe combination of meteorological and hydrological conditions that is considered reasonably characteristic of the geographical area in which the drainage basin is located, excluding extremely rare combinations. Such floods, as used by the Corps of Engineers, are intended as practicable expressions of the degree of protection that should be sought in the design of flood control works, the failure of which might be disastrous."

It should be pointed out that other terms such as "intermediate regional" or "probable maximum" have been used to define areas of inundation. As recommended by the Corps, however, the Standard Project Flood should be used for general planning purposes.

The above-mentioned report recommends channel clearing and improvements, including some short levees, in the Salt-Gila River system from Granite Reef to Gillespie Dam. A 2000-foot wide low flow channel is included in the plan.

The Agua Fria River, from the northern limits of the study area to Camelback Road, is covered in a report entitled "Flood Plain Information, Agua Fria River, Maricopa County, Arizona" which was prepared for the County by the Corps of Engineers in 1968.[36] This report includes guidelines for reduction of damages from future floods and delineates the area of the Standard Project Flood as shown on Plate 6. A similar report has been prepared for the New River, but the area covered lies just to the east of the study area (from Greenway Road to the north).[37]

In 1970, the U.S. Geological Survey at the direction of the Congress, prepared a series of maps of "Flood Prone Areas". Plate 6 shows the extent of these areas for the Agua Fria River below Camelback Road and for that portion of the New River within the study limits. Flood boundaries were estimated from topography, computations of approximate conveyance and historical information on actual flooding. The USGS has stated that flood-prone areas have a 1 in 100 chance on the average of being inundated during any year. It appears that areas so defined would approximate those of a Standard Project Flood although detailed information by the Corps of Engineers would be needed for accurate definition.

CHAPTER V

SUBSURFACE WATER

As previously discussed, the structural basins between the up-lifted mountain ranges are filled with materials derived from the original rocks and transported by running water to their place of deposition. This material is called alluvium and consists of clay, silt, sand, gravel and boulders. Within the study area, as in most of the inter-mountain basins, our knowledge of alluvial deposits is essentially limited to the information obtained from wells drilled for water. Because of economic limitations, most water wells in the study area are drilled to a depth of less than 1,000 feet, although in a few rare cases wells have been drilled to a depth of approximately 2,500 feet without encountering bedrock. The thickness of the alluvial fill is usually expressed in terms of "several thousand feet". Although considerable additional information is needed, recent geophysical investigations indicate that the depth to basement rock may be as much as 11,000 feet in the study area.

Geohydrology

The investigation of the relationship of subsurface water and the rocks in which it is found is called geohydrology ("earthwater - study"). The older alluvial fill contains many water-bearing sand and gravel beds interfingered with relatively impermeable lenses of silt, clay or cemented coarse material. In the Study Area, as in most cases, these beds (water-bearing strata or material) are hydraulically connected and form a single aquifer. There is evidence that more than one water body lies under much of the Study Area.

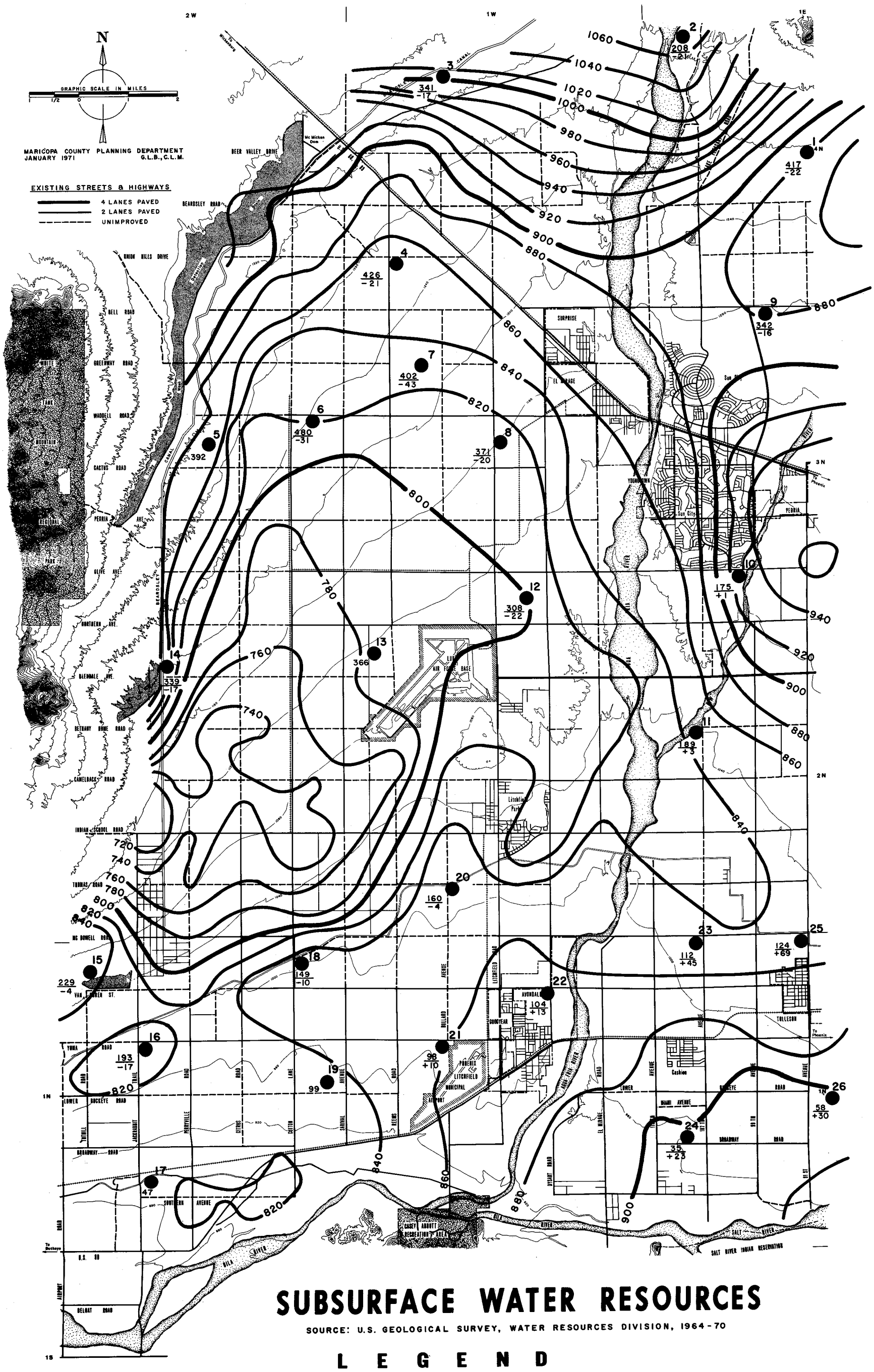
Plate 7 is an adaption from a study made in 1964[31] by the U.S. Geological Survey (USGS) based upon information from over 280 wells within the general limits of the Study Area. The contour lines, at an interval of 20 feet, connect points of equal altitude of the water level and depict the shape of the water-table surface for the date indicated. In addition, Plate 7 shows the location of twenty-six Index Wells that the USGS has used for water-level measurements from 1965 to 1970. The upper figure at the lower-left of each well-spot is the depth to water in 1970 as measured from the land surface. The lower figure indicates the change in water level during the 1965-70 period.

It is apparent from Plate 7 that there is not only a great variation in the altitude of the water surface, but also, the effects of withdrawal during the five-year period are quite different throughout the area. In the north-central portion, the water level dropped a maximum of 8.6 feet per year, while to the southeast there was a maximum rise of 13.8 feet per year. In the north central portion of the area where groundwater is the bulk of the water used, the continuing decline reflects pumpage in excess of recharge. In the southeast portion, where more surface water is available, the rises reflect the higher than normal surface deliveries and the corresponding lower pumpages in the period. Thus, during the period, recharge was considerably in excess of pumpage.

Subsurface Water Volume

Since water is the critical resource in the Study Area, as well as the entire valley, an attempt has been made in this report to estimate the total volume of underground water that might be available for future needs. A study was made of well records in the area and a number of drillers logs, indicating the types of alluvial rocks that had been encountered, were selected. The data from the drillers logs were plotted on measured strips, which in turn were put together in a series of interrelated cross-sections. (An example of a typical cross-section is shown in Appendix C). Although drillers logs are subject to considerable interpretation, it became evident that the alluvial materials could be correlated from well to well.

WEST CENTRAL MARICOPA COUNTY, ARIZONA



SUBSURFACE WATER RESOURCES

SOURCE: U.S. GEOLOGICAL SURVEY, WATER RESOURCES DIVISION, 1964-70

L E G E N D

820

ALTITUDE OF WATER LEVEL, 1964

(CONTOUR INTERVAL, 20 FEET, DATUM MEAN SEA LEVEL)

INDEX WELL

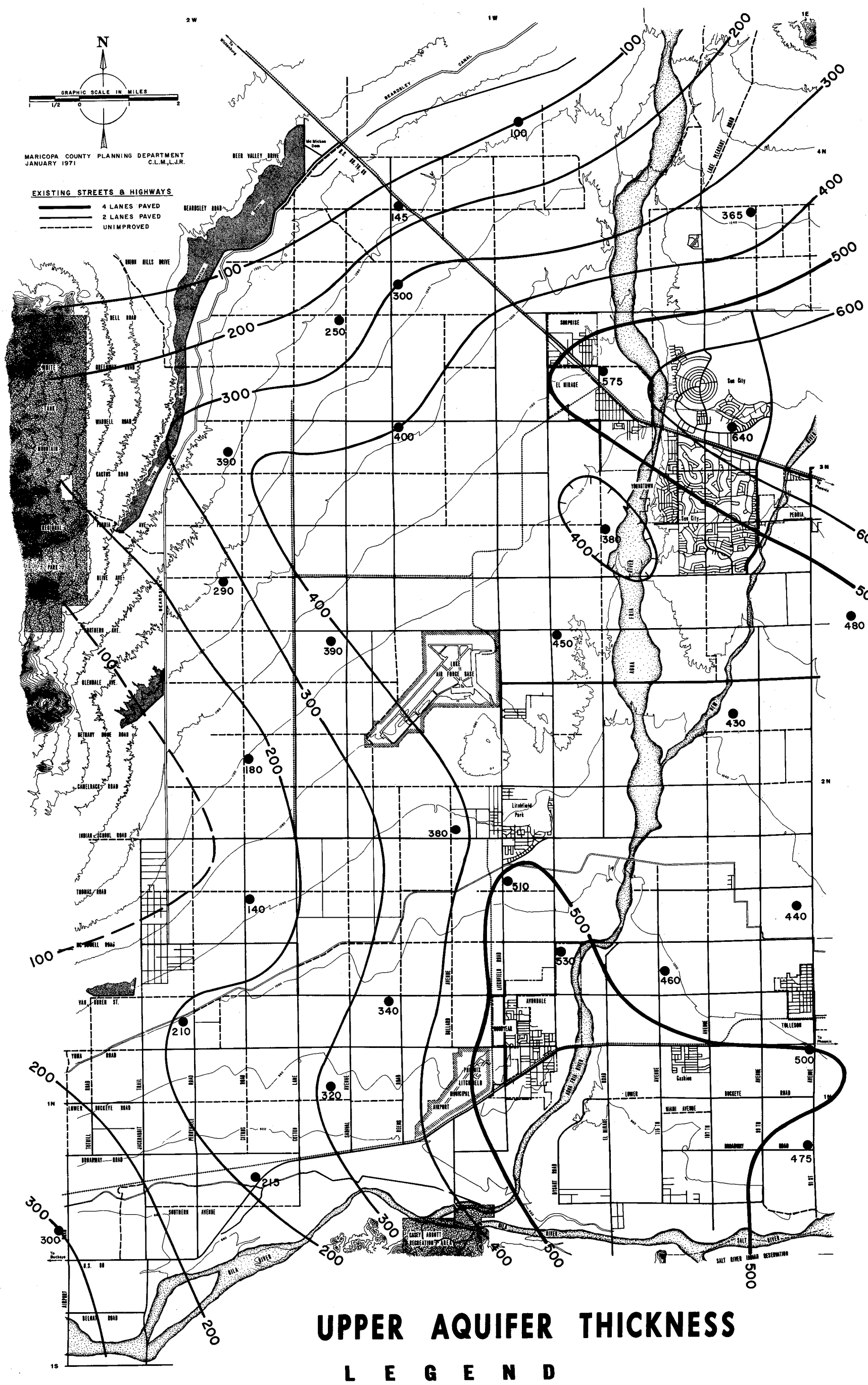
10 **WELL NUMBER**

130 **DEPTH TO WATER IN FEET, 1970**

-45 **CHANGE IN WATER LEVEL, IN FEET, 1965-70**

PLATE 7

WEST CENTRAL MARICOPA COUNTY, ARIZONA



UPPER AQUIFER THICKNESS

L E G E N D

● 300 THICKNESS FROM TOP OF WATER IN 1964 TO TOP OF MASSIVE CLAY

—400— CONTOUR INTERVAL: 100 FEET

PLATE 8

At a depth of approximately 800 feet, a rather thick layer of clay was reported in nearly all wells. This formation has been referred to as the "massive clay" and although it may contain thin sandy streaks, it is usually considered to be quite impervious and thus forms the lower limits of the aquifer in the Study Area.

As previously mentioned, the most complete records of water levels were obtained by the USGS in 1964. This data was plotted on the cross sections and the thickness of the water-bearing sediments from the top of the water table to the top of the clay layer was determined. A contour map was then prepared connecting points of equal thickness of the saturated upper aquifer using a contour interval of 100 feet, (see Plate 8, Upper Aquifer Thickness). By the use of a planimeter the surface area between each contour interval was determined. In turn, the total volume of sediments within the aquifer was calculated by multiplying the surface area between each contour interval by the average thickness for the particular interval. By this method it was determined that there are approximately 69 million acre-feet of alluvial sediments in the presently-utilized upper aquifer.

Studies by the USGS of a number of alluvial basins in the State have indicated that the average specific yield of water from the upper aquifer is about 15 percent. This is the amount of water that can actually be produced from the formation and is not the percent of total pore or void space. On this basis (15 percent of total sediment volume) there were slightly over 10 million acre-feet of water in place as of 1964. At first reflection, this appears to be a great quantity of water available for use. In later chapters, however, predictions will be made of the future depletion of this water source under various conditions of development.

As previously mentioned considerable more knowledge is needed concerning the potential aquifers lying below the "massive clay" and above the basement rocks. This is not only true of the Study Area, but also applies to the entire Phoenix and Mesa Basins. A thorough investigation, including geophysical surveys, deep test

wells and detailed analyses, is urgently needed for this regional area. Through cooperative efforts of several agencies, a thorough groundwater investigation of this type has been conducted in the Tucson Basin.

Subsidence Due to Groundwater Withdrawal

Subsidence due to the withdrawal of subsurface fluids is a most common type of man-made geological hazard. The removal of large volumes of water from weakly consolidated sediments reduces the fluid pressure and increases the effective stress borne by the aquifer skeleton. The aquifers respond chiefly as plastic bodies and compaction is continuous although it may be small.

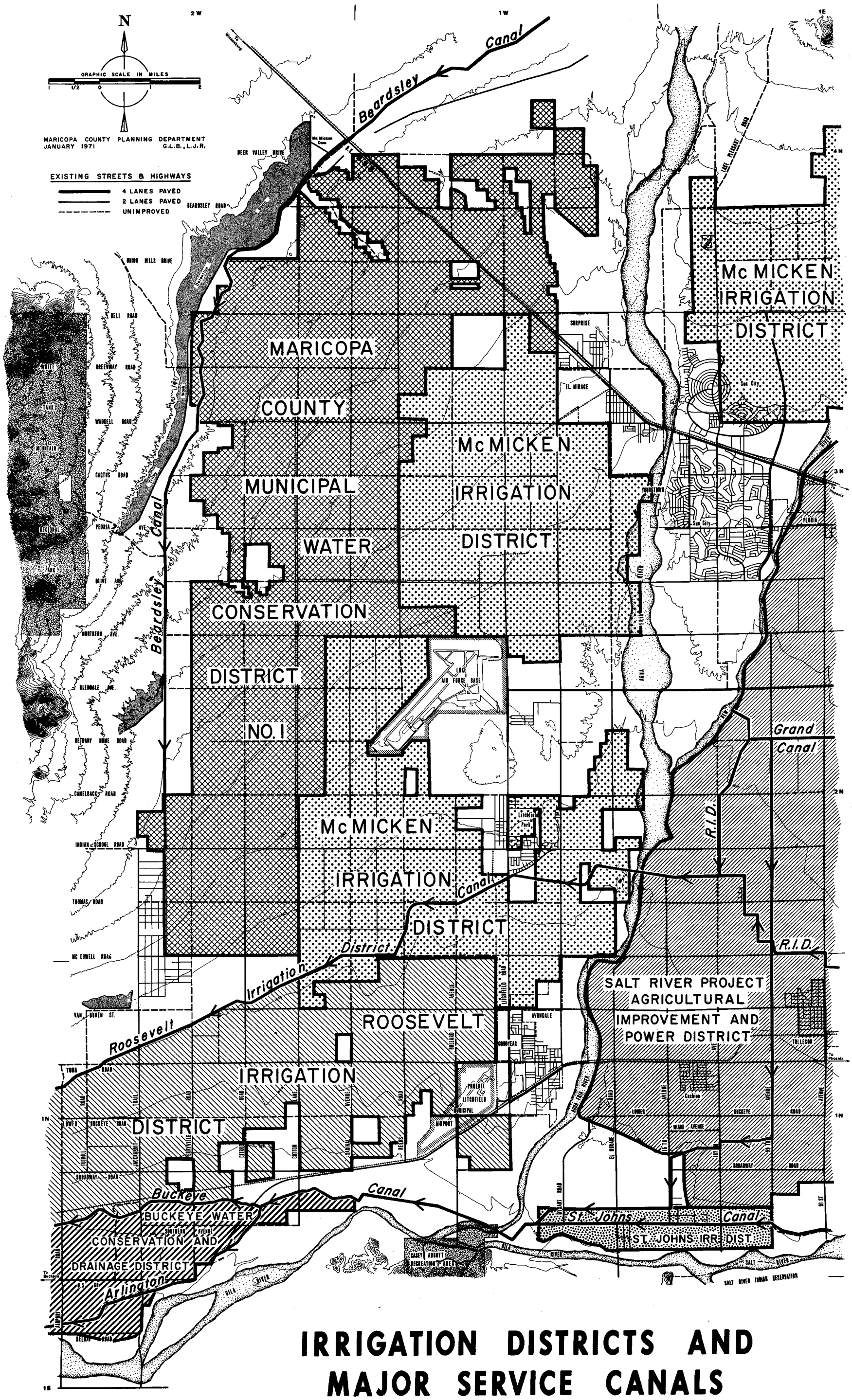
Surface indications of subsidence are evidenced by related earth cracks or fissures. In many water basins throughout southern Arizona, there has been attendant damage to railroad beds, highways, wells, reservoirs, and canals. Recently, subsidence has become noticeable in urban areas. These fissures commonly occur along the periphery of areas that have had maximum historical groundwater level declines.[45]

Although there have been no in-depth studies of land subsidence within the study area, there is evidence that it is taking place. In the area around Luke Air Force Base and in the townships to the north and northwest of the Base, there are a number of wells that have had a history of casing collapse. In addition, three earth fissures (in Section 25, T3N, R2W, Sections 2 and 17, T2N, R1W) have been identified.[31]

Reference to Plate 7, Subsurface Water Resources, shows that this area of subsidence lies on the northeastern edge of the area where the altitude of the water surface is the lowest.

It can safely be predicted that damage from this geological hazard will increase in the future if withdrawal of subsurface water continues at present rates in the Study Area.

WEST CENTRAL MARICOPA COUNTY, ARIZONA



IRRIGATION DISTRICTS AND MAJOR SERVICE CANALS

SOURCE: U.S. DEPARTMENT OF INTERIOR, BUREAU OF RECLAMATION

PLATE 9

CHAPTER VI

OTHER WATER SOURCES

In addition to the amounts of water available from the surface and subsurface as previously discussed, there are several sources of supply that are presently available in the study area or may become available in the future. These sources include irrigation imports, groundwater recharge from irrigation losses, allocations from the Central Arizona Project, and reclaimed waste water from treatment plants.

Irrigation Imports

Plate 9 shows the areal extent of the irrigation districts and the location of the major service canals within the study area. As previously discussed, all water available from Lake Pleasant is diverted to the Maricopa County Water Conservation District No. 1, by means of the Beardsley Canal. In the three areas comprising the McMicken Irrigation District, all irrigation water is obtained from subsurface wells.

In August, 1921, the Salt River Valley Water Users' Association (SRVWUA) signed an agreement with the Roosevelt Irrigation District (RID) which provided for the exportation of water outside the Association's boundaries. Because of the waterlogging of the soils in the western portion of the project area, SRVWUA was desirous of having these lands drained. At the same time, RID was anxious to obtain water for the irrigation of approximately 35,000 acres lying to the southwest of the project area. The agreement allowed RID to drill many wells and to move the water by a main canal to the lands within the District.

The maximum allowable export per year is 155,000 acre-feet and accumulated 5-year withdrawal is not to exceed 725,000 acre-feet (an average of 145,000 acre-feet per year). An official of the Roosevelt Irrigation District has estimated that approximately 40 percent of this import water is used within the Study Area. Since there is no termination date for the water portion of the agreement, there is an average of 58,000 acre-feet of water available per year, at least until such time as the subsurface reservoir is depleted.

As a result of litigation settled in December, 1943, the Salt River Valley Water Users' Association was required to supply a maximum of 80 acre-feet per day, or 1.1 percent of all water diverted at Granite Reef and used within the project area, to the Buckeye Water Conservation and Drainage District. Water produced from surface gravity sources in the Project area averaged approximately 1,200,000 acre-feet for the years 1968 and 1969. The median between 1959 and 1969, however, was about 880,000 acre-feet. As a dependable future source, the Salt River Project has estimated that an average of 750,000 acre-feet per year is a future dependable supply. At a diversion rate of 1.1 percent, approximately 8,250 acre-feet of water is available to the Buckeye District. Since about 23% of the total acreage in the District lies within the Study Area, there would be an average annual surface import of about 1,900 acre-feet.

Construction and river control upstream along with drainage pumping depleted the flow to the St. Johns Irrigation District. In January, 1922 an agreement was reached between the District and the SRVWUA whereby the Association would supply a certain quantity of water. The Association furnishes this water from two wells, however, and since the wells are located within the Study Area, the water is not imported but is part of the subsurface reserve.

A portion of the Salt River Project east of the Agua Fria and New Rivers falls within the study area. There are approximately 23,680 acres within the boundaries, or 9.94 percent of the Project's total assessed area of 238,262 acres. Since the water produced from wells is included in the analysis of subsurface reserves, only surface water brought into the area is considered at this point. As noted above, 750,000 acre-feet is estimated to be a dependable future supply in the Project area. Assuming that the water used would be in the same proportion as the acreage, nearly 75,000 acre-feet annually is imported from the Project's surface sources.

Irrigation Recharge

A part of the water applied to the land for irrigation is returned to the upper groundwater reservoir by infiltration. In addition, the aquifers are recharged by seepage from unlined canals and ditches carrying surface water supplies. The amount of water returned depends not only upon the amount applied, but also depends upon the permeability of the materials through which it must pass. Other factors, such as type of crop grown, depth of the root zone, and temperature, also influence the return to groundwater from irrigation sources.

Various investigations have revealed that the amount of irrigation water returned to subsurface aquifers ranges from as high as 70 percent to nearly zero percent of the water supplied to the surface. Since the surface soils and the upper subsurface rocks in the study are are of a rather uniform nature, it must be assumed that percolation rates would be good. However, in most of the area, the depth to groundwater is sufficiently great to indicate that recharge to the aquifer might be difficult. In the Lower Colorado Region Study prepared by the Pacific Southwest Interagency Committee[32], it was estimated that in the intermountain valleys of the southwest as much as 25 percent of water applied to the land for irrigation is returned to the groundwater reservoir.

The amount of recharge from surface irrigation to subsurface aquifers in a specific area is a complex and controversial subject. Some scientists and specialists familiar with the Study Area feel that because of the depth to the water table, little or no percolating water ever reaches the water table. As pointed out by staff members of the Arizona Water Commission, however, depth to water affects recharge in two ways. The first effect is that on travel time between the land surface and the water table. This, of course, is dependent upon the porosity and permeability of the materials through which the water must pass. The second effect is the increased possibility of a lessening of the amount of percolating water due to the need to saturate the upper volume of alluvium before percolating water can reach the water table. In much of the Study Area, the water levels were historically quite shallow and the strata between the historic and current levels has probably remained at a saturated capacity. Thus, once the percolating water is below the root zone, it suffers no loss in its movement downward. Transit time for a "particle" of water may be large because of the greater depths. However, since irrigation has been practiced in the area for many years, it is probable that the water table is continually receiving percolating recharge. Therefore, it will be assumed in this study that some recharge does take place.

As noted above, only percolating water which penetrates below the root zone of plants is available for subsurface recharge. As a result of an investigation of present land use, it has been determined that there are approximately 109,000 acres subject to irrigation in the Study Area. Since a variety of crops is grown, there is considerable variation in amount of acre-feet of water used each year. In a study by the Agricultural Experiment Station of the University of Arizona[26] the results of experiments on the "consumptive use of water" by various crops was recorded. These experiments aimed at arriving at the most efficient use of water on a given area for transpiration, building of plant tissue and evaporation from

adjacent soil for various irrigated crops. The annual seasonal use varied from less than 2 acre-feet for most vegetables to over 6 acre-feet for alfalfa. For most of the important crops grown in the Study Area, approximately four acre-feet of irrigation water was considered to be efficient use.

The ratio of actual application of surface water in excess of consumptive use is commonly referred to as "irrigation efficiency". Assuming 4 acre-feet as consumptive use, 75 percent irrigation efficiency would mean that 5.33 acre-feet of water was being applied to the land surface. The excess of 1.33 acre-feet would therefore be available for subsurface recharge.

During the year 1970, the Maricopa County Municipal Water Conservation District estimated that approximately 4.6 acre-feet of water was applied to a total of 23,410 cropped acres. This is an efficiency rate of 87 percent and must be considered to be very good. However, the District has had an intensive program of irrigation water conservation, and for the entire Study Area it is very doubtful that such an efficiency has been reached. It is probably more realistic to assume that an average of 6 acre-feet of application is the present practice. Nevertheless, because of increased experimentation, education and conservation necessity, it is hoped that total application of not more than 5 acre-feet of irrigation water would be accomplished within the time period of this study.

If all of the 109,000 irrigation acres within the Study Area were under irrigation, it must be assumed that at an average rate of 1 acre-feet of excess irrigation water, 109,000 acre-feet of water would be returned to subsurface reservoirs. This water resource will be available in the future by means of pumping wells.

Losses by conveyance of water in canals and lateral and service ditches are even more difficult to approximate. The total loss, in addition to the seepage from unlined transmission facilities must include consumptive use by plants adjacent to the water channels and accepted over-deliveries to users. Carollo Engineers, in their 1968 report[30], determined that in the entire area of the Salt River Project there was a total conveyance loss of about 310,000 acre-feet per year. Since approximately 10 percent of the Project acres fall within the Study Area, total loss would be 31,000 acre feet in the area east of the Agua Fria and New Rivers. Of the total acreage under irrigation in the Study Area, approximately 28 percent is within the Salt River Project. At the above rates, there is a total of about 110,000 acre-feet of conveyance loss per year in the Study Area.

Under existing conditions, it is believed that 70 percent of conveyance loss would be available for the recharge of basin aquifers. However, the present continuing program of canal and ditch lining will reduce present seepage losses and it will be assumed that only one-half of delivered water will be available as future pumpage. Therefore, 55,000 acre-feet of water per year will be added to potential future water resources.

CHAPTER VII

FUTURE WATER SOURCES

Before an attempt is made herein to summarize the total water resources in the Study Area, a brief examination will be made of potential future sources of water. From a broad regional standpoint, it is a popular conception that the desalination of seawater or deeper, brackish subsurface waters offers an almost unlimited source. Because of technological limitations, this source must be considered a remote possibility, especially insofar as the Study Area is concerned and within the time span (25 years) of the plan. "Break-throughs" in technology, however, can happen at any time and desalination may become the important source of future water. Future supplies obtained from the importation of water by means of the Central Arizona Project and the reclamation of waste waters from sewage treatment plants are more realistic potential sources of water.

Central Arizona Project

The Bureau of Reclamation initially proposed the Central Arizona Project (CAP) in 1947. Since that time there have been numerous hearings, voluminous reports and news articles, and almost endless discussion on the merits of this undertaking. Only recently, the Boards of Supervisors of Maricopa, Pima and Pinal Counties passed resolutions petitioning the Arizona Water Commission to proceed with the formation of a water conservation district and this district has now been formed by the State Legislature. The water conservation district will be the contractual agent for the payment of reimbursable construction charges of the

Central Arizona Project. The powers entrusted to the new Water Commission appear to provide an excellent means for the realization of the project and should also be of great value to future water conservation efforts in the state.

The general plan of development for the project provides for the conveyance and delivery of Colorado River water through a main aqueduct system extending from Lake Havasu to the Phoenix-Tucson area. The conceptual framework and principal objectives of the project have remained substantially unchanged since its origin.

Reference to Plate 5 will show that the proposed aqueduct will pass just north of the limits of the Study Area. Since the principal purpose of the project is to provide for supplemental water for irrigation, municipal and industrial uses, it is assumed that a turn-out structure serving the Study Area would be provided. An analysis will be made of the amount of water that might be available for future use from this source.

In 1964, the U.S. Supreme Court upheld the right of the State of Arizona to the use of 2.8 million acre-feet of Colorado River water per year from the mainstream and nearly one-half of this amount has been committed to Arizona uses on the mainstream. Due to increasing consumption in the Upper Basin as provided in the Colorado River Compact, the remaining amount of water will not be constantly available to Central Arizona. As of January, 1971, the U.S. Bureau of Reclamation (USBR) had projected the average annual project deliveries as follows:

Year	Acre-Feet
1980	1,562,000
2000	1,173,000
2030	990,000

TABLE 2

WEST CENTRAL MARICOPA COUNTY, ARIZONA

"Expressions of Interest in Central Arizona Project Water"
Through April 1, 1971 (Unit: Acre-Feet/Year)

	Purpose			Possible Deliveries		
Name	Irrigation	Municipal and Industrial	Total	1980 (29.90%)	2000 (22.45%)	2030 (18.95%)
Maricopa County Municipal Water Conservation District No. 1	84,165		84,165	25,165	18,895	15,949
Roosevelt Irrigation District (50%)*	37,500		37,500	11,213	8,419	7,107
McMicken Irrigation District (75%)*	147,000		147,000	43,953	33,001	27,857
Buckeye Water Conservation District (25%)*	8,500		8,500	2,542	1,908	1,611
Salt River Project (10%)*	30,000		30,000	8,970	6,735	5,685
City of Avondale		6,137	6,137	1,834	1,378	1,163
Town of Surprise		3,800	3,800	1,136	853	720
Arizona Water Company		2,460	2,460	736	552	466
Litchfield Park Service Company and Village		11,543	11,543	3,451	2,591	2,187
Totals	307,165	23,940	331,105	99,000	74,332	62,745

*Percent of total acres within the Study area

Source: Phoenix Development Office, U.S. Bureau of Reclamation

Also in January, 1971, the USBR tabulated "Expressions of Interest in Central Arizona Project Water" for all agencies in the project area. A total of 78 agencies expressed interest for a total of 5,224,200 acre-feet of Colorado River Water. Based on the above proposed deliveries, only 29.90% of the "requested" water would actually be available in 1980. By the year 2000, the percentage would drop to 22.45, and in the year 2030 it would have dropped to 18.95 percent.

The Arizona Water Commission, in cooperation with the USBR, has a research program under way to develop a recommended water allocation on the basis of need and benefit. Since their recommendations are not yet available, an analysis of possible CAP water for the Study Area will be made (1) on the basis of "expressions of interest", and (2) the ratio of water expected to population.

Table 2 shows the agencies within or partially within the Study Area and the amount of water for which they have expressed an interest. Assuming that each agency would receive only that percentage which is available for the entire project as noted above, projection of possible deliveries have been made. On this basis, the entire Study Area would receive about 100,000 acre-feet in 1980 and the amount would be reduced to approximately 63,000 acre-feet by the year 2030. It is not anticipated that these amounts actually would be available since several of the "requests" appear to be quite high and downward adjustments would be most likely.

Any formula that is adopted for the allocation of CAP water undoubtedly will contain some factor or factors relative to population distribution. The project waters will be used primarily in the central valley counties of Maricopa, Pinal and Pima which, according to the 1970 final census count, had a combined

population of 1,387,105 persons. In accordance with USBR extensions of available CAP water, each person now living in the area would be "entitled" to the following:

Year	Acre-Feet
1980	1.13
2000	0.85
2030	0.71

The present population in the study area is approximately 50,000 persons. If future allocations of CAP were made on strictly population pro-rata share basis, the following annual amounts would be available in the West Central part of Maricopa County:

Year	Acre-Feet
1980	56,500
2000	42,500
2030	35,500

Although the above analyses are of a very general nature, it is indicated that not less than 35,000 acre-feet and certainly not more than 100,000 acre-feet of future CAP water would be available in the study area. For planning purposes, however, two points of caution should be noted: 1. The long history of delays in getting the project under way may be repeated in the future and the actual availability of CAP water may be much beyond the year 1980.
2. The CAP water supply to the area could be reduced to zero if no one in the area chooses to contract for it, regardless of the recommendations of the Arizona Water Commission.

Wastewater Effluents

Water, being the valuable commodity that it is in the arid Southwest, has most always been "used" no matter what its source may be. For many years, effluents from Waste Water Treatment Plants (WWTP's), especially those in smaller communities, have flowed either involuntarily or deliberately after treatment to recharge groundwater reservoirs or to irrigate pastures and golf courses. With the development of larger WWTP's to serve growing urban areas, less efficient use of effluents is obvious. Effluents flows from the Phoenix metropolitan area now discharge into the Salt River channel where some flows are diverted for irrigation use, a small amount is pumped into an experimental facility at Flushing Meadows, some flows to the Buckeye heading and is diverted, and the remainder in part recharges the subsurface aquifers in the vicinity of the channel.[45]

It has been an American philosophy that sewage, as well as other forms of waste, should be quickly removed and best forgotten. With water being the critical resource that it is, this attitude must change. Future population growth and urbanization will supply an ever-increasing amount of effluent that can and should be reclaimed and recycled. It is encouraging to note that just recently the Phoenix City Council authorized the city manager to seek a $750,000 federal grant for experimental treatment of waste water to make it suitable for unrestricted agricultural use.

As pointed out above, effluents from WWTP's have been used for irrigation for many years and the use of such wastewater is probably best suited to agricultural needs. State regulations require that before wastewater may be released into a stream bed, it must have "complete treatment" which is essentially a reduction to certain limits of Biological Oxygen Demand (BOD) and suspended solids.

To the water engineer, this type of treatment means primary plus a secondary stage of reduction. "Complete treatment" should include tertiary and quaternary stages of reduction needed to bring the effluents to domestic drinking water standards.

In 1968, John Carollo Engineers, in addition to the Waterworks Report previously referred to[30], prepared a companion report entitled "Wastewater Report for the Valley Metropolitan Area of Phoenix, Arizona".[29] This comprehensive study covers existing facilities, wastewater contributions, effluent disposal, and outlines for the treatment and collection of wastewater based on projected needs. For detailed information on wastewater problems, reference should be made to this report. Some information affecting the West Central study area will be summarized in the following paragraphs.

Several of the small communities as well as the rural areas within the study limits are without sewers and must depend upon septic tanks for water-water disposal. The existing wastewater treatment plants, the rating in millions of gallons per day (MGD) and the general method of treatment is shown in Table 3. The total rated capacity is 72.41 MGD, although all plants may not be operating at full potential. Converted to acre-feet per year, these plants are capable of treating over 81,000 acre-feet of effluent annually within the general study area. As noted in Table 3, the bulk of the capacity is within the Phoenix 91st Avenue Plant and most of the capacity rights for the plant are held by jurisdictions outside of the study area. In a gravity collection system as used for the 91st Avenue Plant, the point for picking up wastewater is at the low point of the system. Without extensive redistribution works, the effluent from this plant is most "available" to lands within the study area.

Future urban development and the availability of sewers in areas now using septic tanks will increase the effluent produced, assuming, of course, that plant

TABLE 3

WEST CENTRAL MARICOPA COUNTY, ARIZONA

Existing Wastewater Treatment Plants

Contributor	MGD[1] Rating	General Method of Treatment
Apollo Mobile Home Park	0.04	Extended aeration + seepage pits
Avondale-Goodyear	0.75	Primary sedimentation + aerated oxidation ponds + digestion
Litchfield Park	0.21	Primary sedimentation + digestion + oxidation ponds
Luke AFB	3.00	Primary sedimentation + two stage trickling filters + secondary settling + digestion
Luke AFB	0.11	Oil separator
Phoenix Trotting Park	0.30	Extended aeration + evaporation ponds
Sun City	0.50	Aerated oxidation ponds + stabilization pond
Tolleson-Swift Company	2.50	Primary sedimentation + two stage trickling filters + secondary settling + digestion
Phoenix 91st Ave Plant	65.00*	Primary sedimentation + 5 mgd trickling filter + 60 mgd activated sludge + secondary settling + digestion
Total	72.41	

*Capacity rights held in plant by Phoenix, Scottsdale, Tempe, Glendale, Mesa, Youngtown, and Peoria. The 5 mgd section currently inactive.

From: "Waste Water Report for the Valley Metropolitan Area of Phoenix, Arizona" by John Carollo Engineers, 1968.

(1) Million gallons per day.

capacities would be expanded to handle the increased wastewater flow. Carollo estimated that between the 91st Avenue Plant, drawing from both outside and within the study area, and effluents from other jurisdictions, total availability could range as follows:

Area	MGD Flow 1980	MGD Flow 2000
91st Avenue Plant	74.0	142.0
Avondale	1.2	1.8
Goodyear	0.5	1.0
Litchfield Park	3.3	6.8
Luke AFB	1.0	1.0
Goodyear Aux. Airfield	1.2	1.2
Total	81.2	153.8

Based upon these estimates, approximately 90,000 acre-feet annually would be available by 1980 and this amount would increase to about 170,000 acre-feet by the year 2000.

Since the above indicates that effluents are a substantial future water resource, even within the study area, consideration should be given to costs involved. A comparison will be made with potential CAP water costs as they apply to domestic water use, described by CAP studies as Municipal and Industrial (M & I) water.

At present, Project water for M & I use is proposed to be sold at $50 per acre-foot as raw water at canal-side. At this rate, the water will have a basic cost of 15¢ per 1000 gallons. Additional charges, such as ad-valorem taxes, may bring the canal-side cost to as much as 17.2¢ per 1000 gallons. Although the quality of the water is such that it could be used directly for irrigation, further treatment will be needed for municipal use. Carollo has estimated that it would cost at least 6¢ more per 1000 gallons to treat the water and an

additional 1¢ per 1000 gallons to build the plant. The above figures do not include the cost of pipe lines which may be needed to bring the water into distribution systems. Thus the cost to the consumer could well be over 25¢ per 1000 gallons. As a comparison, it should be noted that the average family in Phoenix using 200 gallons of water per person per day now pays approximately 32¢ per 1000 gallons.

As noted previously, the effluent treated at the 91st Avenue plant is of sufficient quality that it can presently be used for the irrigation of forage crops and golf courses. Relative to the costs of bringing this water up to additional standards, Carollo has summarized as follows:

> "Additional treatment costing less than 10 cents per thousand gallons would make the effluent usable for general irrigation. Further additional treatment removing phosphates and ammonia, costing about another 15 to 20 cents per thousand gallons, including amortization of facilities, would produce water suitable for municipal uses. Such water would compare favorably with the Salt River supply during dry years and would be better than many of the well water supplies being used in the valley".(30)

As future economic conditions may dictate, wastewater effluents are an important future as well as present source of water. The treatment, storage and distribution of all such water is, of course, a rather complicated regional problem, and is beyond the scope of this report. Because of its broad application, one solution summarized by Carollo is quoted as follows:

> "Because the Salt River Project has long standing commitments permitting exportation of irrigation water, it is most logical to try to use the treated wastewater effluent in an exchange arrangement. The exchange concept is simply the substitution of treated wastewater for "fresh" water in irrigation practice with "fresh" water credit being given for the use of wastewater. The exchanged wastewater could be used on-project or for off-project commitments; the exchanged "fresh" water could be used both on-project and off-project. Exchanges would not necessarily be confined only to export commitments; wastewater deliveries could be made for agricultural purposes within the SRP boundaries as well. Export commitments are on the order of 200,000 a-f/year. By the year 2000 as much as 300,000 a-f/year of wastewater may be expected to flow to Valley treatment plants."(29)

CHAPTER VIII

WATER QUALITY

The science of "water quality" is the study of the chemical, biological and physical characteristics of the water and the effects of environment on these characteristics. The effects of use on the quality of water have only recently received the serious attention that the problem deserves. Not only is water being used faster than supplies are being replenished, but there is a deterioration in the general quality.

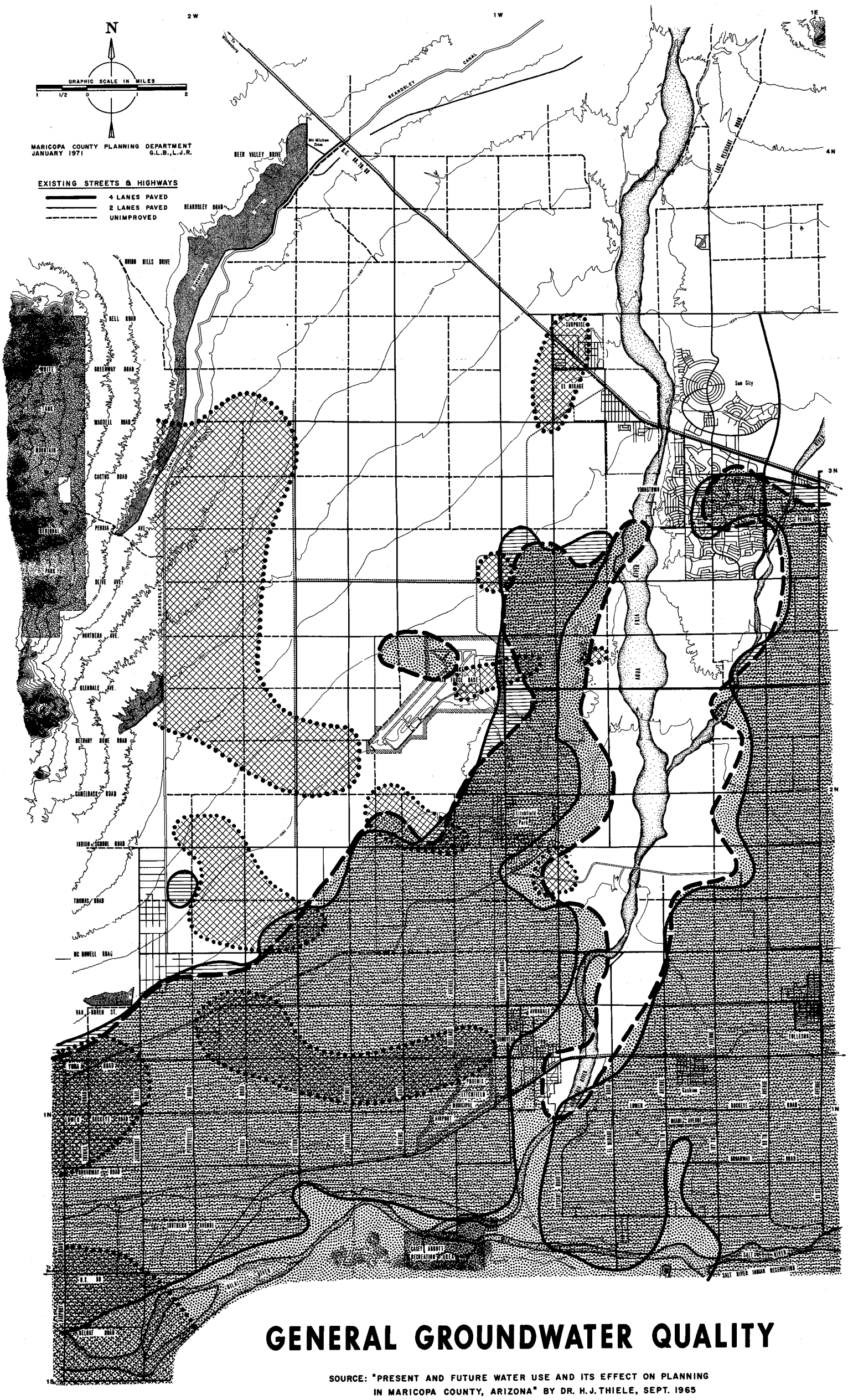
As water goes through its natural cycle - from rainfall, to surface flow and underground flow, to evaporation from lakes, streams and irrigation systems - it is constantly undergoing changes. Because of the rapid movement of surface water, the chemical and physical changes can be detected easily. Changes in underground water occur much more slowly and are apt to be more subtle due to the slow movement of water through the complex subsurface materials.

The following criteria are among those usually measured for the purposes of analyzing water quality:

1. Total Dissolved Solids (Soluble Salt Content) - These are salts of calcium, magnesium, sodium, patassium, et cetera, which are dissolved by water moving through or upon the rocks and soils, or added inadvertently by man.

2. Total Hardness - Hardness is a result mainly of dissolved calcium and magnesium (expressed as calcium carbonate equivalent) and is related to the amount of soap required to form a lather or deposits in boiler feedwaters.

WEST CENTRAL MARICOPA COUNTY, ARIZONA



GENERAL GROUNDWATER QUALITY

SOURCE: "PRESENT AND FUTURE WATER USE AND ITS EFFECT ON PLANNING IN MARICOPA COUNTY, ARIZONA" BY DR. H.J. THIELE, SEPT. 1965

LEGEND

- HIGH FLUORIDE (OVER 1.4 PPM)
- HIGH SALT CONTENT (OVER 500 PPM)
- HIGH HARDNESS (OVER 250 PPM)
- HIGH FLUORIDE WITH HIGH SALT OR HARDNESS
- HIGH SALT AND HARDNESS
- HIGH ALL THREE

PLATE 10

3. Fluorides - Groundwater coming in contact with granite rocks often has a high fluoride content. Too little fluoride in drinking water leads to a higher incidence of dental cavities among young children and too high a fluoride content may lead to a condition in which the teeth become discolored, mottled or brittle.

General Groundwater Quality

In 1962, the U.S. Department of Health, Education and Welfare issued their most recent revised edition of a publication entitled "Public Health Service Drinking Water Standards". These revised criteria are used by the Maricopa County Health Department in their review process for the approval of proposed water supplies and upper limits of chemicals in drinking water, some of which are mandatory and others recommended are as follows:

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

In 1965, Dr. H. J. Thiele prepared a report entitled "Present and Future Water Use and Its Effect on Planning in Maricopa County, Arizona".[34] The report was prepared for, and in cooperation with, the County Planning and Zoning Department. Several Plates showing the range of water quality criteria are included in his study. Plate 10 has been adapted from material presented in the Thiele publication and shows the areas wherein each of the three components exceed the suggested upper limits as defined by the Maricopa County Health Department. Several areas near the White Tank Mountains have waters with a high fluoride content but otherwise are of satisfactory quality. In most of the southeastern and southern parts of the Study Area, however, the groundwaters contain unsatisfactory levels of two or more components.

The information used in the Thiele report was based on records for the year 1963. It would be desirable to have continuous records which would reveal the changes in water quality, especially in problem areas as shown on Plate 10. A study, soon to be published, has been made by the Water Resources Division of the USGS of groundwater quality in the general area of this report. This study includes an analysis of over 450 wells, and preliminary information indicates that there may be additional areas with groundwater of poor quality. In addition, this report will contain information upon the discovery of what may become a commercial salt deposit to the east and southeast of Luke Air Force Base. An area of saline groundwater at depths of more than 1,000 feet below the land surface has been delineated. This preliminary information indicates that deeper potential aquifers may also have water of poor quality.

As an example of a modern water treatment plant, mention should be made of the installation at Buckeye, Arizona, just to the southwest of the Study Area. This electrodialysis plant has a design capacity of 630,000 gallons per day and treats raw well water of some 2,300 ppm total salts to a reduction below 500 ppm. Carollo has determined that if the plant could be operated at 90 percent continuous load, the cost would be about 35 cents per thousand gallons including amortization of the facility.[30] Since the Buckeye plant operates at lesser loads, its actual cost is 63 cents per thousand gallons including amortization. It is interesting to note that after the installation of the plant and the resultant increase in water costs, consumption of water was reportedly reduced nearly one half.

Quality of Surface Water

As previously noted, rainfall either percolates into the soil or is collected in storm drains for discharge into normally dry, gravelly river beds. Except for bacteria and turbidity, this water is otherwise of generally good quality and contains few dissolved salts. Storm water, which is of extremely low mineralization,

picks up minerals from the surface very rapidly unless the surface is rocky. Although there is little information on the quality of water from the upper Agua Fria River Watershed, it should be noted that the total soluble salts of 675 ppm is higher than desirable for human consumption. This water is satisfactory for normal irrigation uses and all the water from this source is presently being used for this purpose.

Potential water from the Central Arizona Project will also have high levels of dissolved mineral salts. In the 1964-65 water year, the U.S. Geological Survey, at a station below Parker Dam (Lake Havasu), measured dissolved solids from 705 to 818 ppm and hardness from 340 to 378 ppm. In the recent Lower Colorado Region Study, it was projected that dissolved solids would reach a concentration of 910 milligrams per liter (equivalent of parts per million) by 1980 and could reach 1140 mg/l by the year 2000.[33] In the "Summary of Findings" in this study it was stated that:

> "The major cause of salinity increases is due to increased development of the Upper and Lower Colorado Regions. It includes the additional stream depletions for municipal and industrial use, irrigations, thermal-power production, exports, reservoir exportation, and the additional salts leached from newly irrigated lands."

It is obvious that in the future all water, either for domestic or agricultural use, will require some form of treatment. As a comparison, Carollo reported that on January 11, 1967, an analysis of the effluent from the 91st Avenue Sewage Treatment Plant indicated total soluble salts to be 900 parts per million. Even with only secondary treatment, this effluent is as good or better quality than some but not all other surface and subsurface sources.

CHAPTER IX

SUMMARY

Environmental conditions in the study area, although not particularly unique insofar as the whole Salt River Valley is concerned, are of such a critical nature that careful consideration must be given to these factors in formulating a future development plan. A proper ecological balance of all of nature's components must be maintained in order that there will be the best conservation of human and natural resources that is possible.

The geology of the area forms the framework for the physical setting. Most of the two mountainous areas containing hard-rock outcrops are conserved as recreational and open space by virtue of their being a part of the Maricopa County regional park system. Some of the gentler topographic slopes on the east side of the White Tank Mountains, although unsuitable for agriculture, could be adapted to other land uses. However, problems of drainage, water supply and wastewater disposal pose definite limitations.

Climate, although having definite effects upon the physical materials, is neither unusual for the region nor is it a decisive factor in planning in the study area. The low annual rainfall is part of the whole water problem.

All of the soil types are suitable for agriculture, although there is some difference in the management and cultivation practices required from one kind to another. The greatest area of the most desirable soils for agriculture is found in the west-central portion of the study area. Likewise, there are no severe degrees of limitation on the use of the soils for non-farm, engineering or general planning purposes.

TABLE 4

WEST CENTRAL MARICOPA COUNTY, ARIZONA

Summary of Water Uses and Supplies

PRESENT USES	Ac-Ft Per Year
Urban (50,000 people at 200 gpcd)	11,200
Agricultural (109,000 irrigated acres at 5.0 acre-feet)	545,000
Total Annual Use	556,200
PRESENT INPUT SOURCES	
Agua Fria River base supply diversions from Lake Pleasant	20,000
Pumpage equalling White Tank Mountain rainfall recharge	4,000
Pumpage equalling rainfall recharge in drainage area below Lake Pleasant	4,000
Roosevelt Irrigation District import pumpage used in southern portions of study area	58,000
Buckeye Water Conservation and Drainage District surface import used in southern portion of study area	1,900
Salt River Project surface import used in south-eastern portion of the study area	75,000
Pumpage of recharge from farm headgate irrigation water	109,000
Pumpage of recharge equalling conveyance losses less evaporation	55,000
Total Annual Input	326,900

Water, in all its aspects, is the critical problem in the study area as well as being a regional problem. Table 4 is a summary of present water uses and input sources. On the basis of the best available information, it has been estimated that over one-half million acre-feet of water is used in an "average year" in the Study Area. Total average annual input has been calculated to be 326,900 acre-feet. It should be pointed out that an average of 5.0 acre-feet per year for irrigation is an "ideal use" under carefully controlled circumstances. Likewise, the amounts of recharge from surface sources may be quite optimistic, especially during times of extended drought.

The present deficiency of 229,300 is obtained from the depletion of the groundwater reserves above the amounts of recharge. It has been calculated that as of 1964, there was approximately 10 million acre-feet of water remaining in the upper aquifer in the study area. At the present rate of depletion, this groundwater source would be exhausted prior to the year 2010.

The differences in the amount of water used per unit area for agricultural versus urban purposes can vary considerably. Using the basic factors as employed in the previous Table 4, calculations were made of the comparative use of water as land might be converted from irrigation to urban development. This information is plotted on Plate 11. Plate 11 shows that there would need to be a total population of about 775,000 people before irrigation and urban uses would be equal.

To supplement present water sources, an investigation was made of future potential sources. The results revealed that there are two major possibilities and the amounts in acre-feet per year are estimated as follows:

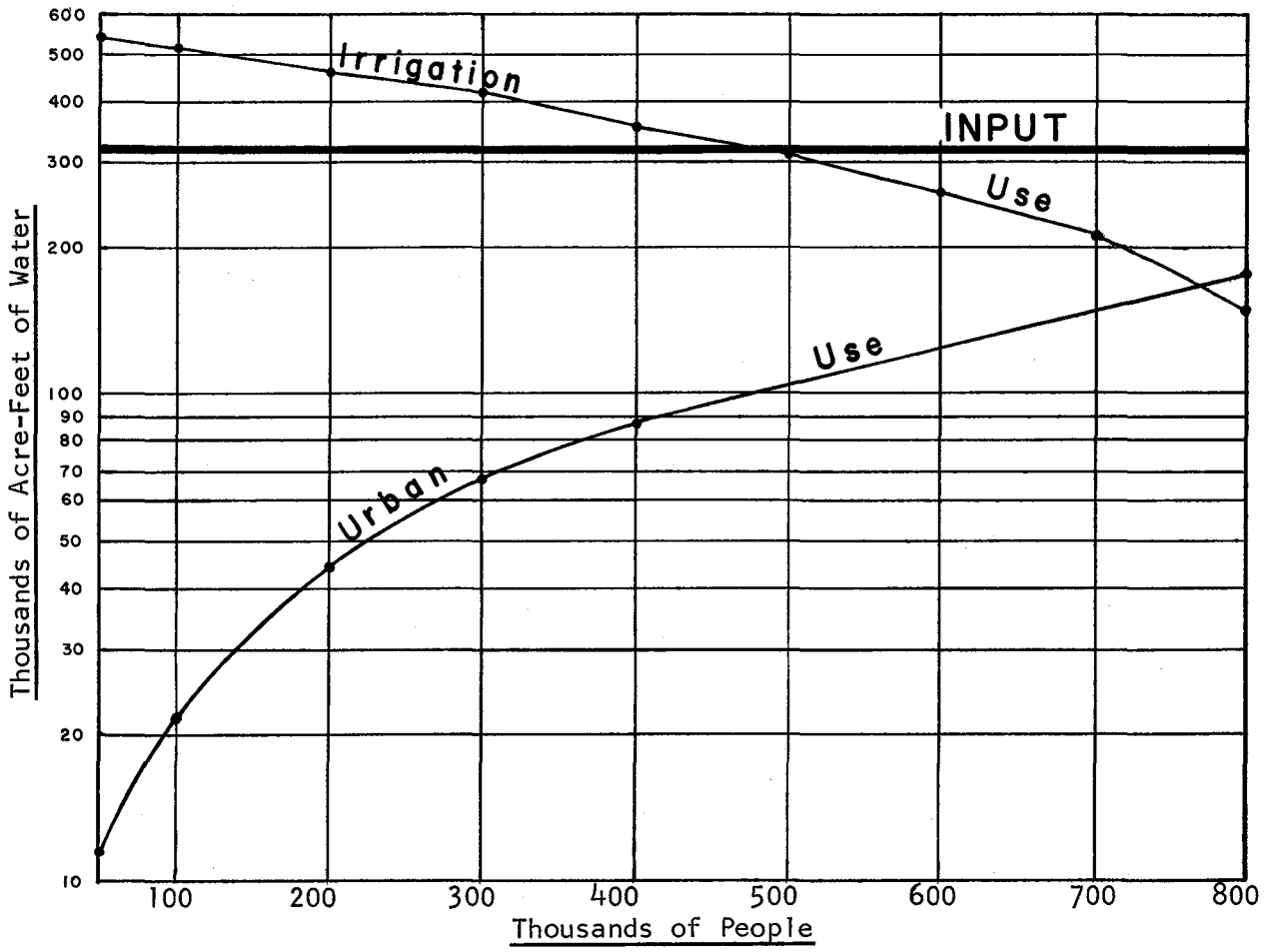
Central Arizona Project:	
Maximum available	100,000
Minimum available	35,000
Wastewater Effluents:	
Maximum available	150,000
Minimum available	80,000

PLATE 11

WEST CENTRAL MARICOPA COUNTY, ARIZONA

Comparison of Irrigation

and Urban Use of Water



Factors:

1. 5.0 acre-feet of water per year per irrigated acre (109,000 irrigated acres in 1971).

2. 200 gpcd urban consumption (50,000 persons = 11,200 acre-ft per year).

3. On the basis of 7,000 square-foot lots, each additional 100,000 persons would require 16.2 square miles or 10,368 acres of land.

Subsurface water quality in the Study Area varies from one part of the aquifer to another. Also, the quality of surface water varies with its source and the effects of the materials over which the water flows. It is obvious that presently, much of our water needs some form of treatment and more treatment will be needed in the future. It is important to note, however, that water can be treated to obtain satisfactory quality within reasonable economic limits. A higher cost to the consumer is a necessary result.

As pointed out several times in this report, many of the separate facets of the water problem need additional detailed study and a study on a regional basis. To qualify for federal assistance, studies of this nature will be necessary. As an example, the new-created Environmental Protection Agency, as of January, 1971, has issued a report entitled "Guidelines for Water Quality Management Planning". Under provisions of the Federal Water Pollution Control Act, any municipal waste treatment facility or interceptor sewer receiving grant support must be included in a total basin water plan, and where appropriate, also a metropolitan/regional plan. This must certainly be considered a forecast of future directions in other areas of environmental control.

APPENDIX A

BIBLIOGRAPHY

The publications listed in this bibliography are grouped under three major headings and the references are listed alphabetically by author under each heading. The numbers are consecutive and are not in order as referred to in the text.

There are many additional publications and reports that might have been included in this list. However, an attempt was made to select those which are most recent and most representative of the subjects and areas covered. Many of the publications in this bibliography contain listings of additional references.

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APPENDIX B

Glossary of Terms Common in Environmental Studies

Acre-Foot (AC-FT, ac-ft) - The quantity of water required to cover one acre to a depth of one foot and is equivalent to 43,560 cubic feet or 325,851 gallons. (U.S.G.S.)

Alluvium - Clay, silt, sand, gravel or similar material deposited by running water.

Alluvial Fan - A deposit built by rivers issuing from mountains upon lowlands. They are low, cone-shaped masses, steepest near the mouth of the valley, and sloping gently outward with decreasing gradient.

Alluvial Terrace - Banks of loose material, generally unconsolidated, which skirt the sides of the valleys about rivers, ponds and lakes.

Aquifer - A formation, group of formations, or part of a formation, usually consisting of permeable rock, sand or gravel, and which is water bearing.

Attitude - The position of something in relation to a frame of reference.

Basement Rock - A name commonly applied to metamorphic or igneous rocks underlying the sedimentary sequence (See Bedrock).

Bedrock - Any solid rock underlying soil, sand, clay, etc.

Biosphere - The part of the world in which life can exist.

Caliche - A crust of calcium carbonate that forms in or on the stony soil of arid regions.

Confluence - The place of flowing together of two or more streams.

Electrodialysis - The separation of substances in solution by means of electrical current.

Fault - A fracture or fracture zone along which there has been displacement of the two sides relative to one another and parallel to the fracture.

Inundate - To cover with a flood.

Lithosphere - The solid part of the earth.

Meteorology - A science that deals with the atmosphere and its phenomena and especially with weather and weather forecasting.

MGD (Million gallons per day) - Term used in rating capacity of Wastewater Treatment Plants (WWTPs). Equals 3.069 ac-ft/day or 1120 ac-ft/year.

Outcrop - The part of a hardrock formation that appears at the surface of the ground.

Permeability - The property of rock in its capacity for transmitting a fluid. Degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the latter.

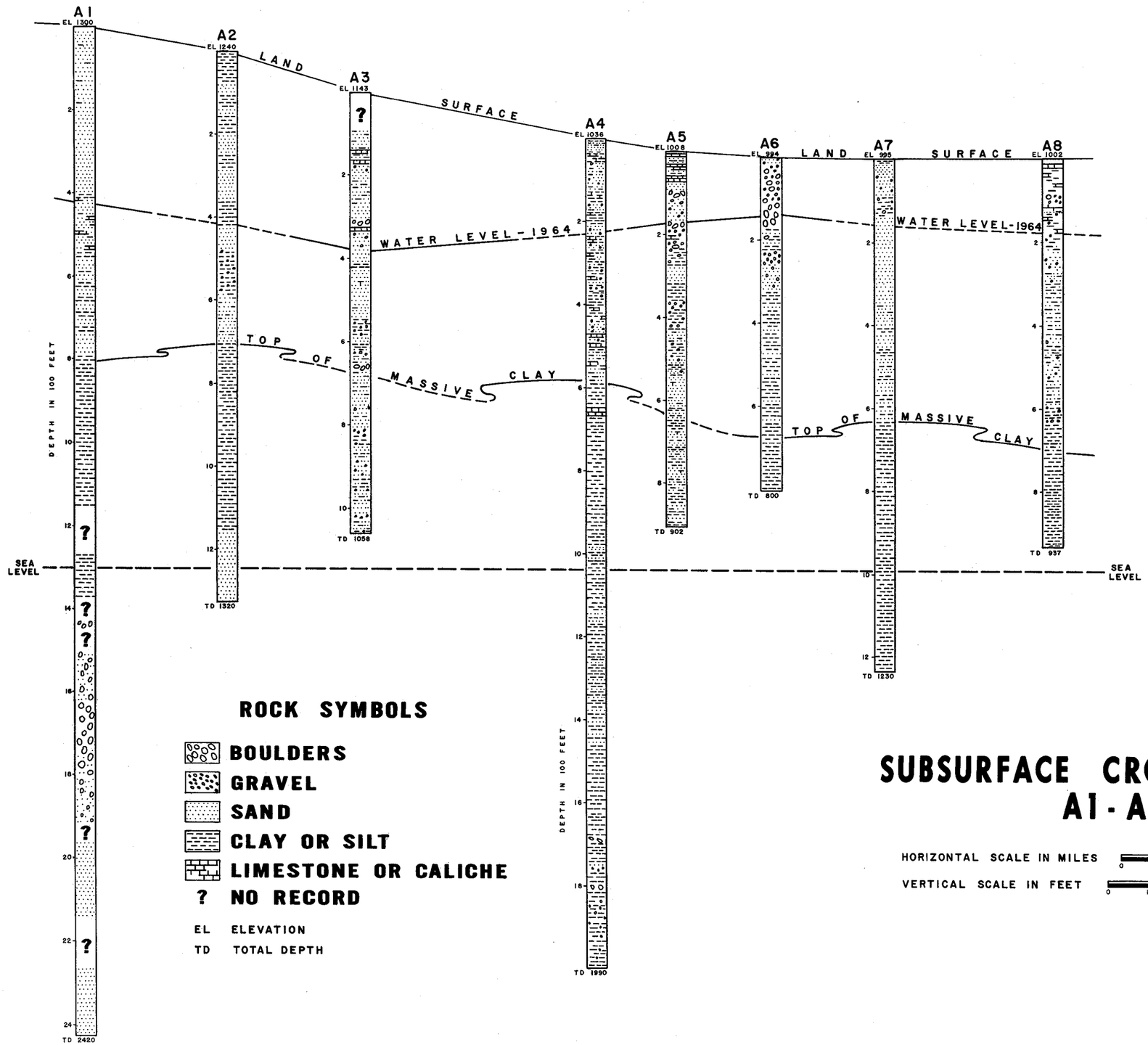
Photosynthesis - The combining of chemical compounds with the aid of radiant energy, especially sunlight.

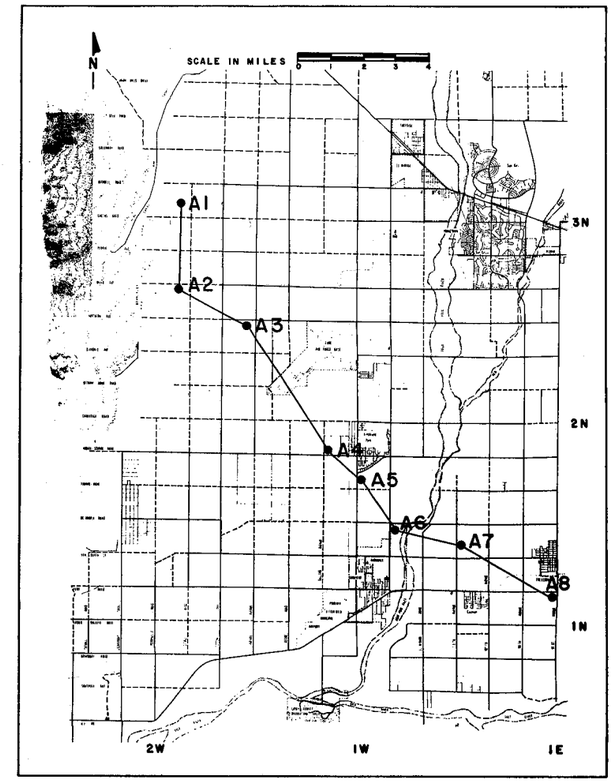
Planimeter - An instrument for measuring the area of a plane figure by tracing its boundary line.

Porosity - The ratio of the volume of void or open spaces of a material to the volume of its mass. It is usually stated as a percentage.

Sedimentary - Formed of fragments of other rock transported from its source and deposited in water (sandstone and shale), or formed by precipitation from solution (limestone, gypsum, salt).

Subsidence - The sinking downward or falling toward the bottom.





SUBSURFACE CROSS SECTION A1 - A8

HORIZONTAL SCALE IN MILES 0 1 2 3 4

VERTICAL SCALE IN FEET 0 100 200 300 400 500

APPENDIX C

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