EVOLUTION OF FLOOD CONTROL POLICIES AND PRACTICES IN CENTRAL ARIZONA

By

Esther Ruth Bajza

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POLICIES AND PRACTICES IN CENTRAL ARIZONA

By

Esther Ruth Bajza

May 1978

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ABSTRACT

This thesis examines the historical evolution of flood control policies and practices in the Phoenix metropolitan area. The circumstances and conditions that have influenced this evolution are discussed. Among the factors affecting flood control are the natural physical elements of the flood problem, namely meteorology and surface hydrology. Man's intervention in the natural systems as the Phoenix area changed from an Indian settlement to an agricultural community to an urbanized society is also investigated. This intervention has increased both the flood hazard and the damage potential, and has resulted in the need for human adjustments to flooding. The extent of human adjustment to date is closely examined and carefully detailed and includes both structural and nonstructural solutions to the flood problems. Finally, other factors which influence the flood hazard, such as changing values and perceptions, are discussed in light of their impacts on flood control policies and practices in the Phoenix metropolitan area.

ACKNOWLEDGEMENTS

Many individuals and agencies have provided information, photographs, and assistance during the research and writing of this thesis. Several individuals and groups have been especially helpful. The staff of the Salt River Project has given me access to many of their files and has supplied numerous photographs used herein. Photographs of various floods within the Phoenix metropolitan area have also been obtained from the Bureau of Reclamation, Boulder City, Nevada. Dr. Charles Sargent, Department of Geography, Arizona State University, has been kind enough to grant permission to include his maps depicting urban development within the Greater Phoenix area. Misters W. T. "Terry" Kirkpatrick and H. W. "Will" Worthington of the U.S. Army Corps of Engineers, Phoenix, Arizona, have been most helpful in providing information, background, and insight into the flood problems within the study area. Also, Mr. David Burris, Engineering Department, City of Phoenix, has been of great assistance in discussing aspects of the flood situation in Phoenix and suggesting other avenues for obtaining information. Especially, I am grateful to Dr. Robert W. Durrenberger for his assistance, guidance, and supervision in the preparation of this thesis.

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CHAPTER I - INTRODUCTION

Although the Phoenix metropolitan area is situated in a desert region, it is subject to serious and catastrophic damages due to flooding (Figures 1 and 2). Heavy rains producing flood conditions are infrequent, but they have occurred in the past and will occur again.

A significant flood hazard exists in many parts of the Phoenix metropolitan area. Usually the streams are dry and contain flows only during and immediately after storms (Figure 3). But intensive severe "flash floods" can result over small drainage basins, affording little or no time to warn affected communities of impending danger to life and property. Aggravating the flood problem are the braided, poorly-defined stream channels in the valley lowlands, the inadequate capacity of these channels, and the rapid urbanization of the area, with resultant encroachment onto the flood plain (Figures 4 and 5). The flood plain land is usually flat and not obviously subject to flooding.

A significant portion of the recent growth of metropolitan Phoenix has occurred in flood prone regions. Many of the alluvial fans and outwash areas, where the

Figure 1. 1972 Flooding Along Indian Bend Wash, Scottsdale, Arizona

Source: Salt River Project

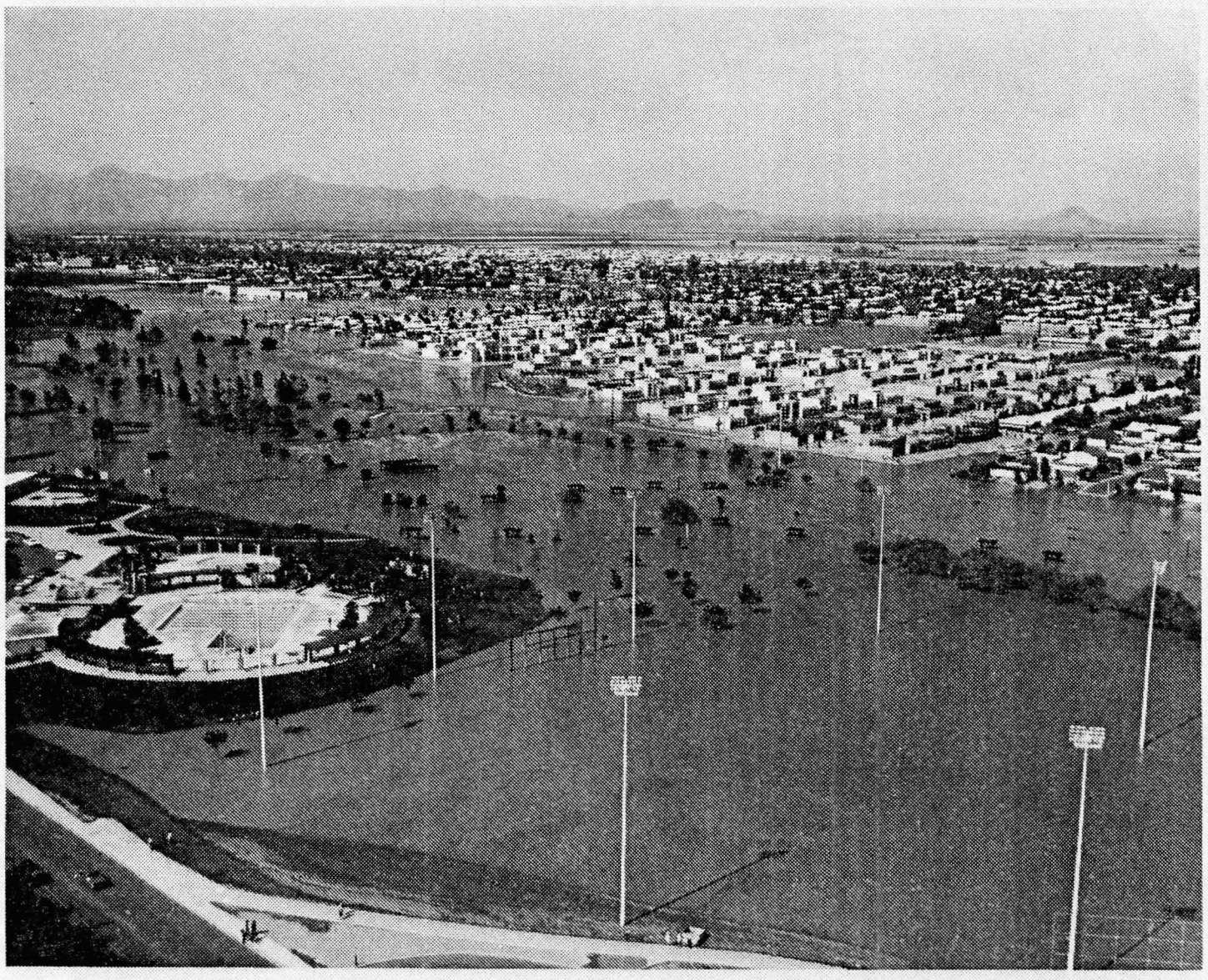


Figure 2. 1965 Flooding Along Salt River at 19th Avenue, Phoenix, Arizona

Source: U. S. Department of Interior, Bureau of Reclamation, E. E. Hertzog

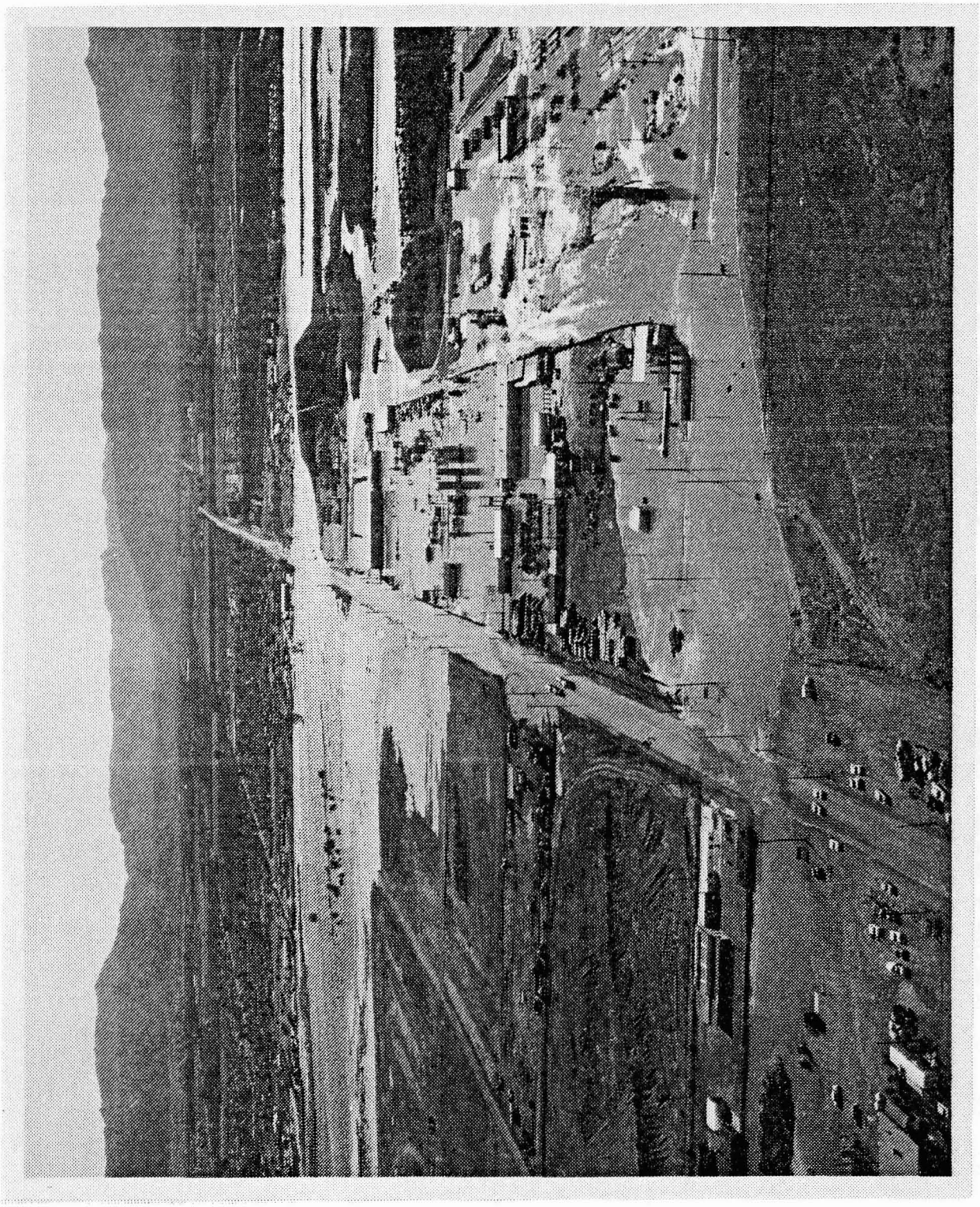


Figure 3. 1965 Flooding of a Cattle Feedlot Along Salt River Upstream of 40th Street, Phoenix, Arizona

Source: U. S. Department of Interior, Bureau of Reclamation, E. E. Hertzog

Figure 4. Urbanization Superimposed on Landscape with Braided, Poorly-Defined Channels, Phoenix Metropolitan Area, Arizona

Source: Landis Aerial Surveys and Photography, 1978

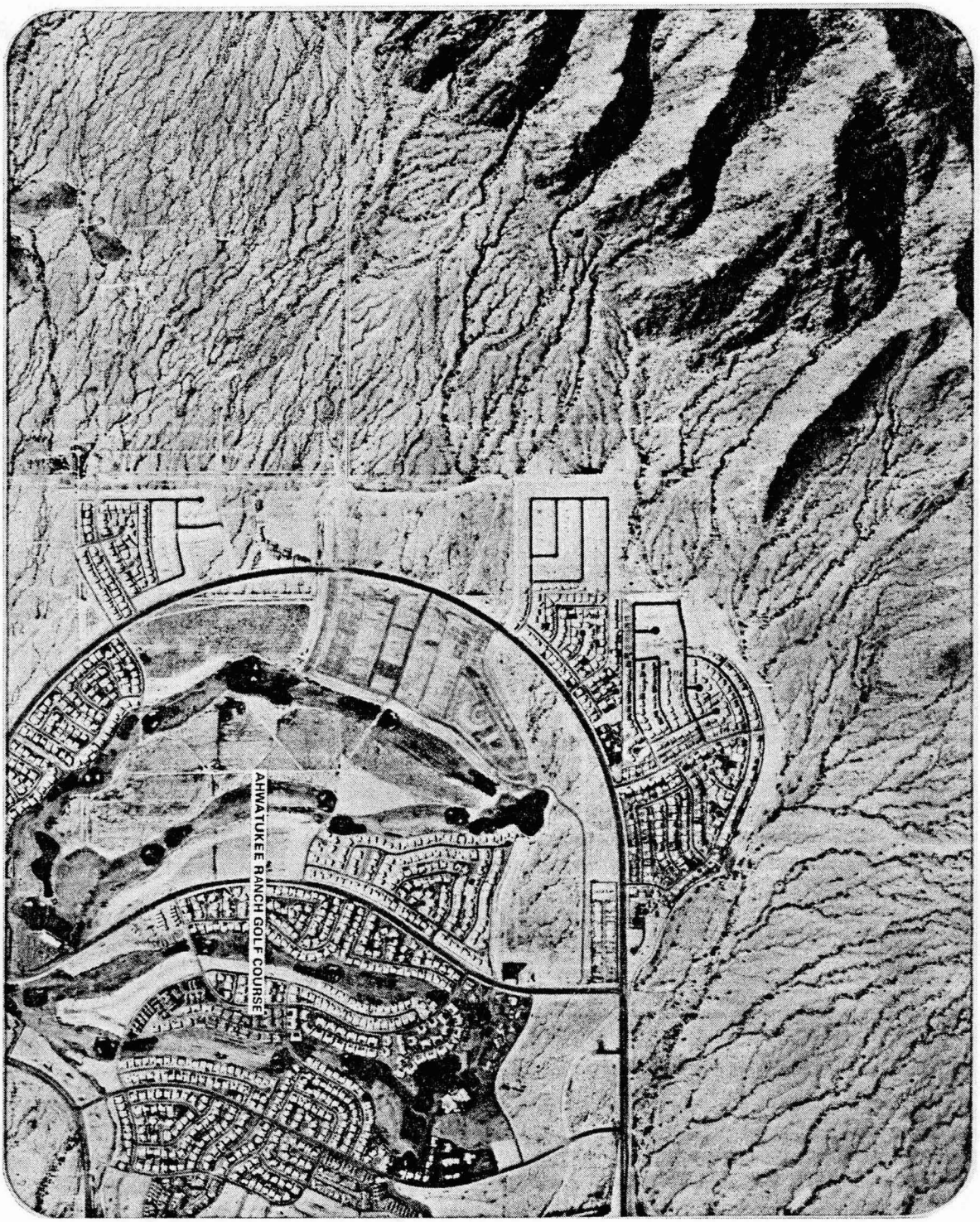
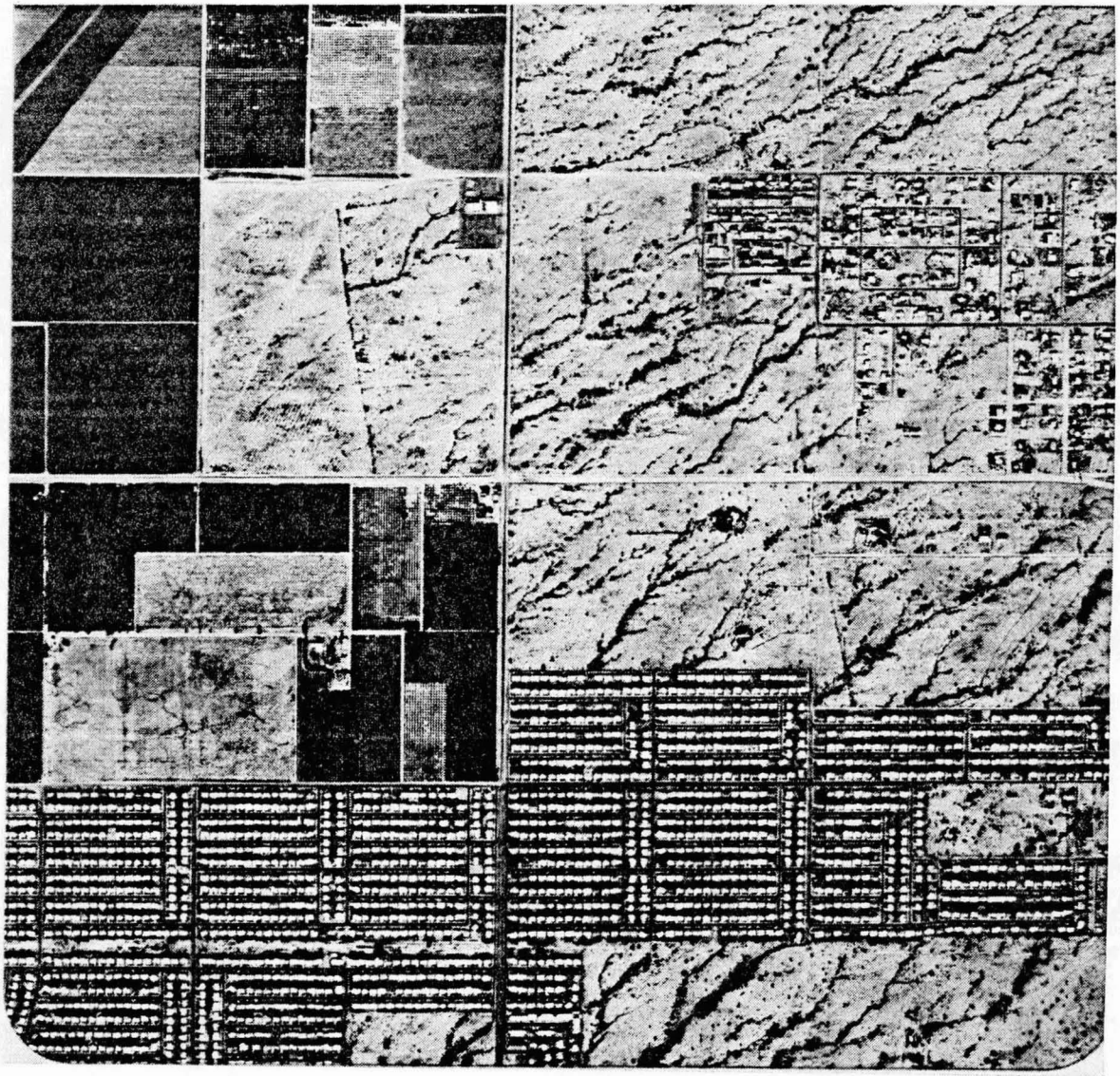

AHWATUKEE RANCH GOLF COURSE

Figure 5. Urban and Agricultural Development of Braided, Poorly-Defined Channels, Phoenix Metropolitan Area, Arizona

Source: Landis Aerial Surveys and Photography, 1978



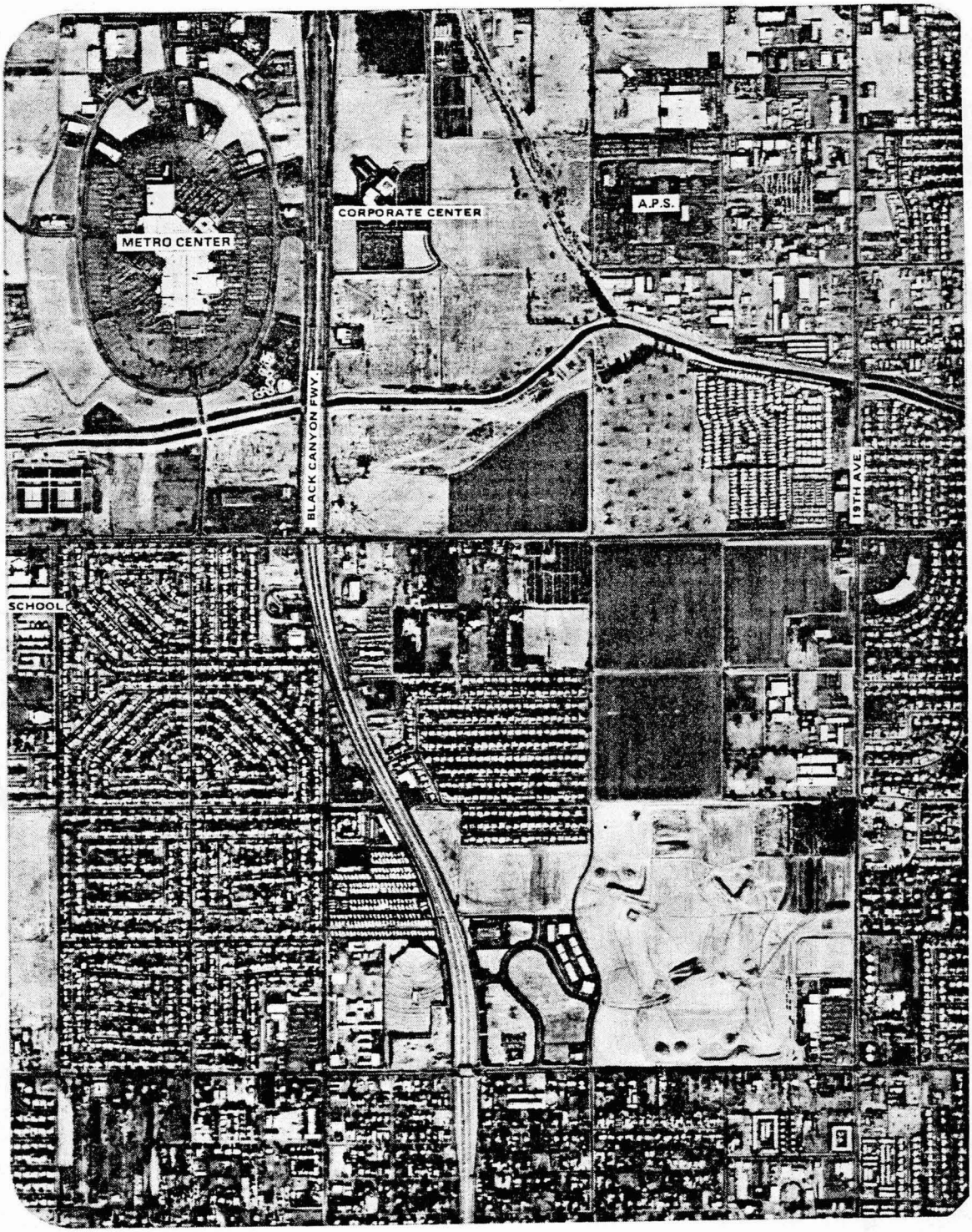
paths of water flow were not well defined, have undergone urbanization. In many parts of the valley the flood plains have been altered and the wide, shallow channels have been obliterated by development. South of the Arizona Canal, where most of the developed land is located, first agricultural and later urban growth have obliterated any traces of the Cave Creek and other stream channels (Figure 6). The Arizona Canal is a key link in the Salt River Project canal system that delivers water to the Phoenix urbanized area and to the surrounding agricultural area.

The problem along the Arizona Canal is twofold: (1) flood flows pond behind the north bank of the canal and inundate adjacent lands; and (2) flood flows enter the canal and may overtop the canal banks after the canal has reached its capacity and, thus, property to the south or downstream side of the canal is damaged. Therefore, it is difficult, if not impossible, for new residents to discern the potential hazard associated with occupance of such areas.

The scenario presents a disturbing situation. Water from heavy rains must drain through the city as a consequence of the topography. Floods would necessarily pass through urbanized areas of residential subdivisions

Figure 6. Cave Creek Channel Obliterated South of the Arizona Canal by Agricultural and Urban Development, Phoenix Metropolitan Area, Arizona

Source: Landis Aerial Surveys and Photography, 1978


METRO CENTER
CORPORATE CENTER
A.P.S.
BLACK CANYON FWY.
19TH AVE
SCHOOL

and commercial establishments, wreaking havoc and destruction commensurate with the magnitude and duration of the storm.

Without flood control improvements in the metropolitan area, floods would cause equivalent annual damages of $17.9 million expressed in 1975 dollars (U. S. Army Corps of Engineers, 1976a).

Geographers interested in natural hazard research have sought to understand why people live in flood plains and what impact public action to reduce flood damages would have on local land use and the national economy (White, 1974).

STATEMENT OF PROBLEM

In the past the Phoenix metropolitan area experienced damaging floods and as the area continued to develop the flood hazard increased. This hazard is a result of many individual and governmental decisions which were made with little understanding of flood damage potential. Thus, the problem is: How have the flood control policies and practices developed in the Phoenix metropolitan area and what should be done to modify these decision-making processes?

STATEMENT OF PURPOSE

Development and enforcement of flood plain regulations must be coordinated with land use planning efforts to insure optimum utilization of flood prone regions. Greater knowledge of the processes by which flood control policies are established and the factors involved in the processes will provide guidelines to enable governments to design and execute effective programs for flood protection. Prior to the formulation, selection, and execution of the best alternative solutions for flood protection and mitigation of losses one must be cognizant of how the present and proposed flood control programs evolved and what factors affected this evolution.

According to White (1974), "it is possible to recognize major limitations and incentives which would affect new government initiatives to hopefully reduce distress." Studies in the realm of natural hazards can, therefore, point out steps for action to rectify the problem. The policy implications of such research are implicit. By understanding the social-physical interactions the policy-makers can influence public action at many different levels. It is the purpose of this study, therefore, to provide an understanding of the development of the flood control programs in order to modify the

decision-making processes in the future.

The objectives of this study are analogous to those pertaining to natural hazard research. They include:

1. Estimating the extent of human occupance in the flood prone regions.

2. Reviewing significant floods and resultant damages.

3. Determining the range of possible adjustments to the flood hazard.

4. Examining how people perceive flooding and the resultant hazard as witnessed by the outcome of proposed legislation pertaining to flood control measures.

5. Determining the critical factors influencing legislation.

6. Discussing factors to be employed for future modification of the decision-making processes regarding flood control.

LIMITATION OF THE STUDY

The scope of the study was limited to an analysis of the historical development of flood control policies and practices. Although recommendations for alternative solutions to the flood problems plaguing metropolitan Phoenix would be valuable, they are not espoused in this study because time does not permit.

The study area was limited to the same area as the Phoenix Urban Study, a comprehensive water resource study presently being pursued by the U. S. Army Corps of

Engineers. The Corps of Engineers' selection of the study area was predicated on the belief that the water resources and water problems of this area were interrelated.

RESEARCH AREA

The study area (Figure 7) was selected to coincide with that of the U. S. Army Corps of Engineers' boundaries for the Phoenix Urban Study. The boundaries encompass those cities and communities expected to comprise the contiguous metropolitan region within the next fifty years and whose flood problems are interrelated.

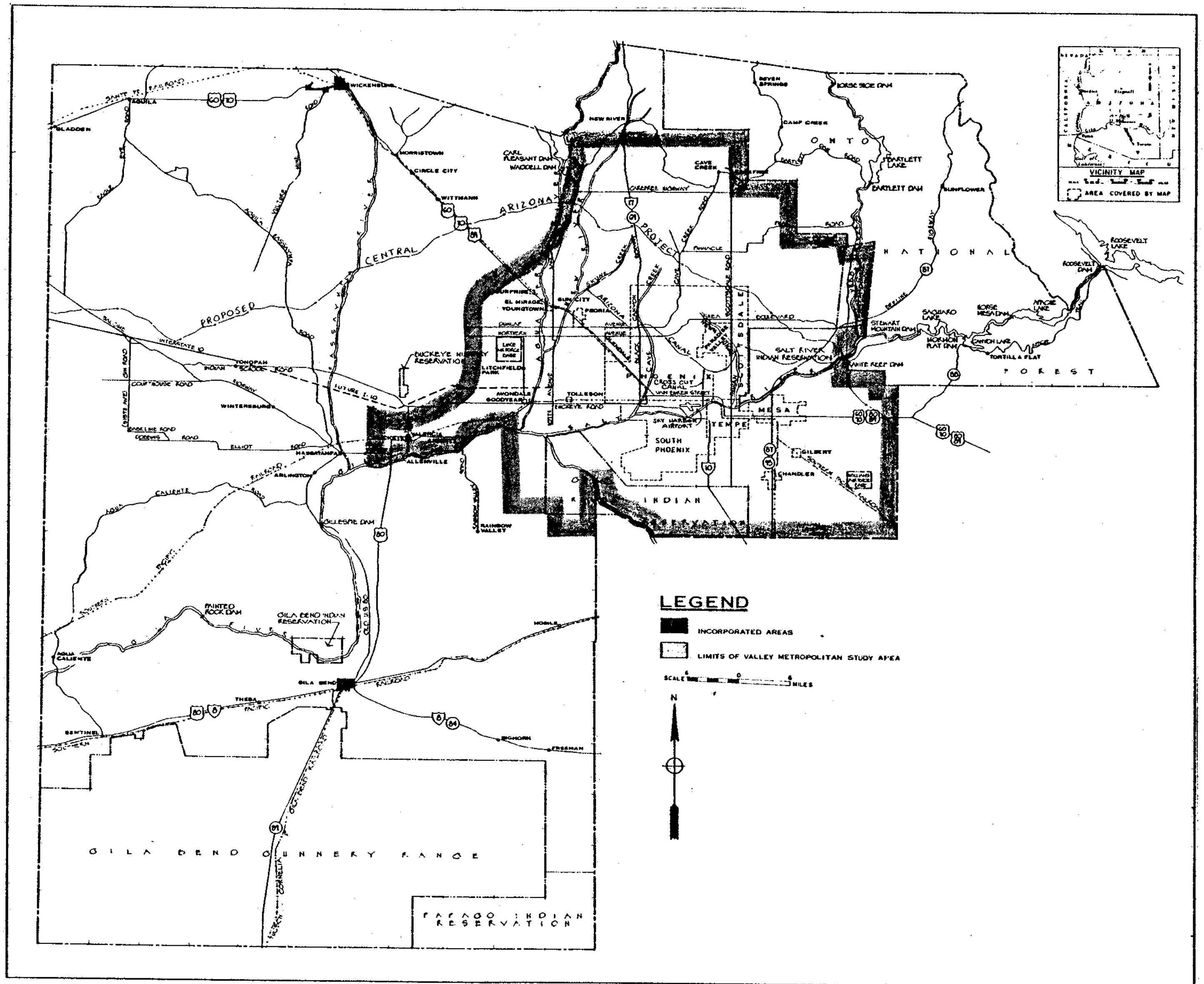
The study area is located in south central Arizona and occupies approximately 2,300 square miles in the heart of the Salt River Valley. Phoenix, Scottsdale, Tempe, Mesa, and Glendale, the five principle cities in the urban area, represent 93 percent of the population of Maricopa County.

Topography and Drainage

The metropolitan region is characteristically a flat, desert alluvial valley encircled by rugged mountain ranges with steep gradients. South Mountain, the Phoenix Mountains, and the McDowell Mountains are the dominant mountain ranges within the study boundaries (Figure 8). Included on the periphery of the study area are the

Figure 7. Study Area, Phoenix Metropolitan Area, Arizona

Source: U. S. Army Corps of Engineers, 1975a


LEGEND
INCORPORATED AREAS
LIMITS OF VALLEY METROPOLITAN STUDY AREA
MILES
N
VICINITY MAP
AREA COVERED BY MAP
WICKENBURG
MORRISTOWN
CIRCLE CITY
WITTMANN
NEW RIVER
CAVE CREEK
CAMP CREEK
SEVEN SPRINGS
BARTLETT LAKE
BARTLETT DAM
SUNFLOWER
ROOSEVELT LAKE
ROOSEVELT DAM
SAGUARO LAKE
STEWART MOUNTAIN DAM
CANYON LAKE
TORTILLA FLAT
SALT RIVER INDIAN RESERVATION
SURPRISE
EL MIRAGE
YOUNGTOWN
SUN CITY
PEORIA
LITCHFIELD PARK
AVONDALE
GOODYEAR
TOLLESON
BUCKEYE
ALLENVILLE
ARLINGTON
HASSAYAMPA
WINTERSBURG
TONOPAH
SOUTH PHOENIX
TEMPE
MESA
GILBERT
CHANDLER
RAINBOW VALLEY
ARIZONA
CENTRAL
PROJECT
PROPOSED
INDIAN
RESERVATION
NATIONAL
FOREST
PAINTED ROCK DAM
GILA BEND INDIAN RESERVATION
GILA BEND
GILLESPIE DAM
SENTINEL
GILA BEND GUNNERY RANGE
PAPAGO INDIAN RESERVATION

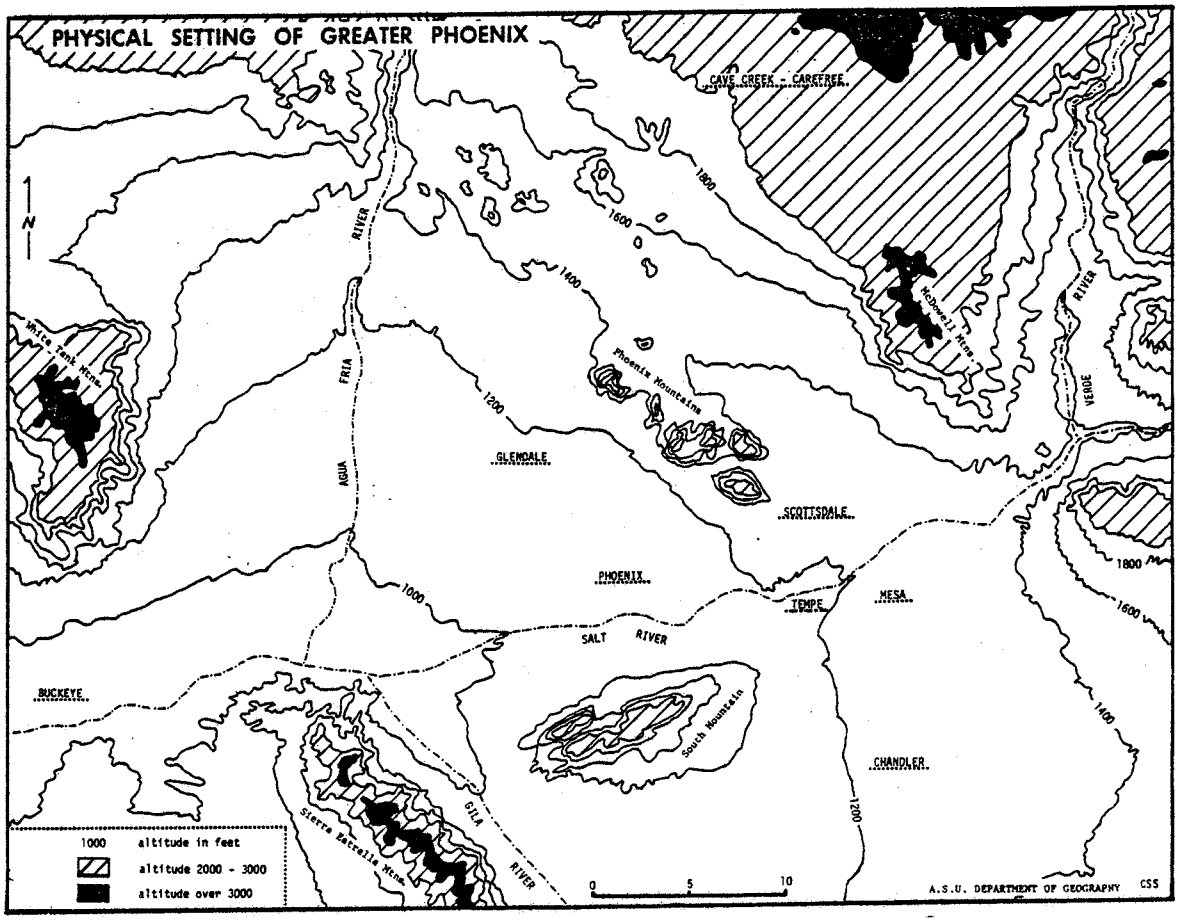


Figure 8. Physical Setting of Greater Phoenix, Arizona

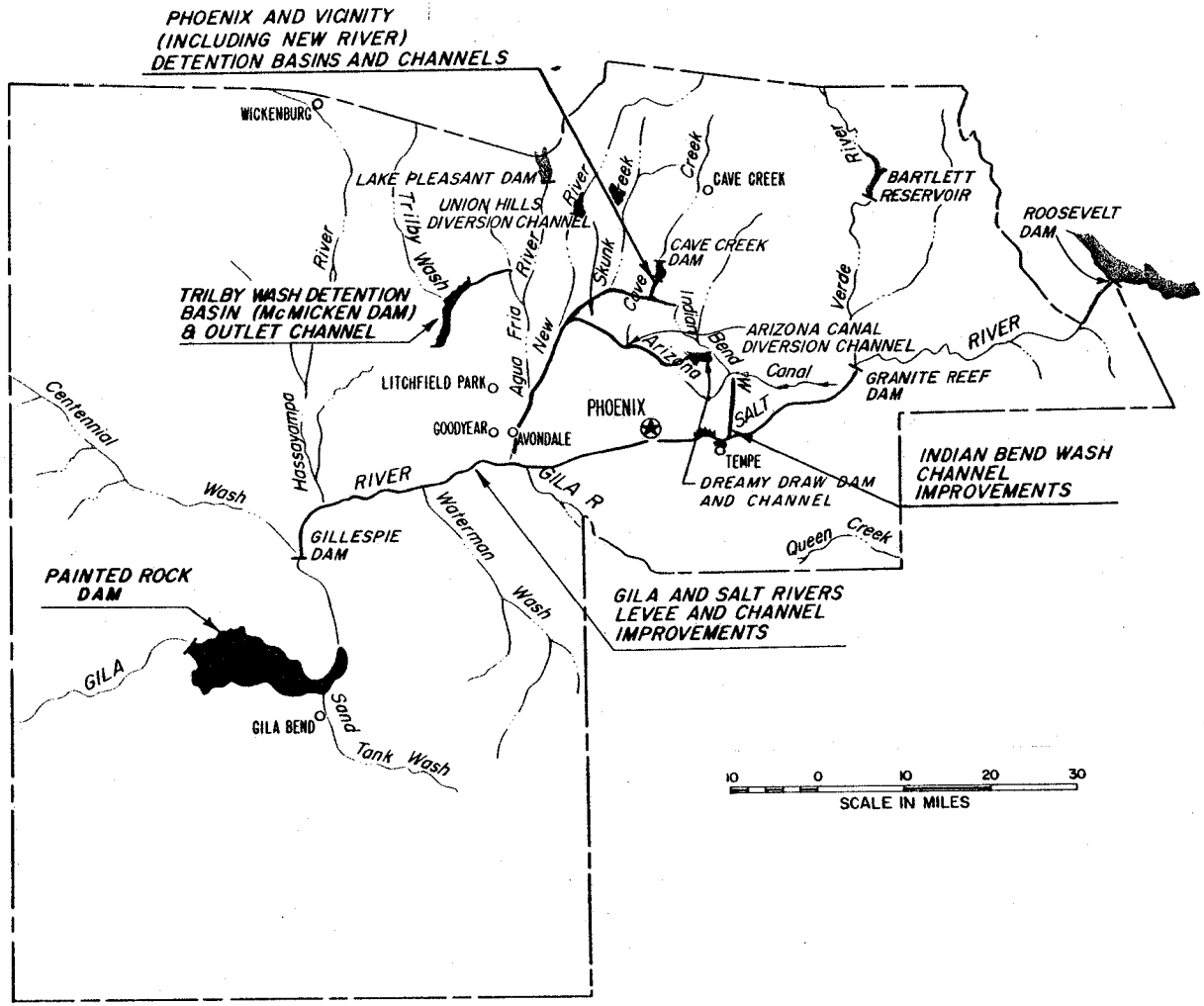
Source: Sargent, 1973

following mountain ranges: the Hieroglyphic and New River Mountains to the north; the Superstition, Goldfield, and Mazatal Mountains to the northeast; the Santan and Sacaton Mountains to the southeast; the Sierra Estrella Mountains to the southwest; and the White Tank Mountains to the west.

The study area is within the Gila River Basin, which is the largest drainage area tributary to the lower Colorado River and comprises 58,200 square miles. The northern and eastern mountain ranges drain into the Salt and Agua Fria Rivers, tributaries of the Gila River, and their tributaries. The drainage basin of the Salt River is 16,040 square miles and that of the Agua Fria River is 2,340 square miles. Major tributaries of these rivers within the study boundaries include Indian Bend Wash, Verde River, Cave Creek, Skunk Creek, New River, and many other washes and arroyos (Figure 9). The confluence of the Salt and Agua Fria Rivers with the Gila is in the southwestern portion of the study area. Surface flow in these streams is ephermeral with flows occurring only after heavy precipitation or releases from the Salt River Project reservoirs northeast of the study boundaries. Elevations range from 910 feet at the confluence of the Agua Fria and Gila Rivers to 7,000 feet in the mountainous region near the headwaters of the Agua Fria River.

Figure 9. Gila River and Tributaries within Maricopa County, Arizona

Source: U. S. Army Corps of Engineers, 1977


PHOENIX AND VICINITY
(INCLUDING NEW RIVER)
DETENTION BASINS AND CHANNELS
WICKENBURG
LAKE PLEASANT DAM
UNION HILLS
DIVERSION CHANNEL
Trilby Wash
River
TRILBY WASH DETENTION
BASIN (McMICKEN DAM)
& OUTLET CHANNEL
Hassayampa
Centennial
Wash
LITCHFIELD PARK
GOODYEAR
AVONDALE
Agua Fria
New
River
Skunk
Creek
Cave
Creek
CAVE CREEK
CAVE CREEK
DAM
Indian
Bend
Wash
Arizona
Canal
ARIZONA CANAL
DIVERSION CHANNEL
PHOENIX
SALT
RIVER
TEMPE
DREAMY DRAW DAM
AND CHANNEL
GILA R
RIVER
GILLESPIE
DAM
Waterman
Wash
Queen
Creek
PAINTED ROCK
DAM
GILA
GILA BEND
Sand
Tank Wash
River
Verde
BARTLETT
RESERVOIR
ROOSEVELT
DAM
RIVER
GRANITE REEF
DAM
INDIAN BEND WASH
CHANNEL
IMPROVEMENTS
GILA AND SALT RIVERS
LEVEE AND CHANNEL
IMPROVEMENTS
10 0 10 20 30
SCALE IN MILES

Topographic characteristics of the major waterways draining the study area are described in Appendix A.

Climate

The metropolitan Phoenix area is located in the Sonoran Desert climatic zone, which is characterized by long hot summers, short mild winters, low annual precipitation, low relative humidity, and a high percentage of possible hours of sunshine. During July, the hottest month, temperatures range from an average daily maximum of 105 degrees Fahrenheit to an average daily minimum of 75 degrees Fahrenheit. In January, the coolest month, average daily maximum and minimum temperatures range from 66 degrees Fahrenheit to 34 degrees Fahrenheit, respectively (U. S. Army Corps of Engineers, 1976b).

Precipitation generally occurs as heavy thunderstorms of short duration in the summer and long light showers in the winter. Widespread precipitation may occur in late summer or early fall as a result of tropical storms. Cyclonic storms are the cause of most winter precipitation. The average annual precipitation is 7.2 inches in Phoenix and about 24 inches in the upper watersheds. Slightly more than half of the annual precipitation falls between November and April. The maximum precipitation for a 24-hour period is 5.0 inches,

which occurred in July 1911 (U. S. Army Corps of Engineers, 1976b).

The average relative humidity ranges from 24 percent in the summer to 54 percent in the winter. Extensive irrigated areas, open canals, and introduced urban plantings have been responsible for an increase in relative humidity in the Phoenix area (U. S. Army Corps of Engineers, 1976b).

Phoenix averages 86 percent of possible hours of sunshine annually with monthly averages ranging from 77 percent in December to 94 percent in June (U. S. Army Corps of Engineers, 1976b).

Winds are most frequently from the east. Average wind velocity is 6 miles per hour with gusts occasionally up to 40 miles per hour. In Phoenix the strongest recorded gust was 75 miles per hour (U. S. Army Corps of Engineers, 1976b).

Vegetation and Wildlife

The biological study area lies within the Lower Sonoran Life-Zone. Vegetation found within this life-zone is termed Southwestern Desert scrub. The Sonoran Desert, one of three subdivisions of the North American Desert, extends over most of southwestern Arizona and is usually characterized by creosote bush and paloverde communities.

Typically, vegetation in this life-zone is found in low, arid regions and extends to altitudes of approximately 3,000 feet where the terrain is gentle, and about 4,000 feet on steep slopes.

The large number of ephemerals or short-lived herbaceous plants is an important feature of the desert vegetation. Following the winter and summer rainfall periods, the ephemerals appear in early spring and late summer. Numerous perennial, winter annual, and summer annual plant species exist in the research area.

The natural plant life of the area can be classified into three types of communities: desert wash or riparian; desert outwash plain or bajada; and desert upland. A number of microenvironments have been produced by the variability of substrates, topography, moisture, and other factors. For this reason it is often difficult to identify discrete vegetative associations in the study area. Therefore, the use of a generalized classification provides a meaningful characterization of the floral environment (U. S. Army Corps of Engineers, 1976b). A plant community and physiographic profile is shown on the following page in Figure 10.

Discussion of the three types of natural plant communities follows:

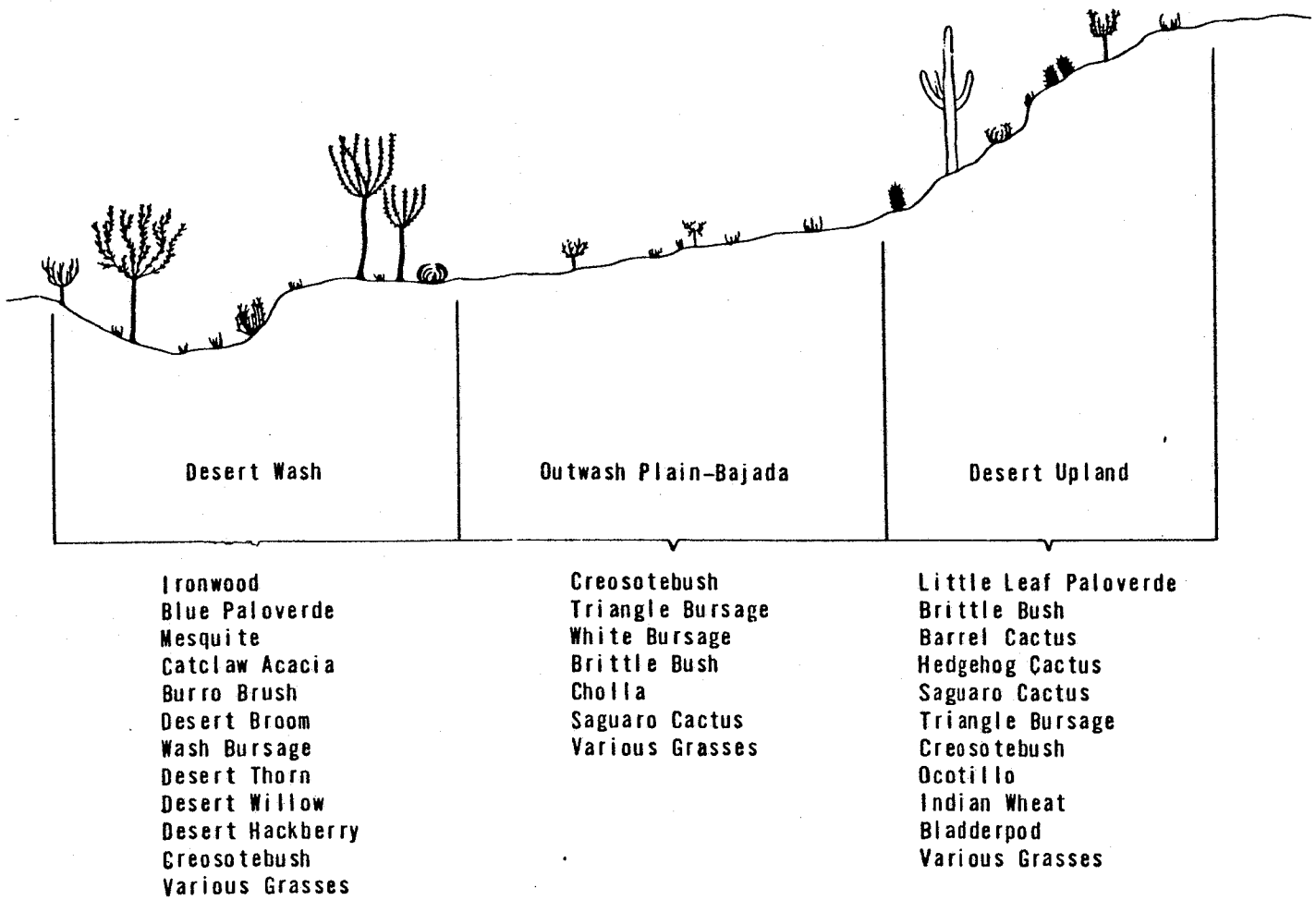


Figure 10. Diagrammatic Profile Showing Desert Plant Communities and Representative Species

Source: U. S. Army Corps of Engineers, 1976b

1. Desert Wash or Riparian Community. The desert wash vegetation is found along arroyos, washes, major drainageways, and slight depressions resulting from concentrated runoff. Characteristic of this type of vegetation are trees such as mesquite, ironwood, desert willow, and blue paloverde; shrubs such as desert broom, catclaw acacia, and burrobrush; and various annual and perennial herbaceous vegetation and grasses. Cottonwood occur along some major drainageways such as the Agua Fria River. The riparian species are distributed more uniformly over the alluvial plain where braided drainage systems have formed. In areas where infiltration is enhanced and evaporation retarded, desert wash vegetation spreads over a large area rather than restricting itself to only the drainage channel. Increase in the size and density of riparian vegetation usually corresponds with an increase in the area of the drainageway.

2. Desert Outwash Plain or Bajada Community. The Lower Colorado Valley Desert, a vegetational subregion of the Sonoran Desert, is predominantly low in elevation and composed of sand and gravel outwash alluvium. The outwash plain vegetal cover occupies much of the arid intermountain plains and lower bajada regions of this desert. The bajada community is characterized by a sparse arrangement of

shrubs, dwarf shrubs, few trees, and annual and perennial herbs and grasses. Outwash plain communities may be composed almost entirely of creosote bush or may include saltbush, cactus, bursage, and, in the drainageways, desert riparian trees. Extensive portions of the metropolitan area were once covered with the desert outwash plain vegetation, but this plant community has since been altered or destroyed by the visages of progress: irrigated agriculture and urban development.

3. Desert Upland Community. Associated with areas not subject to significant inundation, the desert upland plant community is generally a continuation of a denser bajada community. Representative species of the desert upland vegetation include creosote bush, bursage, ocotillo, barrel, saguaro, and cholla cacti, particularly the teddy-bear cholla. Off-road vehicles have eliminated and disrupted this plant community in some areas; however, the desert upland vegetation remains relatively undisturbed within the study area.

Although the natural plant communities that once thrived in Phoenix have been altered or obliterated by urbanization, irrigation for agricultural purposes, domestic grazing, gravel mining, and off-road vehicles, the three plant communities still remain on the periphery

of the urbanized area; on steep slopes; on mountain tops; and along washes, arroyos, and drainageways. Presently, the vegetation found from the urban area west to the Buckeye-Avondale area consists mainly of field and seed type agricultural crops, fruits, vegetables, nuts, and commercial flowers.

The desert wash and upland communities north of Phoenix provide habitat for the most abundant and diverse desert wildlife. The desert fauna adapt to arid conditions, but most species rely on a free water supply for their existence. Depending on the availability of food, water, and shelter, many species thrive along the riverbeds. Urbanization and agricultural practices tend to displace or destroy most desert wildlife, however, several bird species do flourish in the agricultural regions.

Geology and Soils

The research area is located within the Sonoran Desert region of the Basin and Range phsyiographic province. As the name indicates, the Basin and Range Province represents a region comprised of alternating mountains and plains. "In more exact terms it is characterized by roughly parallel and discontinuous mountain ranges, separated by continuous basins" (Dunbier, 1968). The width of the intervening outwash plains is usually greater

than that of the isolated block-faulted mountains. Alluvium and colluvium deposits, particularly sands, gravels, and clays, may extend as much as 1000 feet deep to form the outwash plains. The mountains, which trend from north-northwest to south-southwest, are composed of metamorphic and igneous materials. In the region the block-fault mountains have become highly fragmented as a consequence of violent diastrophism, and therefore, much of the early geological record has become indistinct. However, a long geological history of erosion and deposition is articulated by the dissected mountains and extensive alluvial fans (Dunbier, 1968; and U.S. Army Corps of Engineers, 1976b).

According to Dunbier (1968) the variety of soil types is determined by the climate, landforms, and parent material of the desert. In general, the mountain slopes are rocky with small deposits of soil, the upper bajadas display shallow coarse-textured soils, the lower bajadas have deeper coarse-textured soils, and the flood plains are composed of deep fine soils of recent deposition. The absence of a well-defined profile and lack of humus is typical in most desert soils. Characteristic soil types in the research area include sandy loams, limy clay loams, and limy loamy soils. On slopes greater than 30 percent

rocky soils are often present (U. S. Army Corps of Engineers, 1976b).

Surface runoff often transports heavily mineralized material to the bajadas and flood plains. If the soil moisture is not sufficient to dissolve the salts in this material, the salts accumulate in the soil as the moisture evaporates. The salts form a calcium carbonate substance that acts as a cementing agent with the alluvial deposits. This concrete-like material, termed caliche or hardpan, is detrimental to agriculture and is common in many Sonoran soils (Dunbier, 1968).

The flood problems of the cities and communities located within the study area are interrelated. Of the characteristics discussed topography and drainage are the most critical to an understanding of the flood hazards of the area.

METHODOLOGY

Background information has been obtained through a variety of sources including published documents, legislation, essays, newspaper and magazine articles, and personal interviews. Historical documents and photographs were used to gain an understanding and perspective of the early occupation of the study area. Internal reports and

memos from various agencies and government offices have been utilized to identify some of the elements of change affecting the flood control policies and practices.

A map depicting the evolution of urban development in the flood prone areas was compiled. The base map, made by the City of Phoenix Engineering Department and the U. S. Army Corps of Engineers, outlined the flood prone areas; urban development was superimposed on the map by use of aerial photographs spanning a twenty-five year time period.

REVIEW OF THE LITERATURE

There has been a great deal of research produced in the fields of water resources and natural hazards, particularly dealing with aspects of flooding and flood plain management. Research has emanated from several universities and academic disciplines, state and local governments, and federal agencies.

The relationship between extreme natural events and man's reactions to them has been the focus of Natural Hazards Research carried out by the Departments of Geography at the University of Chicago, Clark University, and the University of Toronto, as well as by the Institute of Behavioral Science at the University of Colorado. The

principal investigators for natural hazards research have been Gilbert F. White, Robert W. Kates, Ian Burton, Stephen Golant, and J. Eugene Haas. The studies of these authorities point to the premise that natural phenomena associated with extremes in weather conditions or tectonic processes may constitute a hazard to man, depending on his adjustments to these extremes. Human adjustment to extreme natural events is predicated on imperfect knowledge.

Gilbert White (1974) indicates that hazards are a function of and defined by man's adjustments to them. For example, the natural occurrence of a river overflowing its banks and onto the flood plain would not constitute a hazard were it not for human occupance of that flood plain. Thus, man by his own initiative has created the potential for disaster and may even have altered the flood regimen. Decisions regarding human adjustments and the effect of such adjustments are determined by the phsyical, social, and political atmosphere at any given time and place.

Much of the work associated with natural hazards has focused on floods. Research on natural hazards initially concentrated on determining the reasons for human occupance of flood prone regions and the impact this occupance had on land use and national economy. Findings

in 1957 revealed that although large quantities of federal funds had been expended for structural methods of flood control, losses caused by flooding were increasing (White, el at., 1958). This disturbing discovery was the catalyst for investigations relative to the nature of the hazard, the adjustments or responses, the alternative choices, human perception, and the recommended solutions to the natural hazard. White and his associates gained national recognition for the pursuit of problems of increased human occupancy of flood plains. These men developed new techniques for appraising and estimating flood damages under a wide range of human adjustments to the flood hazard.

White in Natural Hazards: Local, National, Global (1974) states that two lessons pertaining to natural hazards research are essential to a "sound public approach to environmental management." First, nations must share skills, experience, and research capabilities to minimize the costly threats of extremes of natural phenomena to life and property. Second, reliance solely upon technological solutions is not an effective method of dealing with hazards in the environment.

Natural hazards research represents a burgeoning field of geographic endeavors and viable contributions. Investigations are being carried out at the local, regional, national, and international levels

in an attempt to enhance the understanding of interactions among the social, political, and physical environments. This understanding can be applied in the decision-making processes leading to public action.

In order to understand the evolution of the flood policies and practices in an area, one must view related natural physical elements and the human development imposed on the landscape. Meteorology and surface hydrology, the natural physical elements, have been studied by many nationally reknowned and local scientists. The historical development of the Phoenix metropolitan area has been discussed in numerous books, newspaper and magazine articles, and document reports.

Meteorological conditions that produce flooding originate over various areas of the North American continent and the adjacent ocean bodies. Bryson (1957) discussed the summer precipitation process associated with convection movements. However, moisture associated with tropical cyclones is responsible for the largest falls of precipitation during the summer season. These moist air masses may result in widespread heavy rainfall which causes damaging floods (Thorud and Ffolliott, 1973; and others). Winter precipitation is primarily a result of moist Pacific air rising in cyclonic storms

as the storms travel from the Pacific Ocean over the mountainous regions of the West (Pyke, 1972).

Surface hydrology is a determining factor in flooding. Runoff characteristics have been examined under many conditions. Williams (1975) analyzed runoff characteristics of the Salt River watershed; Cooperider and Sykes (1938) correlated runoff with precipitation of the Salt/Verde watershed and found the relationship between streamflow and precipitation was higher in winter months than in summer. Topography and streamflow characteristics in arid regions were discussed by Dunbier (1968). Runoff patterns as modified by man have been a subject of interest for a number of years. The impact of urbanization on the distribution of runoff has been significant (Kinosita and Sonda, 1967; Burton and Kates, 1964; Kao, Fogel, and Resnick, 1973; Arizona Water Commission, 1973; and Leopold, 1968).

Natural systems and changes therein, veiwed in chronological sequence, help to explain the evolution of flood problems in the Phoenix metropolitan area. The early settlers of the area were the Hohokam. Much has been inferred from archeological data as to their lifestyle and livelihood, particularly as related to the use of the land and water (Harshbarger, et al., 1966; and others).

The alignment of the canal system established by the Hohokam approximates that of the present day Salt River Project system.

Agriculture dominated the landscape in the Phoenix area from the middle of the nineteenth century until after World War II. The history of agricultural development including types of crops, acreage, and development of the canal system was discussed by the Salt River Project (1970). Numerous articles from The Arizona Republic gave insight to the concerns of the populace during this period. Articles also provided historical data regarding floods and the resulting damages and inconveniences. The U. S. Army Corps of Engineers has compiled information relevant to past flooding.

After World War II the Phoenix metropolitan area became an urbanized society. Growth patterns mapped by Sargent (1973) depicted rapid urbanization and population growth. The U. S. Army Corps of Engineers (1976a), Schneider and Goddard (1974), and Leopold (1968) explored the urban development of the flood plains which poses a serious flood hazard to current occupants.

Knowledge of land use characteristics and other forms of human adjustments in flood plains was lacking prior to studies initiated by Gilbert F. White, et al.,

(1958). Prior to White's studies, there had been numerous references to urban flooding and flood damages, but little information regarding the extent and location of flood hazard areas. White and his colleagues categorized flood situations in 1958 to enable meaningful generalizations to be made.

Several government agencies have identified flood problems and possible solutions to these problems within the Phoenix metropolitan area. The Arizona Water Commission (1975) prepared a state water plan which dealt with water resources of the state and their relationship with the present and future economic and social welfare of the state's people. The plan included basic information necessary for understanding water problems and a summary of technical data useful in water development planning. The Water Commission's (1973) flood control program identified the need for flood control projects and flood plain management.

The U. S. Army Corps of Engineers (1964a, 1964b, 1965, 1967a, 1968, 1971) published flood plain information and flood hazard information reports for various water courses, or portions thereof, in the vicinity of the Phoenix metropolitan area. The intent of these reports was to provide information regarding flood hazards in the

flood plains to be utilized by local agencies and flood plain users in developing and using flood plain areas in such a way that flood hazards and future flood damages would be minimized.

There have been a number of studies relative to engineering works, planned or constructed, aimed at reducing flood losses. Relatively satisfactory estimates of probable flood frequency within the study area have been made possible due to the availability of records of past flood stages and discharges. The U. S. Geological Survey (1973) has compiled flood atlases which present hydrologic data such as the depth, extent, and frequency of flooding. These indices are necessary in appraising the relative hazards involved in developing the flood plain areas.

Considerable research and compilation of data is available for any urban area that has experienced substantial losses due to flooding. Flood damage reports, often prepared by the U. S. Army Corps of Engineers (1964c, 1966, 1972a), commonly include documentation as to past flooding, the area flooded, estimated cost of damages and repairs to property and utilities, human suffering and social inconveniences, and the use of the flood prone areas.

Communities and various agencies have frequently responded to the need for flood control and drainage systems by studying and recommending structural engineering solutions. Storm drainage studies have been prepared for various portions of the City of Phoenix (Yost and Gardner, 1956, 1965, 1967a), City of Scottsdale (Coe and Van Loo, 1969; and William and Ellis, 1964), City of Tempe (William and Ellis, 1968), Arizona Department of Transportation (Yost and Gardner, 1964, 1967b, 1968; and Johannessen and Girand, 1968), and the Biltmore Estate (Yost and Gardner, 1966). Generally, these reports include investigations regarding the causes of local flooding, runoff computations for various frequency flows, and recommendations for construction of various sized drains and bridges.

Flooding potential and flood control studies dealing with flood frequencies for 100-year floods or greater have been prepared for many portions of the Phoenix metropolitan area. These studies include the flooding potential of the Indian Bend Wash drainage area (Water Resources Associates, 1967; and U. S. Army Corps of Engineers, 1962), and recommended structural solutions to the flood problem. Yost and Gardner Engineers (1962) prepared a survey report for the Flood Control District

of Maricopa County which described drainage areas in the portion of Maricopa County east of the Agua Fria River and north of the Salt-Gila Divide, estimated probable runoff and resultant flood damage, and suggested numerous channel improvements and storage projects. The Citizens' Advisory Board of the Flood Control District of Maricopa County (Flood Control District of Maricopa County, 1973) compiled a report which consisted of a description of flood potentials of drainage areas within the county, flood control problems, recommended solutions to these problems, cost and benefit estimates, and benefit-cost ratios of various projects. This report was adopted by the Board of Directors of the Flood Control District of Maricopa County as their basic flood control policy statement.

The U. S. Army Corps of Engineers (1957) recommended channel clearing and improvements for the Salt and Gila Rivers from Granite Reef to Gillespie Dams. The plan also called for levees between 40th Street and Tempe Butte.

The Corps of Engineers'(1964d) solution to many of the flood problems threatening the Phoenix metropolitan area was to construct four earth-filled flood control detention dams on Dreamy Draw, Cave Creek, Skunk Creek,

and New River and provide approximately fifty miles of channelization. This plan was later modified to include the four dams, approximately eighteen miles of channelization, and seventeen miles of flowage easements (U. S. Army Corps of Engineers, 1976a).

The U. S. Soil Conservation Service (1954) compiled preliminary data and cost estimates for sixteen potential damsites in the North Phoenix Mountains. This report was not published.

The reports mentioned above deal with structural solutions to flood problems. Many nonstructural solutions or flood plain management practices have gained popularity and support in the recent years.

The picture of past accomplishments in flood plain regulation were described as "bleak" by Murphy (1958). However, he was optimistic about future accomplishments in light of an increasing use of some regulation techniques (e.g., zoning, government acquisition, and urban renewal programs). Murphy expresses the need for organized assistance to promote desired uses and limitations of flood plain regulation and prevent the enactment of unproductive regulation. In Murphy's opinion, the federal government will need to take the lead, but local governments must be prepared to participate in the planning

and administration of such regulatory practices. Maynard (1969) asserts it is the responsibility of the local legislative bodies to enact and enforce regulatory measures.

White, et al., (1958) maintained there were five responsibilities to be borne by appropriate federal agencies in order to develop a more comprehensive flood problem policy: (1) inform citizens of the flood hazard, (2) furnish information relevant to possible adjustments, (3) stop further encroachment onto flood plains, (4) reconcile highway and bridge design with damage reduction, and (5) relate flood control plans to urban development. The purpose of these reponsibilities is to broaden the understanding and spectrum of choices available to indiviuals in making adjustments to the flood hazard.

Many authorities have enumerated methods of reducing flood losses which include structural measures and flood plain regulations or a combination of the two as choices of human adjustment to the flood hazard (Tennessee Valley Authority and U.S. Army Corps of Engineers, 1967; U.S. Army Corps of Engineers, 1976b; and Leopold and Maddock, 1954). The Corps of Engineers and the Tennessee Valley Authority have published pamphlets encouraging the wise use of flood plains to avoid damages

by enacting flood plain management regulations. The U. S. Water Resources Council (1976) prepared a report for President Ford which set forth a conceptual framework and recommended "Federal and State actions for a continuing unified program of planning and action at all levels of government to reduce flood losses through flood plain management."

Sheaffer (1977a) examines and evaluates the social, economic, and environmental effects of flood plain regulations. The aim of the research is to prepare a national assessment of the public and private, direct and indirect, and short-term and long-term costs and benefits of flood plain regulations. Sheaffer (1977b) also identifies established and newly emerging flood hazard evaluation and mitigation measures. He analyzes federal programs involving flood hazard mitigation efforts and requirements, model ordinances, and specific state and local land acquisition and development policies and regulatory ordinances and codes.

Flood plain regulations include practices such as flood proofing and building codes, flood forecasting and evacuation, and flood insurance. Flood proofing measures aimed at reducing flood damages through building design have been described by several experts (Jones, 1977;

Sheaffer, 1967, and 1977c; U. S. Army Corps of Engineers, 1972b; U. S. Department of Housing and Urban Development, 1976a; and U. S. Soil Conservation Service, 1975).

Flood warning systems have been described and analyzed by various institutes and agencies including the Division of Emergency Services, State of Arizona (Arizona State, c. 1978); Institute of Behavioral Science, University of Colorado, (Mileti, 1975; and Mileti, Drabek, and Haas, 1975); U. S. Department of Commerce, Environmental Science Services Administration, Weather Bureau (1970); U. S. Department of Commerce, National Oceanic and Atmospheric Administration, (1971, and 1973); and McLuckie, et al., (1973); Cornell University (Raymond, 1976); and University of Arizona, College of Earth Sciences (Davis, 1977).

The National Flood Insurance Program has been described, examined, and evaluated over the past several years. The American Insurance Association (1962) looked at floods and flood damage and their relation to flood insurance. The report discussed the need for flood plain zoning and the need for continuous study of flood insurance problems by the federal government and the insurance industry due to flood magnitude and damage. Since 1968, the U. S. Department of Housing and Urban

Development, Federal Insurance Administration (1977, 1976b, n. d., c. 1977, and 1976c) has issued a number of pamphlets and brochures discussing the National Flood Insurance Program using a question and answer format and its revised regulations, common misconceptions about the program, what residents in local areas should know about flood insurance, and methods of appealing flood hazard boundary maps or flood insurance rate maps. The National Flood Insurers Association (1976a, 1977, 1975, 1976b, and 1976c) has published a history of flood insurance in America, suggestions to help minimize loss to life and property before and after a flood, and leaflets designed to explain the consequences of not having flood insurance in the event of a flood.

Several investigations have attempted to explain the failure of most residents of flood prone areas to purchase flood insurance even though the insurance is subsidized ninety percent by the federal government. Kunreuther (1976) noted that individual actions with respect to low-probability events, such as flooding, did not conform to the expected utility theory. That is to say, most individuals in flood susceptible areas have not protected themselves against potential damage although the option is economically attractive. Baumann (1976) in

a study of two Texas communities contended that there is general public apathy regarding flood plain regulations and flood insurance. The exception to her findings occurred only after a recent flood had caused considerable damage. Immediately after the event, the public response to flood plain regulations and flood insurance was demonstrable. However, Emmer (1976) looked at the problems of implementing the National Flood Insurance Program in Oregon and concluded that most residents did not realize that subsidized flood insurance was available. Of the few who were aware that flood insurance was available, most indicated they would not purchase it. Emmer's survey also found that most residents of flood prone areas did not object to the idea of the government limiting use of private lands in flood prone areas to agriculture and open space.

Although the National Flood Insurance Program has not achieved widespread public recognition and support, Platt's (1976) midstream perspective of the program asserted that "the National Flood Insurance Program is the best answer to flood plain management which Congress has yet devised." In order to realize the benefits to be derived, the program must now be fully implemented as a land use control.

The selection and implementation of a method or combination of methods mentioned above which are designed to reduce flood losses are influenced by a number of factors of change in the flood hazard system. These factors include changing values, changing perceptions, changing flood risk, changing institutions, and acceptable level of risk. Little has been written which directly addresses the factors responsible for the evolution of flood hazard systems. Changing perceptions and the acceptable level of risk have received some attention. Burton (1962) concluded that farmers in flood plain areas were more aware of the flood hazard and degree of that hazard than urban occupants of flood prone areas. He revealed a direct correlation between the frequency of flooding and the perceived need for conscious adjustment to the hazard. The less frequent the flooding the less apparent the need for adjustment. Downing (1977) in a scenario of a flash flood occurring several years after the Big Thompson flood, supported the contention that individual and community perception of the flood risk diminished over the lapse of time between flood events.

Baker and McPhee (1975) examined "the complex set of interactions between social systems and natural systems which create hazards from the extreme geophysical

events." In general they noted an increase in annual property damage, a decrease in loss of life, and an increase in potential catastrophic consequences associated with natural hazards. The study identified conflicting policies and attitudes regarding land management of hazardous areas and suggested further research to investigate: (1) methods of accelerating the mapping of hazardous areas; (2) factors affecting successful local management of hazardous areas with respect to community goals; (3) impact of those activities on individual property owners and local agencies; and (4) methods of coordinating hazard considerations with other aspects of local planning. The results of such research would aid decision-makers in assessing the benefits and costs of various land management practices and identifying the acceptable level of risk.

Cole, et al., (1975) investigated and evaluated factors of consideration in determining the acceptable level of risk to farmers in flood prone areas in the State of New York. They discussed the history of flooding, problems floods create for farmers, actions farmers can initiate to protect their family and property, applicable legislation regarding flooding, and the decisions farmers must make in considering the acceptable level of flood risk.

Kunreuther, et al. (1977) also heeded the importance of identifying an acceptable level of risk dealing with natural hazards. His research provided an overview and potential application of a community disaster model currently being developed at the University of Pennsylvania. The purpose of the model is to provide the decision-makers with benefits and costs of alternative mitigation and recovery policies for evaluating levels of risk of natural hazard solutions.

In summary, flooding and flood plain management have been topics of research and investigation for many years. While each of the studies cited treats certain aspects of the flood problem, none deal comprehensively with the historical evolution of the flood control policies and practices within the Phoenix metropolitan area.

CHAPTER II - EVOLUTION OF THE FLOOD PROBLEM IN CENTRAL ARIZONA

The intervention of man in the natural systems describes the evolution of the flood problem in central Arizona. The natural systems prior to man's arrival consisted of meteorology and surface hydrology and represented the conditions responsible for flooding. Man's intervention in the natural systems can be separated into three phases of development: under early man, under agricultural practices and uses, and under urbanization. The interplay between man and his environment has resulted in the current flood hazard. Each of these phases and the changing flood problems are discussed below.

THE NATURAL SYSTEM BEFORE MAN

Flooding in central Arizona is a result of the interactions of two physical conditions: meteorology and surface hydrology. Meteorological conditions that produce most flooding occur during two rainy seasons in summer and winter. Surface hydrology, comprised of natural topographic features and human modifications thereof, is a prime contributor to the flood problems

faced by individuals and municipalities in the metropolitan area. The combination of these two conditions is capable of producing severe and catastrophic damage.

Meteorological Conditions that Produce Flooding

Flood-producing precipitation normally occurs during two rainy seasons in Arizona: summer and winter. Runoff is greater during the winter period (late October through April) than in the summer period (June through September). This fact is partially attributed to the greater rates of evaporation and transpiration in the summer than in the winter. Williams (1975) has stated that about 31 percent of the annual flow of the Salt-Verde river system occurs in the summer period and 69 percent in the winter. The percentages were based on median flow values. May and June represent the months in Arizona with the lowest runoff values. This occurrence is associated with the interval between the cyclonic winter storms and the summer thunderstorms. The low flow in September represents the period between the summer monsoon season and the winter period (Williams, 1975; and Cooperider and Sykes, 1938).

Summer Storms. The summer rainy season extends from June through September with most of the rainfall occurring in

July, August, and September. During this period tropical air masses originating in the Gulf of Mexico and the Pacific Ocean off the coast of Mexico bring moisture into the area and release it through thunderstorms. Thunderstorms are the result of convection columns created by the flow of the moist tropical air over the mountain slopes which have been undergoing intense surface heating (Bryson, 1957). Intensive heavy precipitation falling over a limited area is characteristic of thunderstorms. During the late summer and autumn tropical cyclones occur and it is this phenomenon that accounts for the largest amount of precipitation during the summer rainy season. Occasionally, tropical cyclones carry moist tropical air masses into the region which may produce widespread heavy rainfall. Damaging floods, such as that of September 1970 are often a consequence of such an occurrence (Thorud and Ffolliott, 1973).

Winter Storms. The winter rainy season begins in late October and continues through April. Precipitation during this period is primarily caused by the flow of moist air originating in the Pacific that is uplifted within cyclonic storms as it moves from the Pacific Ocean to the mountains in the West (Pyke, 1972). Westerly and northerly winds associated with the passing storms bring cold air from the

north Pacific Ocean to the state. When the storm center lies over Arizona, rains are widespread and many areas in the state receive large amounts of precipitation. Winter storms over the Gila River basin are the cause of most of the annual precipitation and runoff (Williams, 1975).

Extra-tropical cyclones with well-developed frontal systems account for many of the winter storms. Much of the heavy precipitation associated with the extra-tropical cyclones occurs in advance of the cold front and usually lasts only three to six hours (Williams, 1975).

Closed lows are storms lacking a well-developed frontal system that often bring heavy precipitation. These systems "are essentially features of the upper atmospheric circulation that bring moisture and relatively unstable air to Arizona" (Williams, 1975). Widespread precipitation of long duration results from such storms.

Surface Hydrology

Elements of the physical environment of the Phoenix metropolitan area are partially responsible for the flood problems. These elements include the desert landforms and their slopes, soils, and vegetal cover. Each factor plays a significant role in the runoff patterns characteristic of the area.

The metropolitan Phoenix area is predominantly an

alluvial basin with little gradient encircled by mountain ranges (Figure 11). The desert alluvial plain appears flat but actually rises steadily from the flood plain or valley floor to the surrounding mountains. The upper slopes may form alluvial fans with a thin veneer of alluvium covering the pediment*. Alluvial fans are most pronounced where ephemeral streams leave the mountains, but are quickly obscured toward the valley center where they coalesce, producing a single broad slope. The portion of the alluvial fan that is distinct is termed the upper bajada and the portion that forms a gentle uniform slope after several fans coalesce is the lower bajada (Dunbier, 1968). See Figure 12.

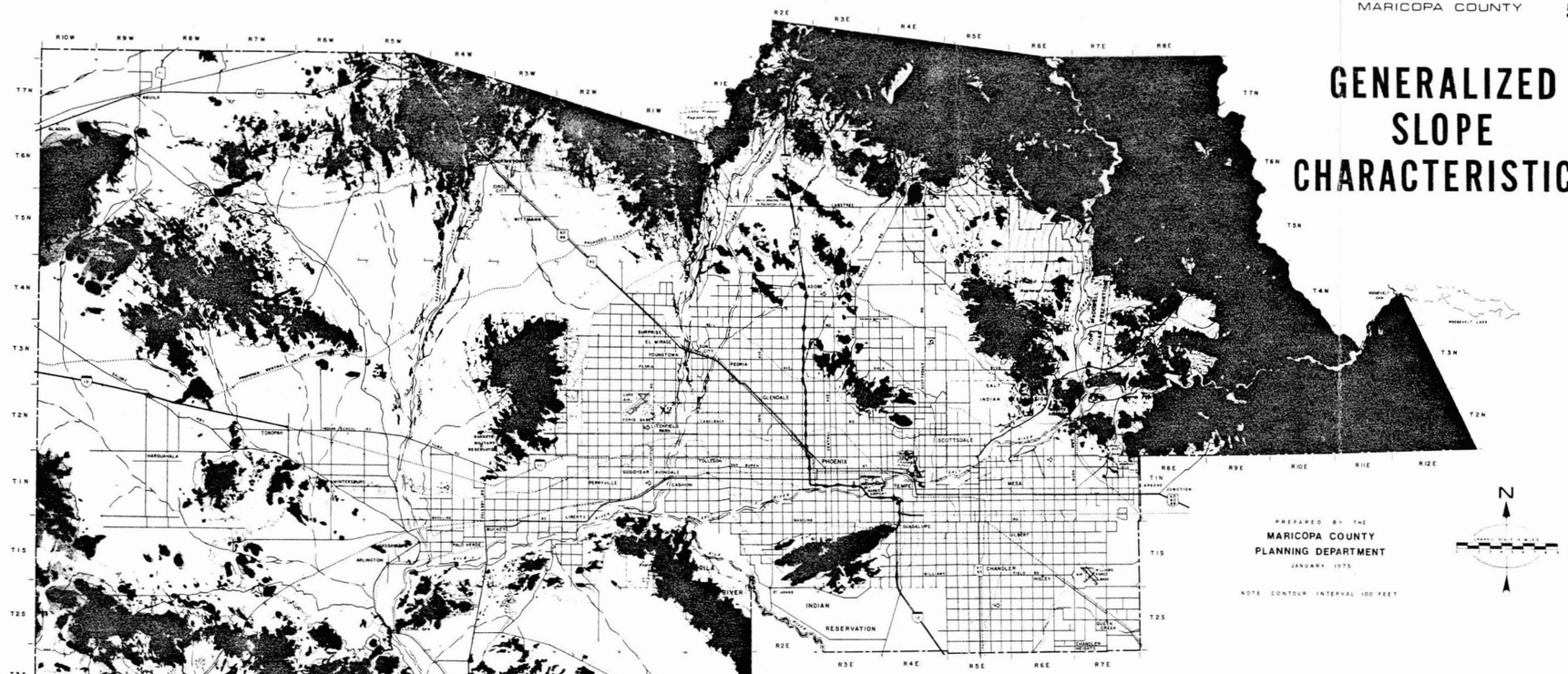
The runoff characteristics of the desert region are seemingly haphazard. Following a sudden shower water rushes down the desert mountains and bajadas to the flood plain. The flood plain is defined as the area where the slopes of two or more bajadas meet and form a desert wash. Washes originate in the desert mountains and may be visible

* The pediment is a broad skirt or platform of solid rock forming the base of desert mountains. A two to five foot thickness of alluvium often covers the pediment. Streams which can shift their courses and cause lateral corrasion of the rock surface represent the chief erosion agent of this landform. The pediment appears as a nearly level plain inclined at the toe of the mountain.

Figure 11. Urbanized Area Encircled by Mountain Ranges, Maricopa County, Arizona

Source: Maricopa County, Planning Department, 1975

GENERALIZED SLOPE CHARACTERISTICS



LEGEND

- 0 to 2% Slope
- 2 to 10% Slope
- 10 to 20% Slope
- 20% Slope or Greater

SOURCE: Slopes interpreted by Maricopa County Planning Department from U.S. Geological Survey, 7½ Minute 30 Minute Series Topographic Maps

GENERALIZED SLOPE CHARACTERISTICS

The Generalized Slope Characteristics map shows the percent of slope for all land within Maricopa County. Slopes are one of several geological characteristics that relate to the probability and economic development of land for urban and agricultural purposes. The various slope categories shown were selected to represent, in a general way, the limits imposed by slope on future land development.

Slope is measured in percent, a slope of one percent indicates a one foot rise in elevation for each 100 feet of horizontal distance, and ten percent slope is a ten foot rise in 100 feet of horizontal distance. Approximately fifty percent of the County land area has a slope of less than 2 percent. Approximately twenty-five percent has a slope of 2 to 10 percent and twenty percent of the area with slopes greater than 20 percent. The majority of the mountains rise sharply upward from the valley floor and less than five percent of the land area is within the 10 to 20 percent slope category.

Nearly all of the County's agricultural development is located on land with slopes of less than 2 percent to accommodate economic irrigation practices. Most urban development is also within the less than 2 percent category. However, a significant amount of urban development has occurred in the 2 to 10 percent category, particularly in the Phoenix-Paradise Valley area and in the Desert Foothills area.

Most slopes up to 5 percent can be utilized for cultivated agricultural purposes provided that soil conditions are appropriate. These slopes are also suited to intensive urban development such as high density residential, commercial and industrial uses. Lower density or large lot residential development can be accommodated on slopes up to 10 percent. When slopes exceed 10 percent construction costs and services become more difficult and more costly. This results as land cannot be utilized as efficiently for urban purposes on steep slopes as on level areas. Efficiency is related to cost, and more cost of developing steep slopes are borne by the general public, especially when governmental agencies must maintain the streets and provide community services. Also, substandard construction practices on steep slopes can create hazards to the general public as well as life and property of the occupants.

Urban development on moderate and steep slopes increases the potential for erosion when the ground cover is disturbed or removed. The surface for absorption of rain water is reduced by impervious surfaces (roofs, streets, patios, etc.) runoff is increased and the potential for erosion is again increased. The increased runoff for steep slope development dictates construction of a more expensive and sophisticated flood control system. In addition to the potential erosion, the scarring of the mountainous terrain and destruction of the natural vegetation is irreparable.

Sanitary sewage disposal has always been a serious problem since the start of steep slope development. Early development depended totally upon private septic systems wherein many leach fields were installed in non-made ground. In impervious soils, leach fields eventually reach total saturation and the effluent reaches the surface. If septic tanks and leach fields are installed on steep slopes and fills, they are more subject to failure than similar installations on more level ground. Where provision is made for a public sewage collection system, the difficulties and costs are significantly greater on steep slopes.

The area required for streets is significantly increased in steep slope areas so the land cannot be utilized as efficiently, thus increasing the construction and maintainance costs. Unless design standards are carefully adhered to, blind street intersections and driveways can create a safety hazard. Also, roadfills of loose rock are hazardous to dwellings below.

Fire protection and water supply is more difficult to provide in steep slope areas. To provide water pressure for fire protection purposes requires separate lift stations at 100-foot intervals to maintain an adequate minimum pressure at the top of each zone. Also, the system must be specifically designed to prevent excessive pressure at the bottom of each zone. The cost of these extra facilities, added to that of excavation in rocky areas, makes water systems in steep slope areas abnormally expensive. Fire protection problems are further compounded by streets and driveways that lack adequate turnaround space or are too narrow or steep to accommodate standard fire fighting vehicles.

It is more difficult and expensive to provide police protection to large widely scattered lots in mountainous areas. It requires more miles of driving to patrol the same number of dwelling units and police records show that vandalism and burglary are directly related to remoteness of the dwelling.

Aside from these public safety and cost considerations, steep slopes can provide a number of values if left undeveloped, such as their visual impact as a backdrop to urban areas. If left undeveloped the steep slopes can give a greater impression of openness than their area alone would indicate. Such land areas can give a sense of place by physically defining and separating neighborhoods and communities from one another. People of all income levels, from the poorest to the richest, benefit from the visual appeal of the natural mountain view. Only a small segment of the population can afford to develop land on steep slopes such as Camelback and Squaw Peak Mountains.

Lands having slopes of more than 20 percent are not suitable for urban or agricultural developments and should be preserved for recreation purposes and natural open space. Open areas in the 10 to 20 percent slope areas are also unsuited for urban development. The characteristics of each site should be carefully weighed to determine if it is economical and efficient to develop the site from the private and public point of view.

The Generalized Slope Characteristics map has been prepared as a part of the continuing planning process of the Maricopa County Planning Department. This map as presented is general in nature, therefore each proposed development should have a detailed slope analysis of the particular site to determine the effects of the slope on proposed development plans.

MARICOPA COUNTY, ARIZONA

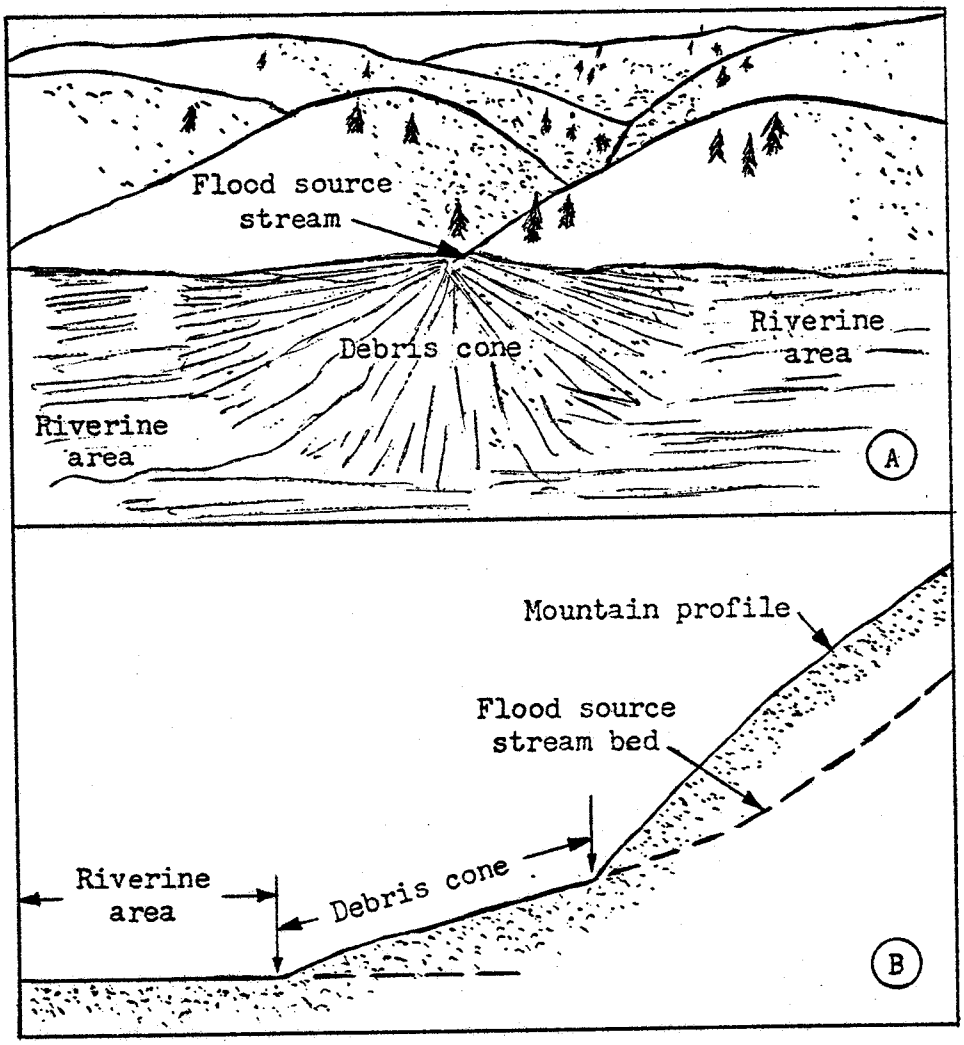


Figure 12. Sketches, Not to Scale, of (A) Perspective View of a Debris Cone and (B) Profile of Cone Area.

Ordinarily, Inhabitation or Development Begins Near the Toe of the Cone and Progresses Upward on the Cone until Halted by a Large Flood; or, if Mainly Agricultural, Development Begins for the Sake of the Water Near Where the Stream Leaves the Mountain, with Habitations Located Where Flood Flows Are Hopefully Not Expected.

Source: U. S. Water Resources Council, 1972

on the upper bajadas. Generally, the streams on the alluvial fan are braided and have a very small capacity. The arroyos become more shallow and reticulated and relatively undefined on the lower bajadas. "The conditions of aggradation which prevail throughout most of the desert valleys allow the water of the ephemeral stream to spread widely over the alluvial plains at the foot of the more steeply sloping bajadas." Runoff then travels as "sheetflow." Sheetflow resembles a continuous thin film of water covering a relatively broad plain that has little gradient. The process of leveling the landscape continues as material from the desert mountains and upper bajadas is transported and deposited on the lower bajadas and flood plains (Dunbier, 1968).

Much of the rock core in the Phoenix valley region is overlain with caliche, a hard, whitish crust formed by deposits of calcium carbonate in the soil. If irrigated, the calcium-rich soil is fertile and excellent for grain crops. However, the calcium carbonate deposits make the ground very hard and resistant to erosion in many places. This hardpan or caliche prevents percolation of rainfall, and hence, increases runoff. Thus, the caliche in the soil accentuates the flood problems in the desert.

Vegetation in the vicinity of the metropolitan

Phoenix area is relatively sparse. Vegetal cover can act to retard flood flows, but the lack of vegetation due to natural and man-induced causes increases the flood threat to the valley.

The desert landforms and their slopes, soils, and vegetal cover add to the flood problems in the metropolitan Phoenix area. These natural features of the environment and the urbanization of the region render some areas more prone to floods than others. Flood prone areas are delineated in Figure 13.

THE NATURAL SYSTEM AFTER MAN

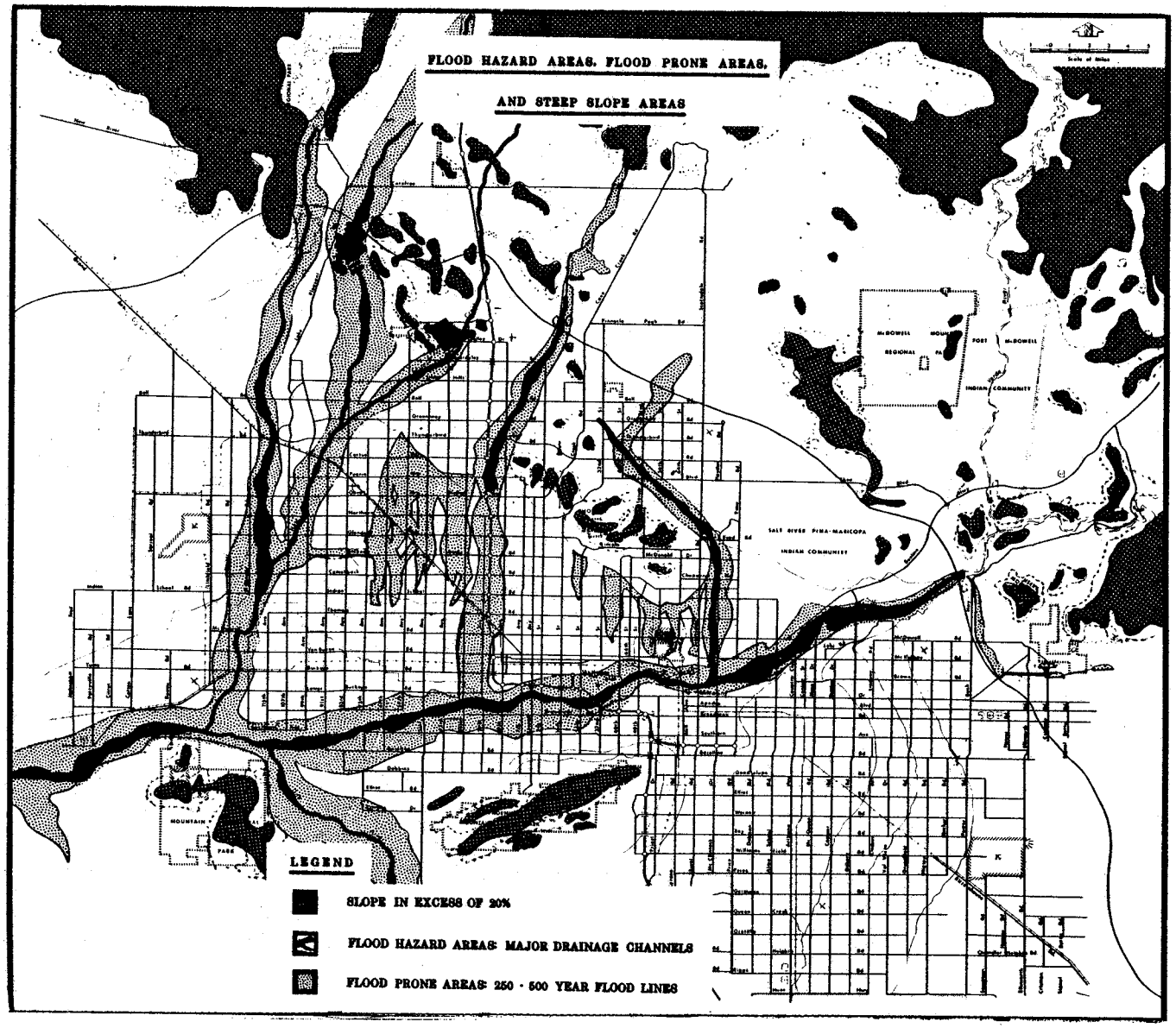
The Natural System Under Early Man

Prehistoric man in Arizona dates back 12,000 to 15,000 years; however, the earliest culture known dates from 800 B.C. The Hohokam, meaning "vanished ones," occupied the area from the beginning of the Christian era to 1400 A.D. This ancient culture lived in the Salt River Valley because the area possessed the essential ingredients necessary to support a settlement--fertile soil, abundant sunshine, and perennial surface water (Harshbarger, et al., 1966).

The Hohokam Indians learned to manage the limited water supply to their advantage. They constructed irrigation canals to divert water from the rivers to their

Figure 13. Flood Prone Areas, Phoenix Metropolitan Area, Arizona

Source: Maricopa Association of Governments, 1977

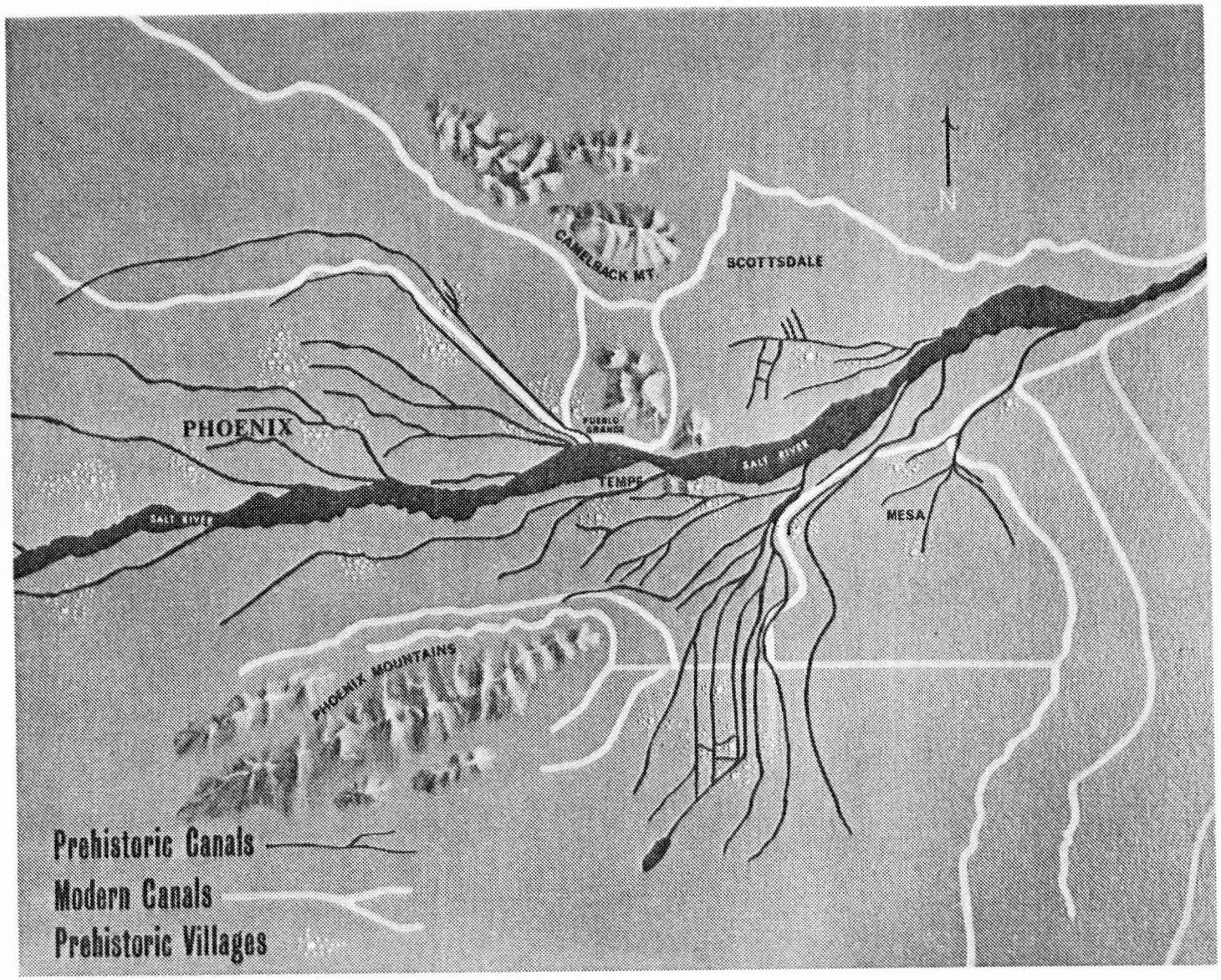

FLOOD HAZARD AREAS, FLOOD PRONE AREAS,
AND STEEP SLOPE AREAS
LEGEND
SLOPE IN EXCESS OF 20%
FLOOD HAZARD AREAS: MAJOR DRAINAGE CHANNELS
FLOOD PRONE AREAS: 250 - 500 YEAR FLOOD LINES
McDOWELL
REGIONAL
FORT McDOWELL
INDIAN COMMUNITY
SALT RIVER PIMA-MARICOPA
INDIAN COMMUNITY
MOUNTAIN
PARK

fields. Many of the main canals were as much as sixty feet wide and had the capacity to carry water to irrigate 250,000 acres of desert land. The Indians availed themselves of primitive tools and many hours of manual labor. The Hohokam canal system was identified by surveyors and confirmed by aerial reconnaisance in 1929 (Figure 14). Today, a few hundred miles of the canal network can still be traced. The Indians also dug some shallow wells to supplement the rainfall and stream flow (Harshbarger, et al., 1966).

Water transported by the canal system was used to irrigate a variety of crops such as tobacco, corn, squash, beans, and cotton. Partly because of their irrigation practices the Hohokams could raise a surplus of food which enabled them to devote time to crafts and leisure. The Indians learned to make pottery and sculpture, make and weave textiles, and play ball games. In so doing, the Hohokam became a model for other nearby tribes. Then the Hohokam vanished. The reason for their disappearance is still a mystery, but some people speculate that a drought lasting several years was chiefly responsible because the Hohokam had no storage reservoirs that would have enabled them to cope with periods of scanty rainfall or the lack of streamflow. They vanished from

Figure 14. Hohokam and Modern Canal Systems, Phoenix Metropolitan Area, Arizona

Source: Salt River Project


N
CAMELBACK MT.
SCOTTSDALE
PHOENIX
PUEBLO GRANDE
SALT RIVER
TEMPE
SALT RIVER
MESA
PHOENIX MOUNTAINS
Prehistoric Canals
Modern Canals
Prehistoric Villages

the area but left the canals behind. "Their achievements demonstrate man's capacity to meet the challenge of a difficult environment, and to manage natural resources wisely" (Harshbarger, et al., 1966).

Little is known of the people who lived in the Salt River Valley during the time between the disappearance of the Hohokam and the arrival of the Spanish explorers. However, the next group of people to exert a great influence on the development of the region was the American settlers occupying the Valley from the middle of the nineteenth century.

The Natural System Under Agricultural Practices and Uses

The Phoenix metropolitan area was primarily an agricultural community from the middle of the nineteenth century until after World War II. A number of men and events were instrumental in transforming the desert landscape into a farming oasis. The use and exploitation of water made possible spatial and population growth in the southwest. Progress in the building of Arizona came slowly. The creation of what is presently the Salt River Project, which was the catalyst for agricultural pursuits, evolved through legal, engineering, horticultural, social, and political problems (Salt River Project, 1970).

John W. (Jack) Swilling recognized the long, low ridges of earth fanning out from the Salt River as irrigation ditches. Fascinated by the idea of making the desert wasteland bloom, he organized the Swilling Irrigating Canal Company, also known as the first "ditch company." Swilling brought tools, wagons, mules, and food to the Valley and in December of 1867 he and sixteen men began construction of the canal on the north bank of the Salt River opposite the present site of downtown Tempe. The men struck caliche at this site and moved to a site near the intersection of 44th Street and Washington where they were successful. Water flowed in the canals in 1868 providing irrigation from the Salt River for farming the Phoenix area. This marked the embryonic stage of the Salt River Project whose canals followed the alignment of the Hohokam system. In 1869 the first crop consisting of barley, corn, sweet potatoes, and pumpkins was harvested and sold to the Army; approximately one hundred people settled near Swilling's ditch with the urban area centered around 26th Street and Van Buren; and the first flour mill in the Valley was built (Salt River Project, 1970). These factors spelled prosperity and growth for the Phoenix area. The extension of farmland adjacent to the canals precluded subdivision of the land by real estate

developers for city lots. As a consequence, a new community developed downstream of Swilling's near Central Avenue and Washington.

The early 1870's marked a time of rapid growth. Population figures increased from thirty in 1868 to approximately seven hundred in 1872. The number of acres in cultivation between 1868 and 1872 also increased as can be seen in Table 1.

Table 1. Number of Acres in Cultivation for Selected Years Between 1868 and 1878

Year	Acres in Cultivation
1868	250
1870	1,700
1871	4,500
1872	8,100
1878	200,000

Source: Salt River Project, 1970

The expansion of the canal system was primarily responsible for the substantial increases in population and territory. Irrigation enabled the settlers to produce a variety of crops including oranges, grapes, figs, peaches, apricots, quinces, plums, corn, alfalfa, wheat, barley, tobacco, pecans, peanuts, and English walnuts.

Despite the obvious progress being made in the Valley, Phoenix was far from being a metropolis. Settlers

were forced to travel to Wickenburg or Maricopa Wells to obtain supplies. However, continued growth in the Phoenix area led to its incorporation on 25 February 1881, with John T. Alsap serving as the city's first mayor.

The agricultural community of the Valley prospered until the big flood of 1891 followed by drought. The 1891 flood on the Salt and Gila Rivers caused extensive damage to the farmland and small urban centers in Maricopa County. Residential and business properties suffered damages estimated at $70,000 (U. S. Army Corps of Engineers, 1957). Towns, ranches, farms, dikes, ditches, and the Tempe railroad bridge were washed out. In Maricopa County with a population of 11,000, one hundred families lost their homes and five persons lost their lives. About a third of the town of Phoenix was inundated as well as several smaller communities located adjacent to the riverbed. The U. S. Geological Survey delineated the overflow areas and calculated the flow to have been the equivalent of a standard project flood (U. S. Army Corps of Engineers, 1957). More details regarding the storm and flood of February 1891 are given in Appendix B.

The 1891 flood was followed by a drought which lasted through 1892. Water trickled in the canals and crops and cattle perished for lack of water. After 1892

agriculture again began to prosper.

In 1896 several hundred acres of citrus and farm crops were planted in Glendale by William J. Murphy. Murphy is credited with altering the agricultural industry by introducing commercial citrus groves. By this time there were one hundred six miles of main canals and two hundred lateral ditches. As president of the Arizona Improvement Company, Murphy was responsible for the construction of the Crosscut Canal which connected the four existing canals. By connecting the canals, Murphy created the first unified delivery system in the Valley with the advantages of controlling the amounts of water and minimizing the losses.

Farmland and urban population increased until the droughts of 1897, 1898, 1899 (Harshbarger, et al., 1966; and Salt River Project, 1970). Unfortunately, the water supply for the canals was dependent on surface water flows with no provisions for storage reservoirs for the lean water years. The drought forced a decline of the cultivated lands by 75,000 acres. Once again, the lack of storage reservoirs contributed greatly to the hardships faced by the agricultural community.

The droughts of the 1890's made the farmers aware of the need for a dependable water supply. Captain William Hancock and George H. Maxwell called for unity

among the landowners in the Salt River Valley and were instrumental in formulating the first plans for construction of dams on the Salt and Verde Rivers. Both men advocated a multi-purpose storage reservoir and equal distribution of costs.

In 1903 the Salt River Valley Water Users' Association was formed to take advantage of federal funds made available for surveying, planning, and constructing dams and storage reservoirs by the Federal Reclamation Act of 1902. As a result Roosevelt Dam (Figure 15) was constructed from 1905 to 1911, and at a height of 280 feet it represented the highest dam in the world at the time. Roosevelt Dam provided a dependable irrigation supply and power generator. The Granite Reef diversion dam was built in 1906 on the Salt River downstream of the confluence of the Verde River to divert water from the Salt River to the irrigation canal system (Harshbarger, et al., 1966).

Between 1911 and 1920 Roosevelt Dam overflowed four times discharging valuable water. The Water Users Association built three more dams on the Salt River downstream of Roosevelt. These dams were Mormon Flat with Canyon Lake, 1923-25; Horse Mesa with Apache Lake, 1924-27; and Stewart Mountain with Saguaro Lake, 1928-30 (Figure 16). The four reservoirs had a combined capacity

Figure 15. Roosevelt Dam Located on Salt River Upstream of the Phoenix Metropolitan Area, Arizona

Source: Salt River Project, Ed Toliver

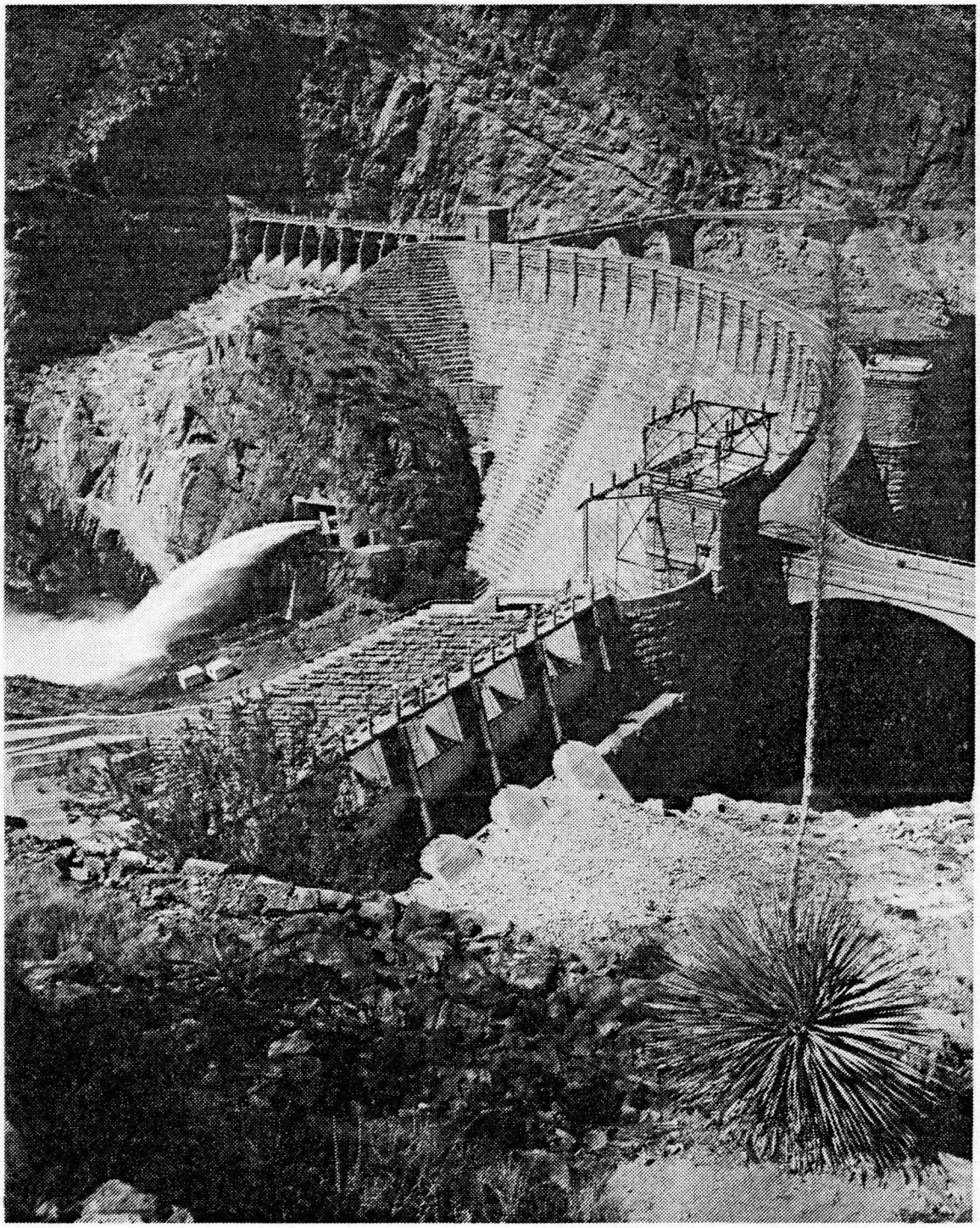
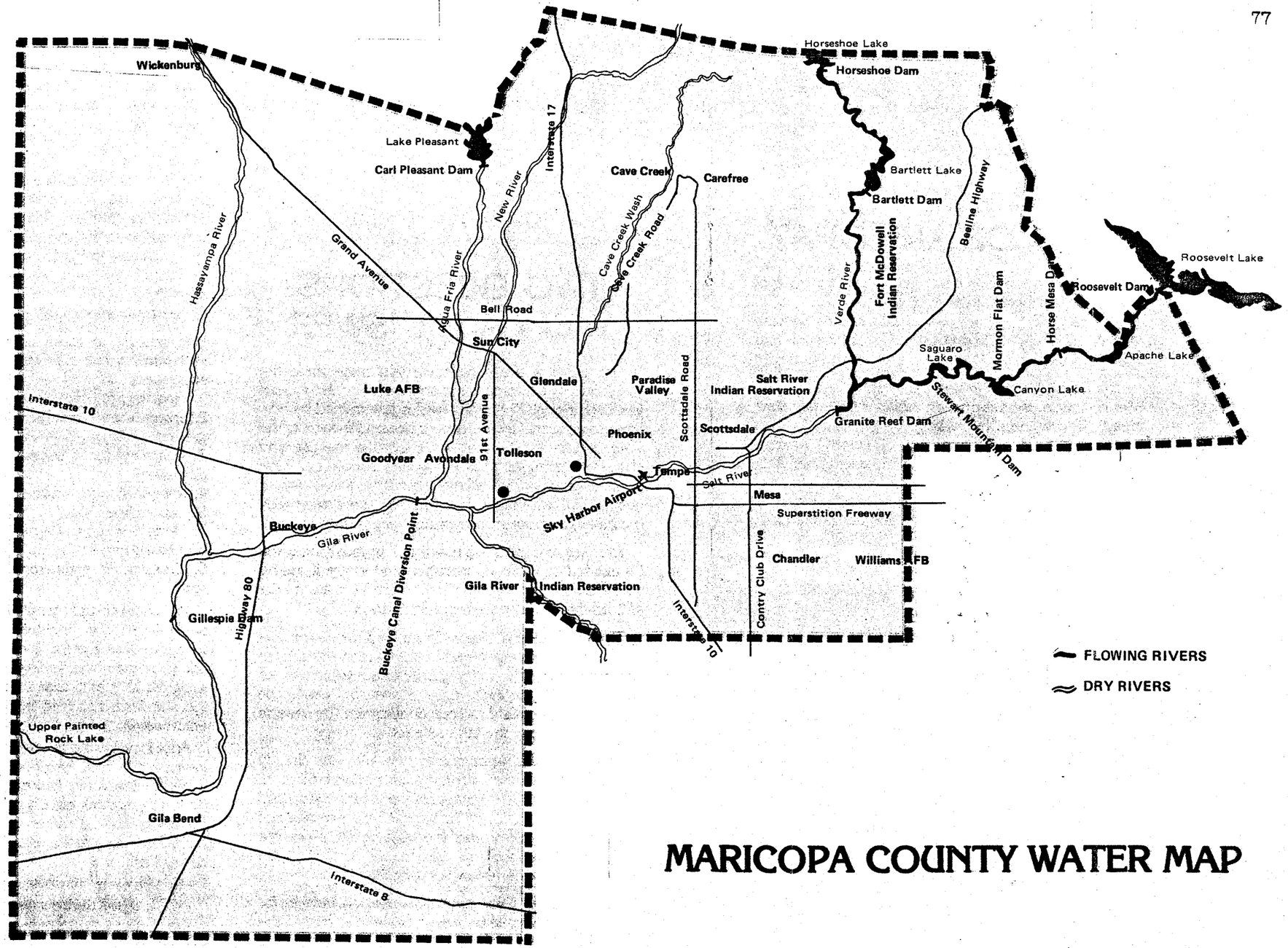


Figure 16. Relative Location of Dam System on Salt and Verde Rivers, Maricopa County, Arizona

Source: U. S. Army Corps of Engineers and Maricopa Association of Governments, c. 1978



MARICOPA COUNTY WATER MAP

of approximately 1,750,000 acre-feet and the spillways could pass a flood of 150,000 cubic feet per second. Lake Pleasant Dam was constructed on the Agua Fria River in 1927 to provide irrigation water for some 50,000 acres in the Maricopa County Municipal Water Conservation District No. 1. The capacity of the dam was 160,000 acre-feet (Harshbarger, et al., 1966).

As dams and reservoirs were constructed, cities and resorts began to appear in the arid region. Developed land or land "committed to other than rural use" was delineated by Dr. Charles Sargent (1973), Department of Geography, Arizona State University. Dr. Sargent's maps depict the greater Phoenix area circa 1925 and developed areas for 1925 and 1940 relative to the incorporated areas in 1973. The maps appear as figures 17, 18, and 19.

Agricultural areas were also realizing spatial expansion prior to the 1950's. The construction of the dams and reservoirs to control the use of surface waters and ground water pumping to supplement available surface water provided the impetus for growth. During the first quarter of the twentieth century irrigation raised the water table in the Valley and many farmlands were water-logged. Drainage wells were dug to pump groundwater and lower the water table. At first the drainage water was

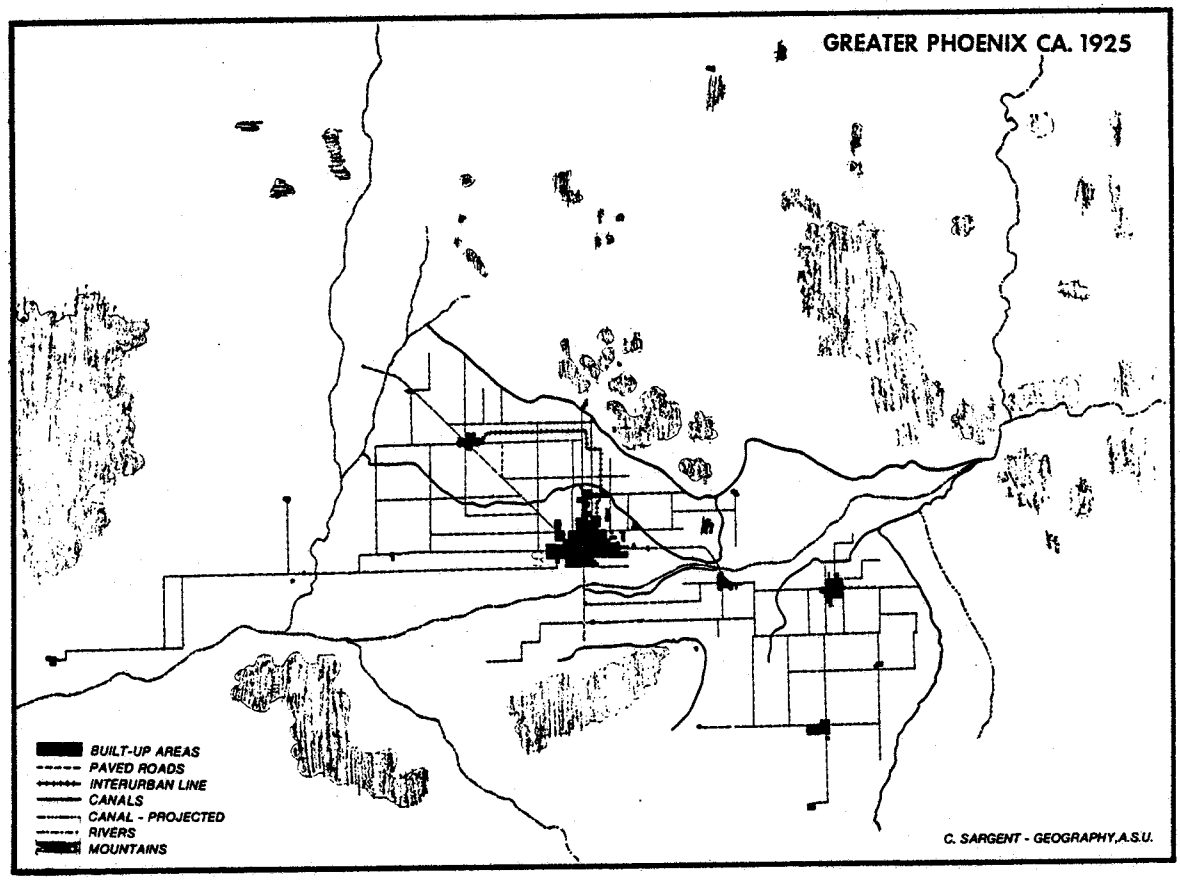


Figure 17. Greater Phoenix Area, Arizona Circa 1925

Source: Sargent, 1973

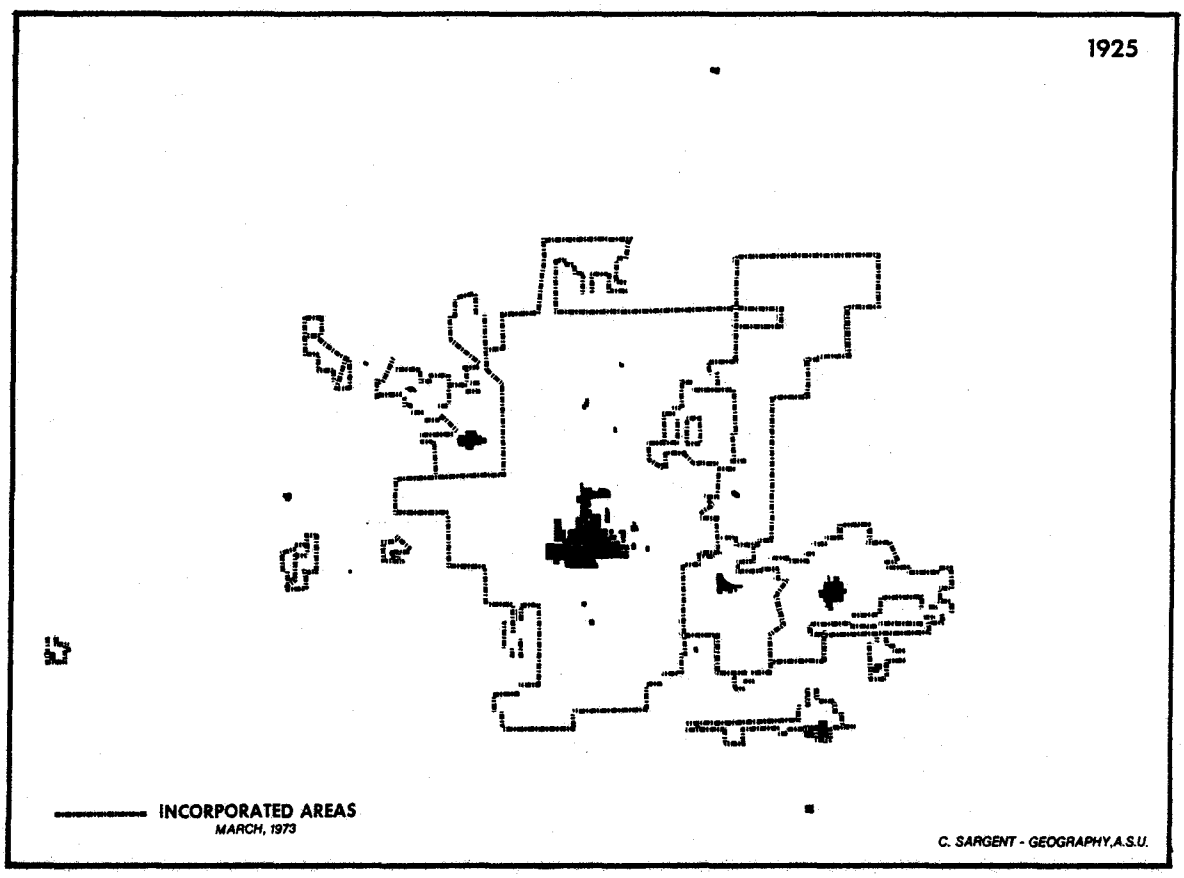


Figure 18. Extent of Development within Incorporated Areas, Greater Phoenix Area, Arizona, 1925

Source: Sargent, 1973

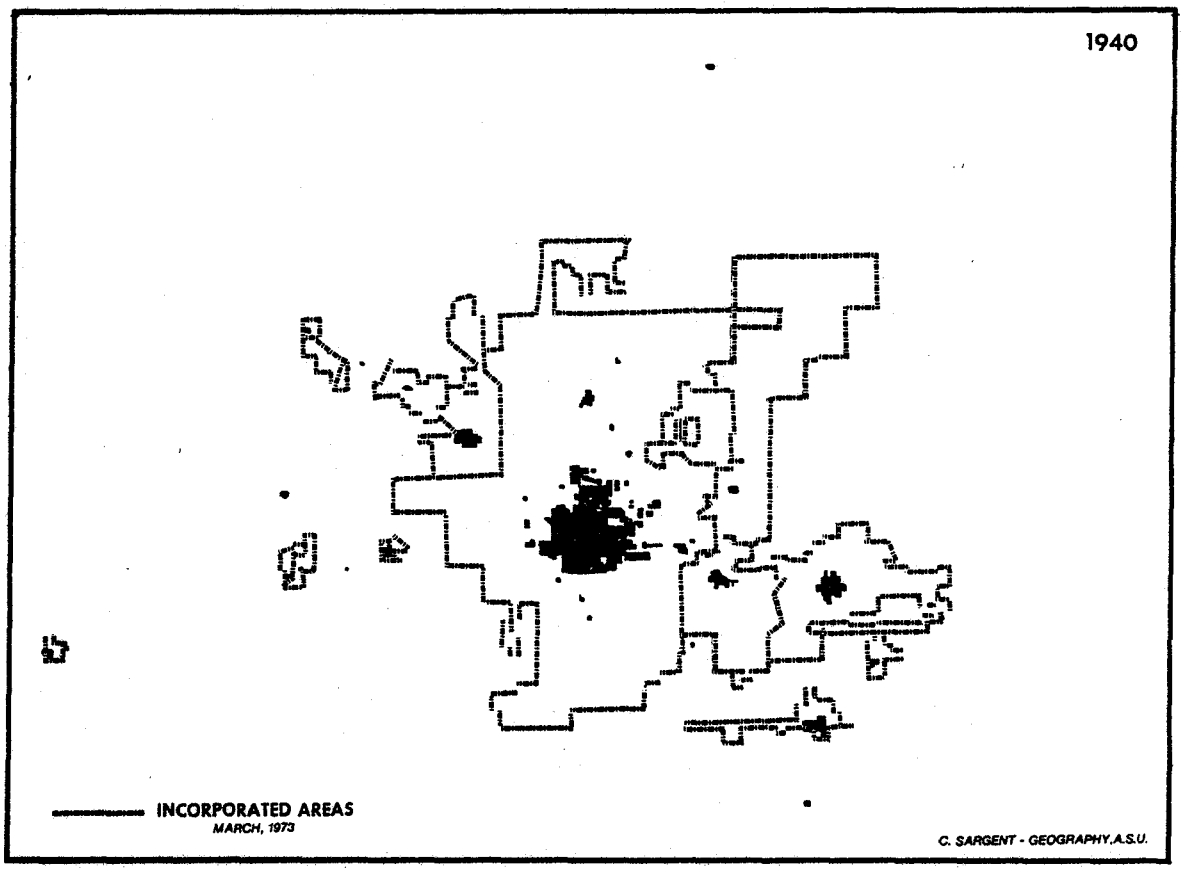


Figure 19. Extent of Development within Incorporated Areas, Greater Phoenix Area, Arizona, 1940

Source: Sargent, 1973

wasted but was later used to supplement irrigation supplies. In 1929 the Roosevelt Irrigation District built canals to transport ground water to areas in the west portion of the Valley where surface water was not available and ground water was of poor quality. The water table in Deer Valley, lower Paradise Valley, and the area east of the Roosevelt Water Conservation District continued to rise prior to 1940. This rise was attributed to the use of surface water for irrigation. During the 1940's cultivated land expanded and irrigation water was pumped from wells. The water table throughout the Valley began to decline.

During the early 1940's, the paradox of water in the desert was again apparent (Figure 20). Heavy rains occurred between March and July of 1941 causing the system of four dams and reservoirs on the Salt River and Lake Pleasant Dam on the Agua Fria River to overflow. Later in the decade the Valley was plagued by drought. The droughts mandated additional pumping of ground water to supplement and supplant the use of surface water. Irrigation and the demand for water were increased following World War II because farm products were in demand and receiving high market prices.

The development of the Phoenix metropolitan area into an agricultural community was evident between the

Figure 20. Paradox of Water in the Desert--Even Though Arizona Seems Dry All the Time, Destructive and Dangerous Flash Flooding Conditions Are Also Common

Source: The Arizona Republic, Reg Manning, n.d.

mid-1800's and 1950. The construction of canals and dams and reservoirs made possible the expansion of agricultural lands and small urban centers. The agricultural communities were first concentrated adjacent to the Salt River and later spread to the north and west as additional canals were constructed. Consequently, the original townsites and farmlands suffered the greatest when the Salt River overflowed. The intermittent floods and droughts made life for the Valley residents difficult to cope with, but did not halt the influx of farmers, ranchers, and urbanites.

The Natural System Under Urbanization

The period from after World War II to the present was marked by rapid growth in the Phoenix metropolitan area. Population growth and spatial expansion were prevalent throughout the Valley. Land use changes modified the desert ecosystems, including the flood hazard, and made legislation necessary to curtail unwise encroachment onto the flood plain.

Since World War II, Phoenix has been transformed from an agricultural region to an urban center. Urban development of the Phoenix metropolitan area was depicted by Dr. Charles Sargent (1973). Figures 21 through 24, provided by Dr. Sargent, revealed the spatial expansion of

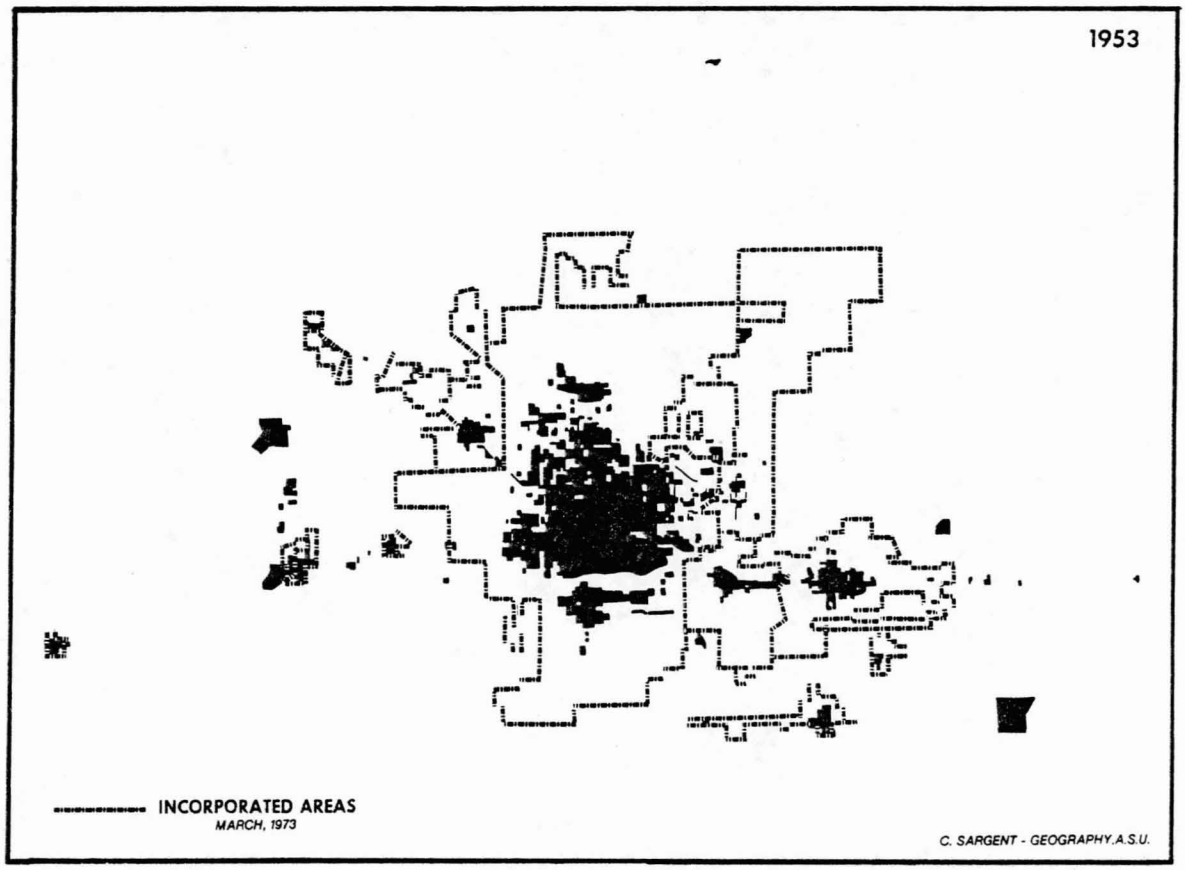


Figure 21. Extent of Development within Incorporated Areas, Greater Phoenix Area, Arizona, 1953

Source: Sargent, 1973

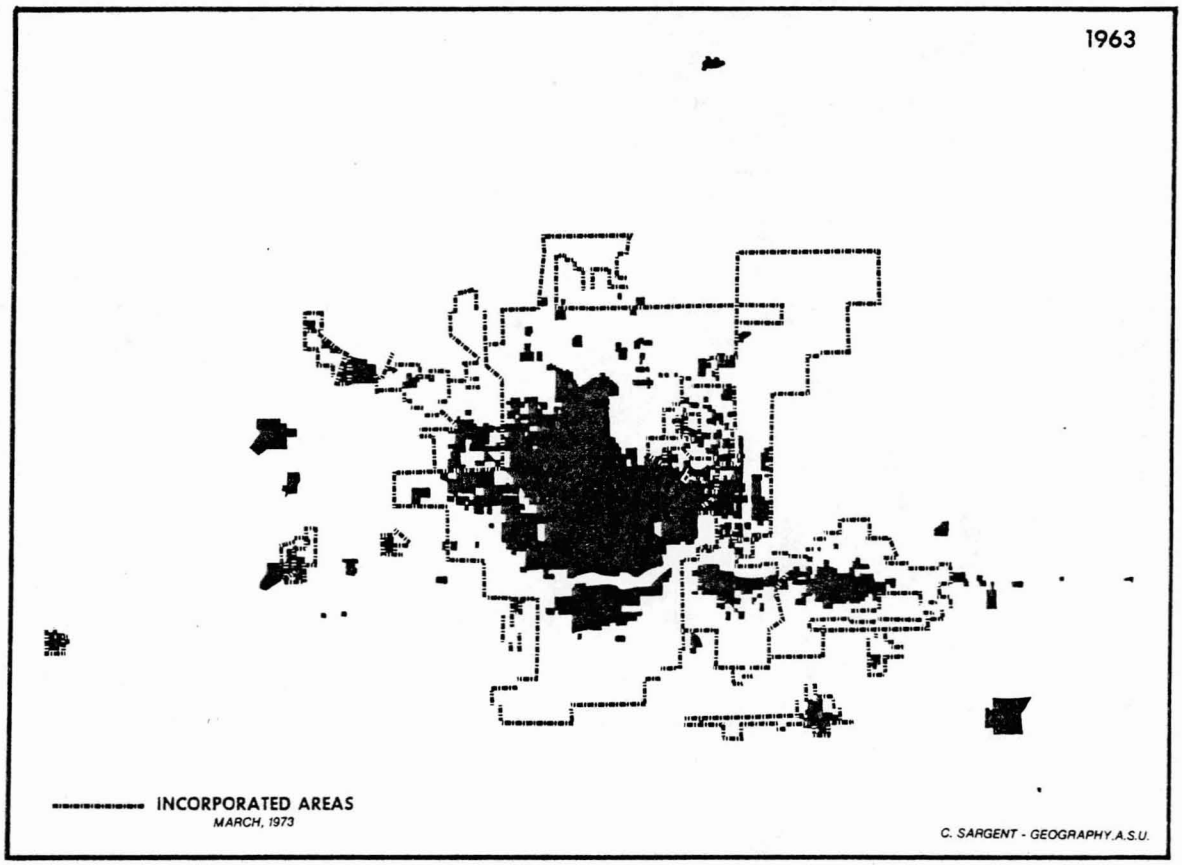


Figure 22. Extent of Development within Incorporated Areas, Greater Phoenix Area, Arizona, 1963

Source: Sargent, 1973

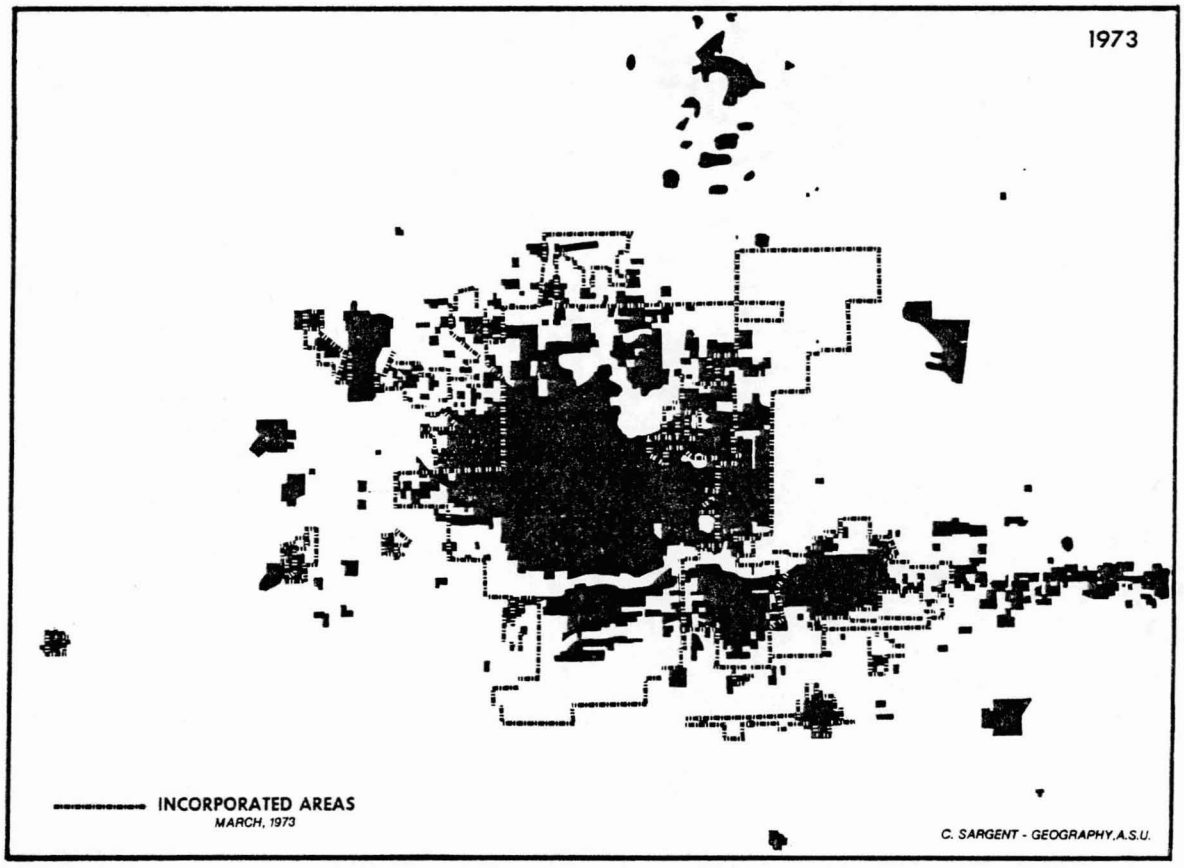


Figure 23. Extent of Development within Incorporated Areas, Greater Phoenix Area, Arizona, 1973

Source: Sargent, 1973

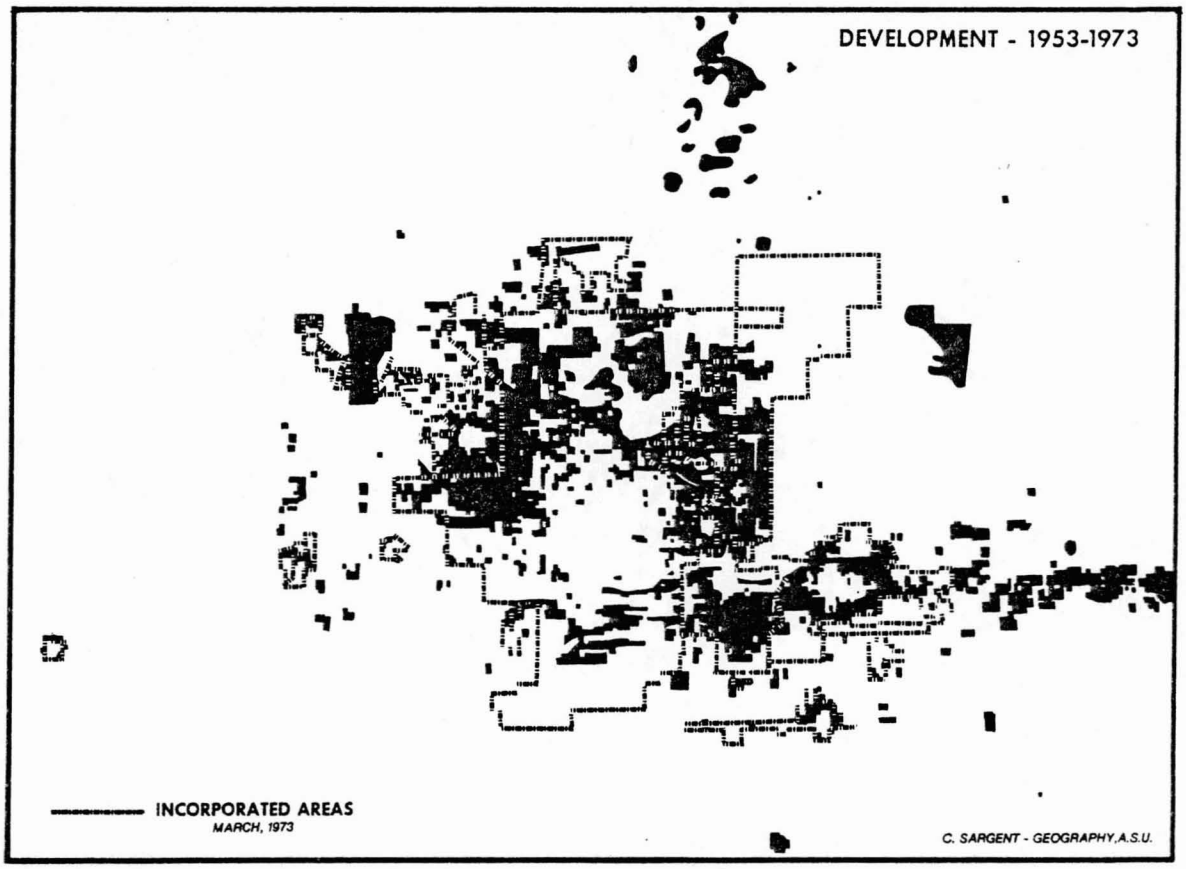


Figure 24. Extent of Development within Incorporated Areas, Greater Phoenix Area, Arizona, From 1953 to 1973

Source: Sargent, 1973

the Phoenix area from 1953 to 1973. The maps portray the major directions of growth to the west and south of Phoenix between World War II and 1953, to the northwest and east from 1953 to 1963, and in all compass directions with varying degrees of expansion from 1963 to 1973. Population statistics compiled by Dr. Sargent (1973) exemplified the surge of growth and urbanization in the major towns comprising the Phoenix metropolitan area. These figures are shown in Table 2.

Further evidence attesting to the land use changes of the past few decades was the statistical analysis of change in area of farmland compared to that of urban use:

> The total acreage in the irrigation project [Salt River Project] was 238,252 acres in 1967. From 1957 to 1969 the net area being farmed decreased from 79 to 64 percent of the total area. The area in urban land use, subdivision, commercial, and industrial, increased from 16 to 32 percent of the total acreage. The average rate of decrease in farm acreage was 3,700 acres per year, although the actual rate had been below this figure since 1963 (Smith, 1972).

The Phoenix metropolitan area houses a major portion of the state's population and irrigated acreage. The arid land economy is diverse, and prosperity, measured by agriculture, livestock raising, manufacturing, industry, mining, and tourism, is dependent on water. The dynamic growth of the Phoenix area and the land use

Table 2. Population (000's of Persons) of Major Towns, Greater Phoenix Area, Arizona From 1910 to 1970

Town (Founding)	1910	1920	1930	1940	1950	1960	1970
Phoenix (1868-70)	11.0	29.0	48.0	65.0	107.0	439.0[b]	583.0
Chandler (1912)	--	.4	1.4	1.2	3.8	9.5	14.0
Glendale (1892)	1.0	2.7	3.7	4.9	8.2	16.0	36.0
Mesa (1878)	1.7	3.0	3.7	7.2	17.0	34.0	63.0
Scottsdale (1896-1913)	.3	.5[a]	.7[a]	1.0[a]	2.0	10.0	68.0
Tempe (1871)	1.5	2.0	2.5	2.9	7.7	25.0	64.0
Other Towns and Rural	19.5	52.4	91.0	82.2	103.8	161.0	140.0
Maricopa County Total[c]	35.0	90.0	151.0	186.0	332.0	664.0	968.0
State of Arizona	204.0	334.0	430.0	499.0	750.0	1,302.0	1,771.0

Notes:
a. author's rough estimates
b. there was extensive annexation to Phoenix between 1950 and 1960
c. includes Gila Bend (1970 pop. 1,800) and Wickenburg (1970 pop. 2,700) which are not part of the study area

Source: Sargent, 1973

changes therein are closely associated with the development of the Salt River Project. Primarily because the Salt River Project supplied power and water necessary for life, the community bore the potential for growth and the growth inevitably resulted in land use changes. The human modifications on the natural systems were related to the evolutionary process of urbanization. Some of the natural phenomena which underwent change as a consequence of urbanization were vegetation and associated wildlife habitats, desert esthetics, and flood plains.

Urbanization has disturbed or altered the natural plant communities throughout the Valley. Gravel mining, particularly in large streambeds, has been the principle agent responsible for the disturbance of many acres of riparian habitat. Farming, off-road vehicles, and urban development have disturbed or obliterated expansive areas of desert outwash plant communities. Domestic grazing and human changes in topography and drainage patterns have altered various plant communities. In addition to natural vegetation in disturbed areas, annual herbaceous species such as Russian thistle, cocklebur, pigweeds, sunflower, and mustards, and shrubs such as desert broom and tree tobacco have developed. Areas along canal banks, where man's activities have increased soil moisture, support

low density riparian growth such as cottonwoods, ironwoods, blue palo verde, and mesquite. Where land which was once cultivated has been fallowed, indigenous species, as well as introduced weedy annuals and perennials, have revegetated and thus, formed disturbed plant associations (U. S. Army Corps of Engineers, 1976b).

Agricultural lands, which represent a significant amount of vegetation in the western portion of the research area, have been disturbed and supplanted by urban development. Urban-related sprawl has replaced the disturbed outwash plain habitats commonly found in and near the agricultural communities. In many instances, native vegetation has been retained as urbanized areas expand, but many other plant species have also been introduced.

Wildlife have been found in the natural desert, agricultural, and urban habitats in the greater Phoenix area. The largest number and greatest diversity of desert fauna within the area inhabited the desert wash and upland areas north of Phoenix because wildlife plant foods and shelter were most abundant here. Intensely developed or farmed lands seldom envelop much variety or quantity of wildlife species. However, several bird species have flourished in agricultural communities. Wildlife were driven from many parts of the Valley but were attracted to

and thrived in the vegetated areas along desert washes, canals, and rivers. Vegetation along these drainageways provides important food, nesting, and shelter sites for the remaining wildlife.

Natural desert habitat and some animal species were eliminated by increases in irrigated agriculture. Some of the more adaptable wildlife species survived the changes and multiplied in these areas. Some song and game birds thrived in the agricultural croplands where they found food, water, and cover. Common bird species associated with irrigated agriculture included red-winged and brewer's blackbirds, brown-headed cowbirds, white-crowned sparrows, and western meadowlarks. In the urban areas species such as the house sparrow, starling, house finch, inca dove, and mockingbird thrived.

Biological communities along stream channels have been considerably altered as a result of off-road vehicular use, sand and gravel mining, and unauthorized waste disposal. Despite these activites, a few reaches of the Cave and Skunk Creeks and the Agua Fria and New Rivers have remained relatively natural.

Natural desert esthetics have been changed by human modifications. The natural beauty of the subtle desert colors on the rocks, the annual flowering shrubs,

and the wide, open spaces have changed as the Valley developed into an urban society. Many Phoenix area residents migrated from more humid climatic regions and their propensity for lush green lawns resulted in grass being planted where desert shrubs and cacti once grew. Residents have opted for swimming pools and man-made residential lakes rather than the natural desert landscape.

As the urban core has become more densely developed, residential developments have appeared on the urban periphery in the desert and agricultural areas. This leap frog development has subjected increasing acreage of farmland and open space to urban sprawl. Thus, the green irrigated lawns, swimming pools, recreational lakes, and residential and commercial dwellings have continued to modify the natural esthetics of the desert.

Urbanization has been the primary source responsible for altering the characteristics of the drainage basins and flood plains in the Phoenix metropolitan area. Continued agricultural practices coupled with rapid urban development altered, and in many cases, obliterated the natural patterns of sheet flow and riverine drainage. Two analyses of land use change in the flood plains illustrated a general trend of development and some of the potential consequences of such development.

Schneider and Goddard (1974) defined the extent and occupancy of flood plains in twenty-six urbanized areas. One of the cities studied was Phoenix. The approach taken in the analysis was to first determine the areal extent of the urban area; secondly, to measure the area of the flood plain within the urban area; and finally, to measure the extent of usage of the urbanized area in the flood plain. Data collected for the study revealed that Pheonix, Arizona, with a population of 863,400 and land area of 387.5 square miles contained 71.2 square miles of flood plain. The flood plains represented 18.4 percent of the urbanized area. Developed areas of the flood plain totaled 63.5 square miles, or 89.2 percent of the flood plain had been developed. Analysis of indices of three aspects of flooding (depth of flooding, precipitation, and physiography) led to the conclusion that there was "no one factor that explains the inclusion of flood plains in urban areas or the degree of development of those flood plains." It was observed that the general pattern of growth in the twenty-six urban communities was initially on the flood plains and gradually moved to higher ground as urbanization continued. Most major cities in the United States have followed this pattern and most have been flooded.

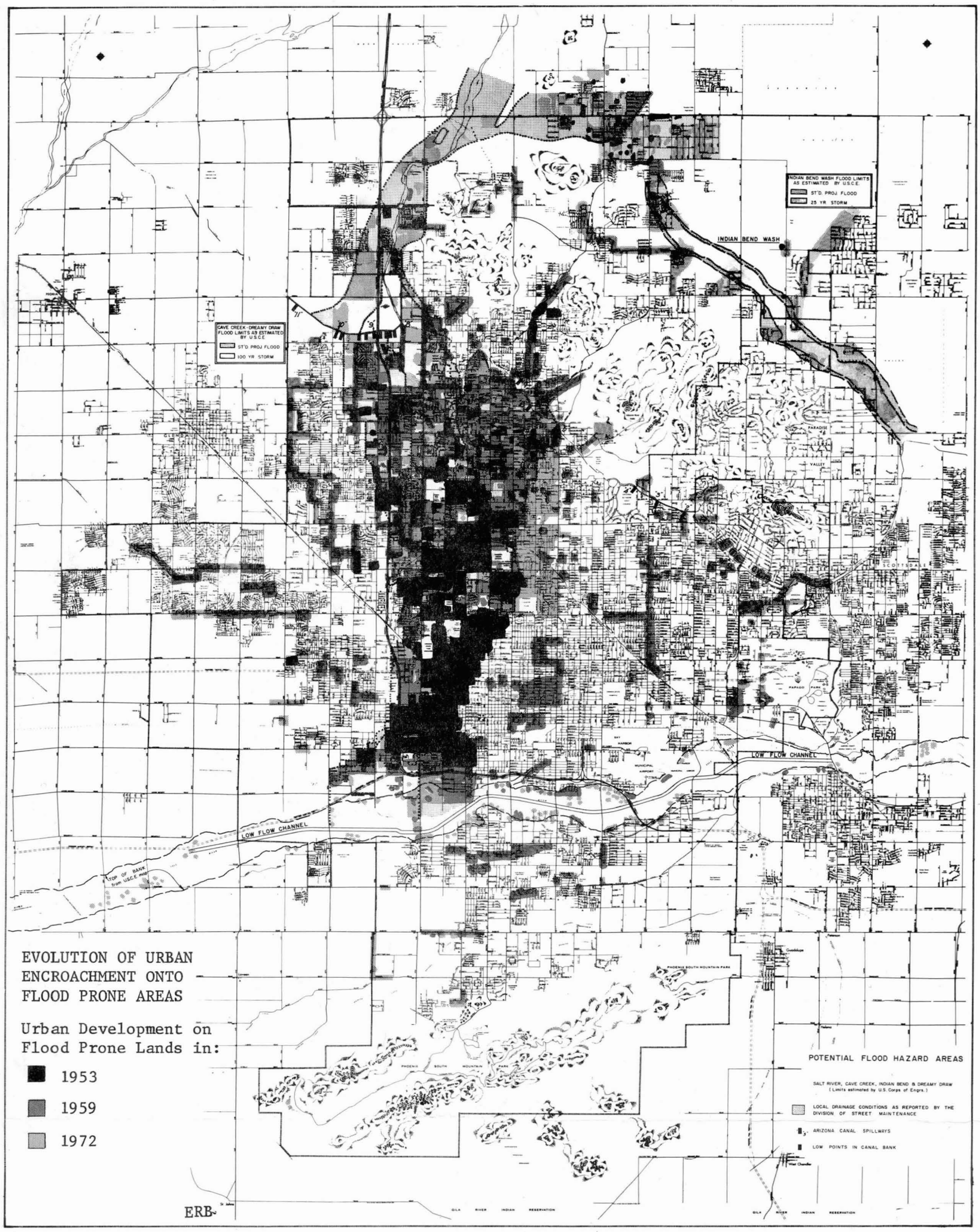
In order to further illustrate urban growth and the incessant urban encroachment onto the flood prone areas of the City of Phoenix, the evolution of residential development was mapped (Figure 25). The base map used delimited the extent of the various flood prone areas as compiled by the City of Phoenix, Public Works Department (1968). Aerial photographs for the years 1953, 1959, 1972 were used to map developed areas in a temporal framework. The stippled pattern appearing on the map in locations not in the flood plains represent areas of low elevation, which consequently, are prone to flooding.

Development of the flood prone areas depicts an interesting spatial pattern. In 1953 development was predominately to the north of the Salt River to Bethany Home Road with several homes located as far north as Northern Avenue. The Cave Creek and Indian Bend Wash regions were free of development with the exception of a few scattered residences.

By 1959 development had encroached upon the Salt River flood plain. Residential development was interjected in segments of land left vacant prior to 1953. However, most of the houses built between 1953 and 1959 were located on the periphery of the 1953 boundaries. Extensive development occurred north of Camelback Road to

Figure 25. Evolution of Residential and Commercial Development Encroaching onto Flood Prone Areas from 1953 to 1972, Phoenix Metropolitan Area, Arizona

Source: Base Map Prepared by City of Phoenix, Public Works Department, 1968


INDIAN BEND WASH FLOOD LIMITS AS ESTIMATED BY U.S.C.E.
ST'D. PROJ. FLOOD
25 YR. STORM
INDIAN BEND WASH
CAVE CREEK-DREAMY DRAW FLOOD LIMITS AS ESTIMATED BY U.S.C.E.
ST'D. PROJ. FLOOD
100 YR. STORM
LOW FLOW CHANNEL
LOW FLOW CHANNEL
TOP OF BANK from USCE map
EVOLUTION OF URBAN ENCROACHMENT ONTO FLOOD PRONE AREAS
Urban Development on Flood Prone Lands in:
1953
1959
1972
POTENTIAL FLOOD HAZARD AREAS
SALT RIVER, CAVE CREEK, INDIAN BEND & DREAMY DRAW (Limits estimated by U.S. Corps of Engrs.)
LOCAL DRAINAGE CONDITIONS AS REPORTED BY THE DIVISION OF STREET MAINTENANCE
ARIZONA CANAL SPILLWAYS
LOW POINTS IN CANAL BANK
PHOENIX SOUTH MOUNTAIN PARK
GILA RIVER INDIAN RESERVATION
GILA RIVER INDIAN RESERVATION
ERB

Dunlap Road. During this period some homes were built in the Indian Bend Wash flood prone regions just north of Bell Road and west of 32nd Street. Other sections not within the anticipated flood limits, but nonetheless, prone to inundation due to low elevations, were also experiencing urban growth during this time period. Some of the more obvious of these sections were centered between Van Buren and Oak Road and 16th Street and 7th Street; a north-south trending segment along 32nd Street from McDowell Road to Campbell; an east-west profile between Broadway and Roeser Road and 16th Street to 15th Avenue; and another east-west build-up between Thomas Road and Indian School Road and 45th Avenue to 63rd Avenue.

Between 1959 and 1972 much of the land not already in residential housing or parks was developed. Besides filling in the existing residential areas, urbanization expanded along the periphery, particularly to the east and north, of the preexisting boundaries of development. The banks and flood plain of the Salt River were interspersed with structures. Much of the growth during this time interval occurred north of Thomas Road and east of 7th Street. The Cave Creek area, especially that portion between Thunderbird Road and Dunlap Avenue, underwent extensive urban expansion. Growth was also experienced

along Indian Bend Wash. Several regions of low elevation were developed. The more conspicuous of these are located: along a north-south axis of 43rd Avenue between Northern Avenue and Bethany Home Road; along the Grand Canal from 71st Avenue to 63rd Avenue; and along the Arizona Canal from 32nd Street to 64th Street.

The flood prone regions comprise approximately thirty-eight of the two hundred-square-mile area used for this study. About eighty-four percent of the lands prone to flooding have been developed for residential purposes. For an estimation of relative dimensions and percentages see Table 3.

Table 3. Relative Area and Percentage of Study Matrix by Type of Area, Phoenix Metropolitan Area, Arizona, 1972

Description of Area	Area In Square Miles	Percentage of Matrix
Phoenix Urbanized Area	200	1.00
Flood Prone Area	38	0.19
Urbanized Flood Prone Area	32	0.16

Urban development of the flood prone areas has been gradual, yet relentless. An extrapolation of the present urban form would no doubt depict continued peripheral migration of urban development into the areas susceptible

to flooding. Thus, the potential damage caused by floods would be expected to increase.

The mounting number of dwellings susceptible to flooding and the increase in damages caused by flooding prompted the enactment of federal, state, and local laws and regulations. These acts and regulations included the National Flood Insurance Act of 1968 (Pub. L. 90-448, 1968); Flood Disaster Protection Act of 1973 (Pub. L. 93-234, 1973); Arizona House Bill 2010 (Arizona House of Representatives, 1973); flood plain regulations for unincorporated areas as Maricopa County (Maricopa County Board of Supervisors, 1974); and various city regulations. Each of these is discussed below.

The National Flood Insurance Act of 1968 (Pub. L. 90-448, 1968) took a new approach to flood plain management. It offered flood insurance at low rate to communities that would adopt flood plain regulations prescribed by the Federal Insurance Administration. This marked the first time that flood insurance was made available to owners of coastal or riverine property. A deficiency in the 1968 act was that the program was voluntary to community and individual participants. The Flood Disaster Protection Act of 1973 remedied the deficiency of the 1968 act.

The Flood Disaster Protection Act (Pub. L. 93-234, 1973) compelled, rather than encouraged, flood prone communities to participate in the flood insurance program and to adopt flood plain ordinances with enforcement provisions consistent with federal standards to reduce potential damage from flooding. Unless a community has enrolled in the National Flood Insurance Program and the owner of an identified flood prone area has purchased a flood insurance policy, no federally related financial assistance shall be available for acquisition or development in flood prone areas. Federal financing includes banks that are members of the Federal Deposit Insurance Corporation and all savings and loan associations. Communities participating in the flood insurance program are compelled to adopt and enforce certain land use regulations for flood hazard areas.

House Bill 2010 (Arizona House of Representatives, 1973), approved on 3 May 1973 by the Governor of the State of Arizona, provided flood plain management within Arizona. The purpose of the act was to encourage, impower, and assist communities and counties within Arizona to adopt flood plain management regulations. These regulations were to be designed to reduce encroachment onto flood prone areas, to reduce the number of obstructions in the

flood plain which restrict the capacity of the floodways, and thus, to reduce the losses caused by floods.

Flood plain regulations for the unincorporated areas of Maricopa County (Maricopa County Board of Supervisors, 1974), adopted on 25 February 1974, required the delineation of flood plains; regulation of construction of structures which might retard, obstruct, or divert flood flows; and establishment of minimum floor elevations and flood proofing methods for uses prone to flooding.

The City of Phoenix (Phoenix City Council, 1974) adopted a flood plain ordinance (Ordinance Number G-1343) in February 1974. The ordinance regulated construction and land use within flood plains in the City of Phoenix to reduce flood losses, prevent unwise encroachment unto the flood plains, and prevent construction within the flood plain that would retard, obstruct, or divert flood waters. "Floodway Encroachment Lines" and "Selected Floodways" are to be established by the Phoenix City Engineer. The "Floodway Encroachment Lines" are the outer limits of the 100-year flood; and the "Selected Floodway" is the limit to which flood plain encroachment will be allowed. The "Selected Floodway" must allow passage of the 100-year flood without significantly increasing the flood heights.

Most of the communities in the metropolitan area

have adopted flood plain ordinances similar to that of the City of Phoenix. The ordinances restrict development within the flood plain.

These laws and regulations are designed to prevent further development within the flood plains that could lead to increasing flood problems. However, serious flood hazards do presently exist within the Phoenix metropolitan area.

CURRENT FLOOD HAZARD

Complicated flood problems exist throughout the Phoenix metropolitan area. Flood hazards have been identified along Cave Creek from the existing Cave Creek Dam to the Salt River, along and below the Arizona Canal between 40th Street and Skunk Creek, along Skunk Creek, along the New and Agua Fria Rivers, along Indian Bend Wash, and along the Salt River. These flood prone areas are shown on Figure 13. Development within the standard project flood* overflow area has been extensive and includes

*Standard project flood is the term used to define the flood which would be caused by the occurrence of the most severe storm of record in an area. It would be exceeded only on rare occasions. Such a flood could occur in the Phoenix area if a storm equivalent in magnitude to the largest storm on record in the general region were to center over the drainage area when ground conditions were conducive to a high rate of runoff. The estimated flood from such a storm represents a reasonable upper limit of the flood producing potential of that part of the basin. (U. S. Army Corps of Engineers, 1974a).

residential, commercial, industrial, agricultural, recreational, open space, public, and semi-public land uses.

The overflow area along Cave Creek is on a broad alluvial fan and extends from the existing Cave Creek Dam to the Salt River, including a breakout from the wash near Cactus Road extending to Grand Avenue. The portion of Cave Creek upstream of the Arizona Canal has a defined channel. The City of Phoenix has made improvements on several reaches of Cave Creek between Greenway Road and the Arizona Canal. Improvements made are in conjunction with Phoenix plans for a linear park along the channel. Agricultural and urban development have obliterated almost all traces of the Cave Creek channel between the Arizona Canal and the Salt River. The overflow area extends from one to two miles in width with shallow depths of a two-foot average. This overflow area encompasses an intensively developed section of the metropolitan region (U. S. Army Corps of Engineers, 1976a).

Flood prone areas associated with the Arizona Canal are located along the north bank of the canal where waters tend to pond behind the raised banks and in several areas below the canal that are the most susceptible, according to historical events and theoretical analysis, to overtopping of the canal levees by flood flows originating north

of the Arizona Canal. Well-defined washes of small capacity transport flood flows to braided streams of very small capacity on the alluvial fans. Flood waters pond along the north side of the Arizona Canal where the levees are above ground elevation (Figure 26). The flows enter the canal system which is designed contrary to what is needed for flood control. That is, the Arizona Canal, an irrigation supply system, has a greater carrying capacity upstream than downstream because water is siphoned off as it travels downstream. Just the opposite is needed for flood control works that intercept more flows as they progress downstream. After the Arizona Canal has been filled to capacity with flood waters the levees on the south side are overtopped and breached (Figures 27 and 28). The drainage area tributary to breaks in the Arizona Canal consists of twenty-one square miles upstream of the canal and extends from Cave Creek east to Cudia City Wash near 40th Street. Approximately 8,900 acres are included within the most probable overflow areas caused by breaks in the canal. These areas are defined as six major breakout areas east of Cave Creek and two west of Cave Creek where water depths in the overflow areas exceed six inches. Canal breaks and overtopping flooded more than 3,000 acres during the 22 June 1972 flood causing

Figure 26. Raised Banks of the Arizona Canal, Phoenix Metropolitan Area, Arizona

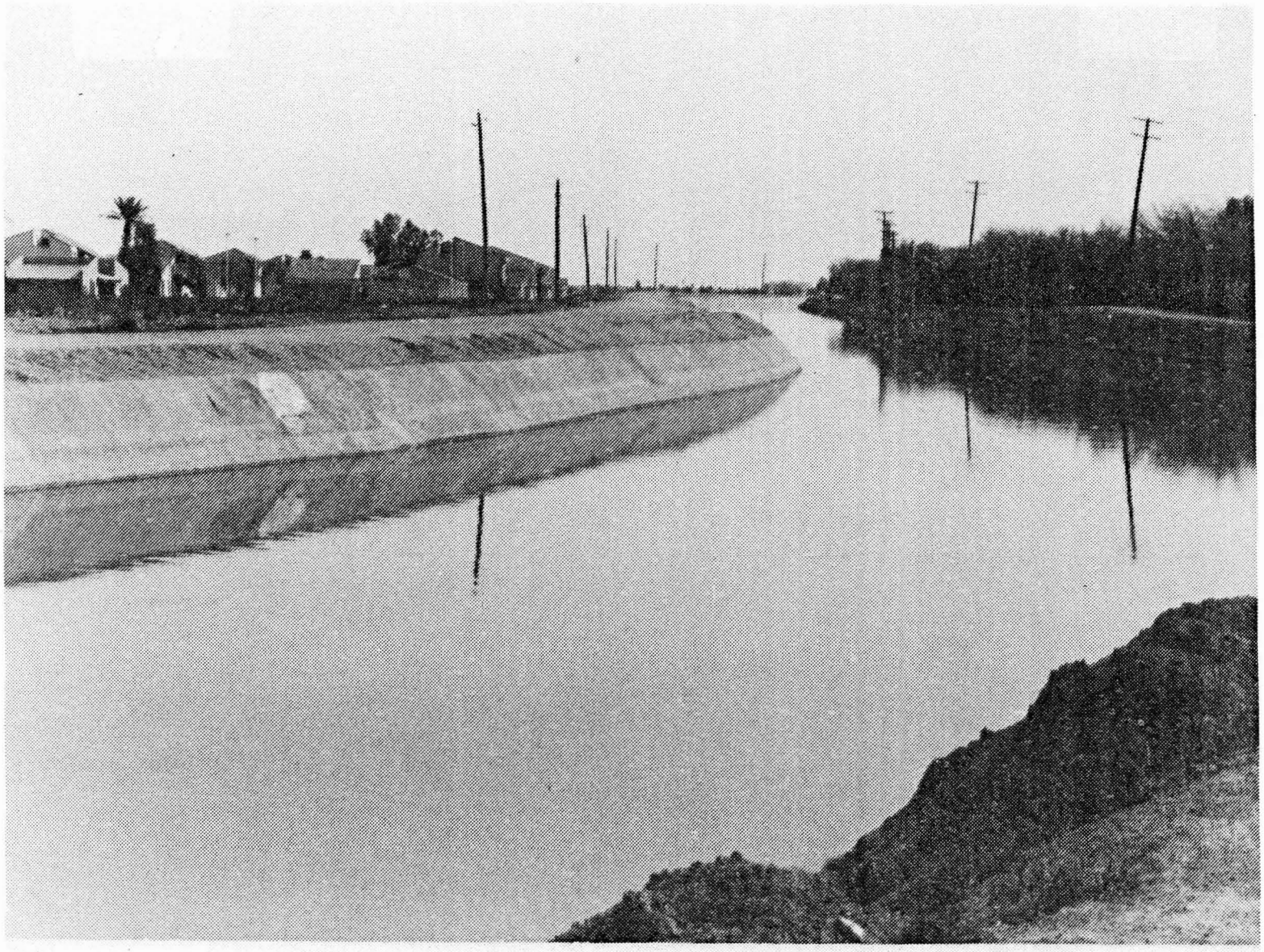


Figure 27. Flood of 22 June 1972 - Motorists Endure Stalled Automobiles and Traffic Delays on Central Avenue near Indian School Road in Phoenix.

Source: U. S. Army Corps of Engineers, 1975b

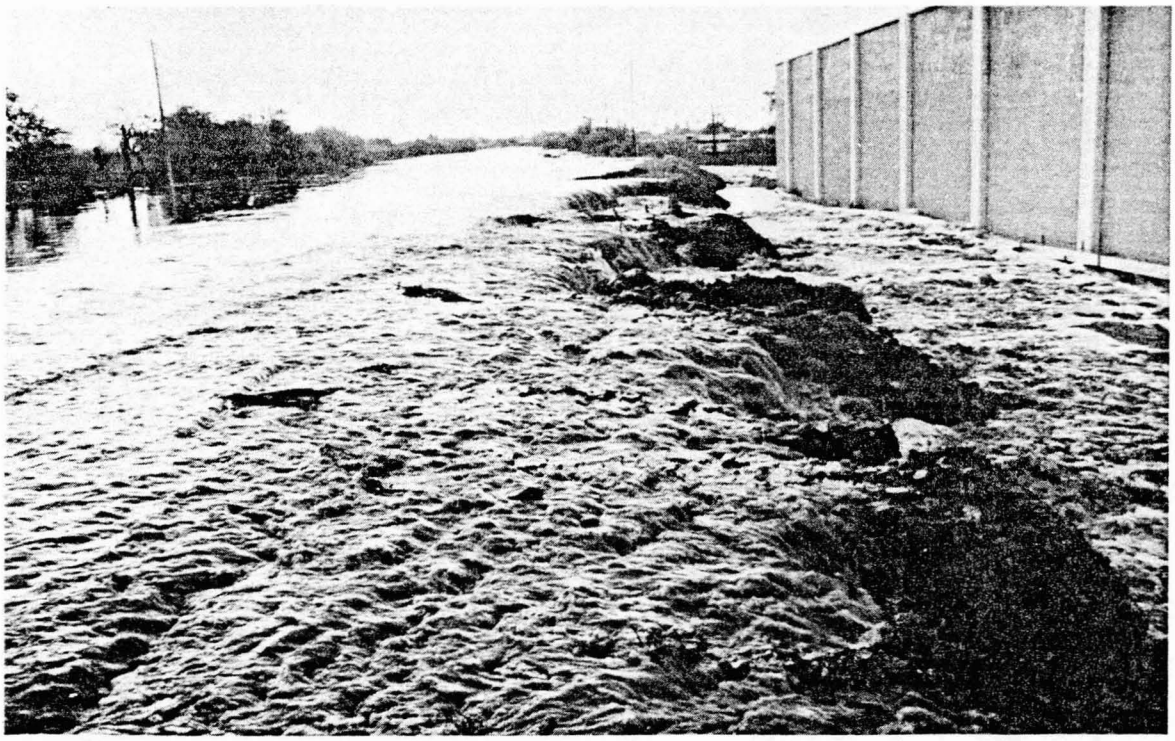


Figure 28. Flood of 22 June 1972 - Floodwaters and Debris Gush over the Top of the Southern Bank of the Arizona Canal East of 16th Street in Phoenix.

Source: U. S. Army Corps of Engineers, 1975b

$4.3 million in damage to residential, commercial, and public property and irrigation works. Breaks in the canal at 32nd and 40th Streets caused damages estimated at $3.8 million (U. S. Army Corps of Engineers, 1976b).

The Skunk Creek and New and Agua Fria Rivers have relatively well-defined channels. Floods of a 10- to 20-year frequency could pass through the channels without causing damage. The standard project flood overflow area consists of 22,300 acres and extends along Skunk Creek from the proposed Granite Reef Aqueduct downstream to the confluence of Skunk Creek and New River, along New River from Paradise Valley Road (extended) to the confluence of the New and Agua Fria Rivers, and along the Agua Fria River from the New River confluence to the Gila River (U. S. Army Corps of Engineers, 1976b).

THE IMPACTS OF HUMAN MODIFICATION ON THE FLOOD HAZARD

The alteration of basin characteristics by man changes the distributional patterns of runoff. The impact of such transformations may not be felt immediately, for their effects are cumulative. Thus, in urban areas the full effect of the construction of buildings and roads may only become evident after a particularly heavy storm.

Urbanization, an artificial inducement upon the

natural landscape, changes the distribution of runoff in several ways. The change that takes place in basin characteristics may be categorized into three parts: decrease of surface roughness, decrease of the previous area, and decrease of the inundation area. Due to the roughness of the vegetal cover, surface runoff proceeds very slowly when the ground is blanketed with trees and shrubs. Urbanization smooths the ground surface and runoff accelerates. Whereas at least some water can permeate soils, it cannot penetrate or infiltrate the roofs of houses or the pavements of roads. Thus, urbanization results in an increase of impervious surfaces. Prior to residential development, waters could flow unobstructed in the flood plain. With encroaching urbanization, waters are forced to flow around edifices and other man-made structures.

These changes induce three kinds of influences upon the distribution of runoff:

1. Increase the total flood volume: this is caused by decrease of the pervious area.

2. Increase of the velocity of the flood wave: this is caused by decrease of the surface roughness and the inundation area.

3. Increase of the peak discharge: this is caused by decrease of the surface roughness and the inundation area. Inundation makes a peak discharge smaller. If the inundation area is removed, the flood wave can hardly be flattened (Kinosita and Sonda, 1967).

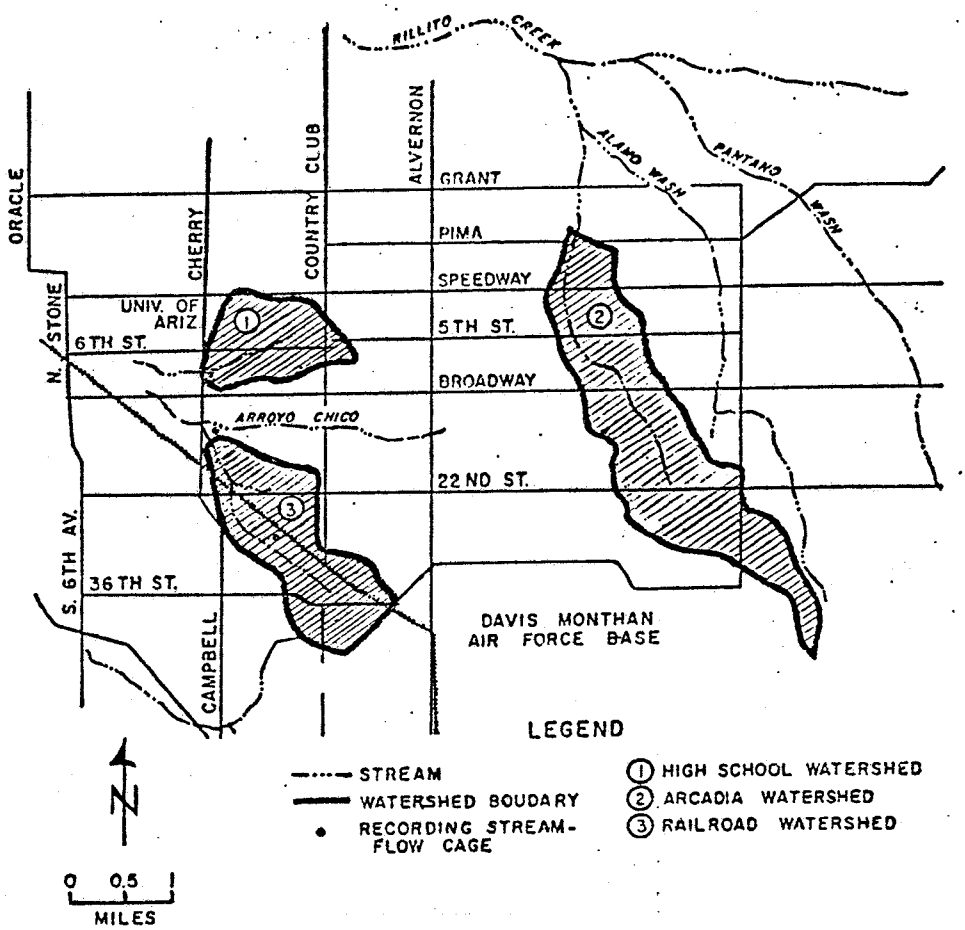
Riverine floods are a result of blockage in the river channel or excessive runoff from the drainage basin adding large amounts of water to the flood plain area (Burton and Kates, 1964). Urbanization almost waterproofs the ground surface (Figure 29). Kao, Fogel, and Resnick (1973) employed the Soil Conservation Service method for determining the relationship between the amount of rainfall and runoff. Testing the hypothesis that "as urban development takes place, the response of a watershed to the rainfall input is departing from its natural condition," they utilized three small urban watersheds and one rural watershed (Figure 30), all in the vicinity of Tucson, Arizona, to determine the hydrologic effects of urbanization on small semiarid watersheds (Figure 31). Records of only summer convective storms were utilized for the purposes of the study. These storms are characteristically high intensity, short duration, widely scattered thunderstorms and often produce severe local flooding.

The following conclusions were drawn from the study:

1. The Soil Conservation Service procedure can be used to relate convective storm rainfall to the volume of runoff from small, semiarid watersheds.

2. The Soil Conservation Service method appears to be sufficiently sensitive to determine the effect of ubanization on the volume of runoff.

Figure 29. Parking Lot Showing Creation of Impervious Area Resulting From Urbanization, Phoenix Metropolitan Area, Arizona



DESCRIPTION OF WATERSHED

Watersheds	High School	Arcadia	Railroad	Atterbury
Area, square miles	0.90	3.50	1.90	0.45
No. of raingages				
(recording)	4	6	4	2
(non-recording)	2	3	3	2
Residential area, %	65.5	60.4	38.7	0.0
Commercial area, %	3.5	6.1	1.5	0.0
Industrial area, %	0.0	0.0	26.3	0.0
Impervious area, %	28.8	21.9	40.3	0.0

Figure 30. Urban Hydrology Experimental Watersheds

Source: Kao, Fogel, and Resnick, 1973

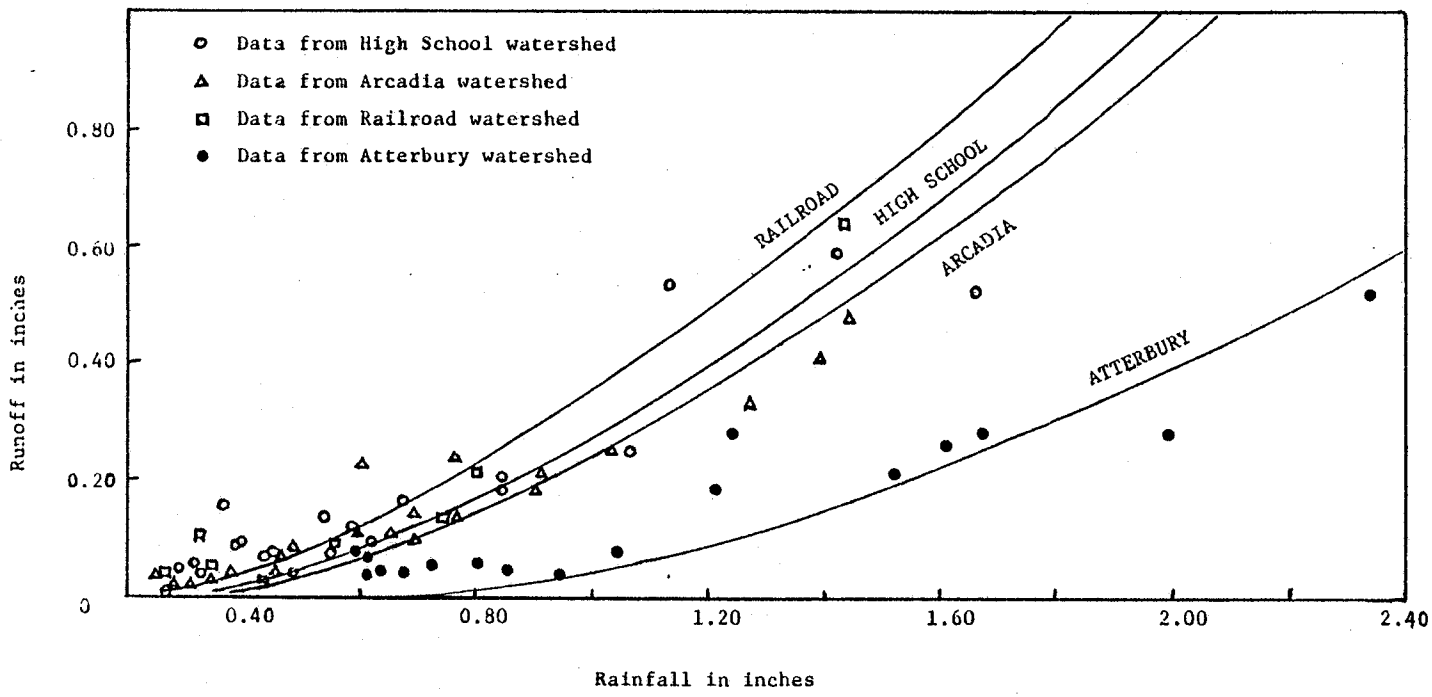


Figure 31. Rainfall - Runoff Relationships for Small Urban and Rural Watersheds

Source: Kao, Fogel, and Resnick, 1973

3. The relationship between the peak flow rate and the corresponding total runoff volume from small urban watersheds is linear.

4. Urban watersheds with the highest percentage of impervious area do not necessarily produce the highest peak rates for a given volume of runoff (Kao, Fogel, and Resnick, 1973).

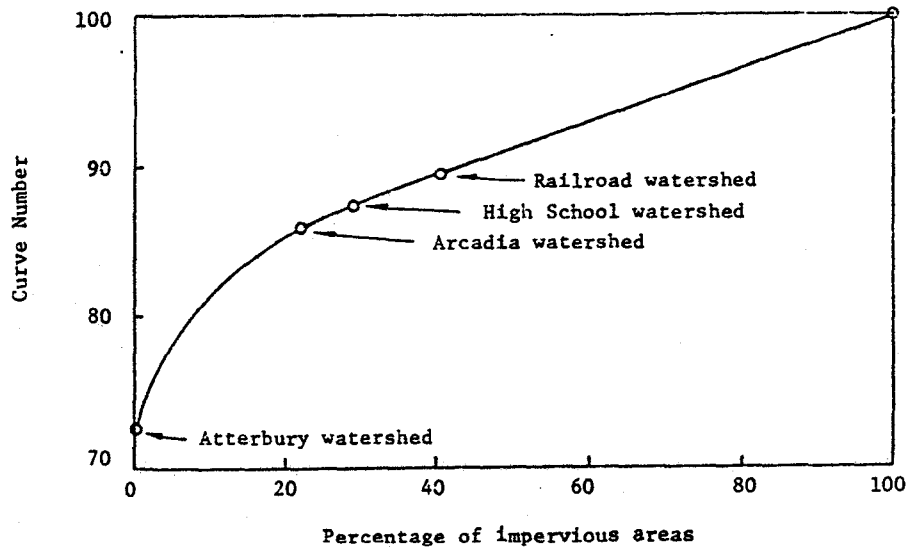
It was shown that the runoff curve number increased as the percentage of impervious area increased (Figure 32).

The hypothesis that urbanization increases the amount of runoff was reinforced by others. When desert lands are developed for residential and commercial uses recent studies have calculated an increase in runoff of over three hundred percent (Arizona Water Commission, 1973). Other estimates indicate that a subdivision or heavily populated area produces 3.5 times the runoff that would occur if the area remained unurbanized (Flood Control District of Maricopa County, 1966). Thus, the flood problems which already exist downstream from an urbanized area are further exacerbated by continued development.

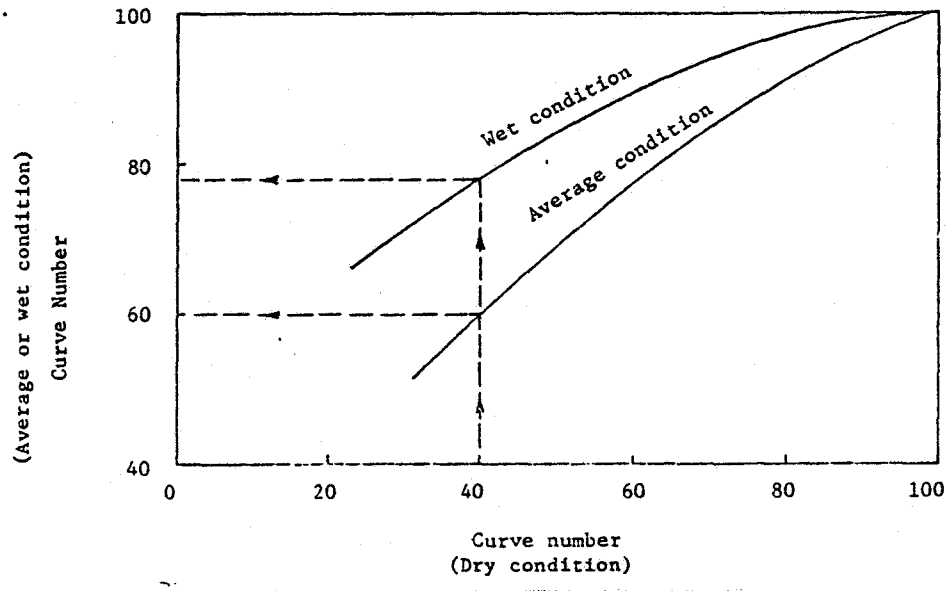
Another significant effect of urban growth upon the flood regimen is the decrease in lag time. The time interval between the peak of precipitation and the peak of runoff, known as "lag time," decreases as the impervious area increases. Leopold (1968) illustrates the

Figure 32. Relationship of Runoff Curve Number to Percentage of Impervious Area

Source: Kao, Fogel, and Resnick, 1973



Effect of urbanization on curve number



Adjustment of curve number for antecedent moisture conditions

THE ESTIMATED CURVE NUMBERS FOR DIFFERENT WATERSHEDS

Watersheds	High School	Arcadia	Railroad	Atterbury
Estimated curve number	87.4	85.9	89.7	72.7
% of variance explained by the model	76.3	84.1	95.6	76.2
Number of storm events analyzed	20	27	8	18

relationship between peak flow and runoff volume for unurbanized and urbanized areas by use of a unit hydrograph* (Figure 33).

Grundler (1972) concentrated on another consequence of urbanization. He noted that the flood frequency and history could be affected by urbanization, which, in turn, increased the magnitude of the flood problems.

"A significant percentage of the Nation's population and tangible property is concentrated on flood-prone areas" (Thomas and Schneider, 1970). Urban growth often blankets the natural course or drainageways for storm waters and, hence, alters the runoff characteristics. Such is the case in the metropolitan Phoenix area.

The construction of roads, buildings, parking lots, and the like has altered the basin characteristics and increased the threat of flooding in the Phoenix area. Another element of urbanization that has affected the flow of flood waters is the system of canals traversing the Valley. These canals trend from east to west at right angles to the natural drainageway. In most cases the canal banks are raised above the existing ground elevation

* A unit hydrograph is a graph depicting the average time distribution of runoff generated by a unit or standard storm. The percentage of the total storm runoff is shown for each successive time unit.

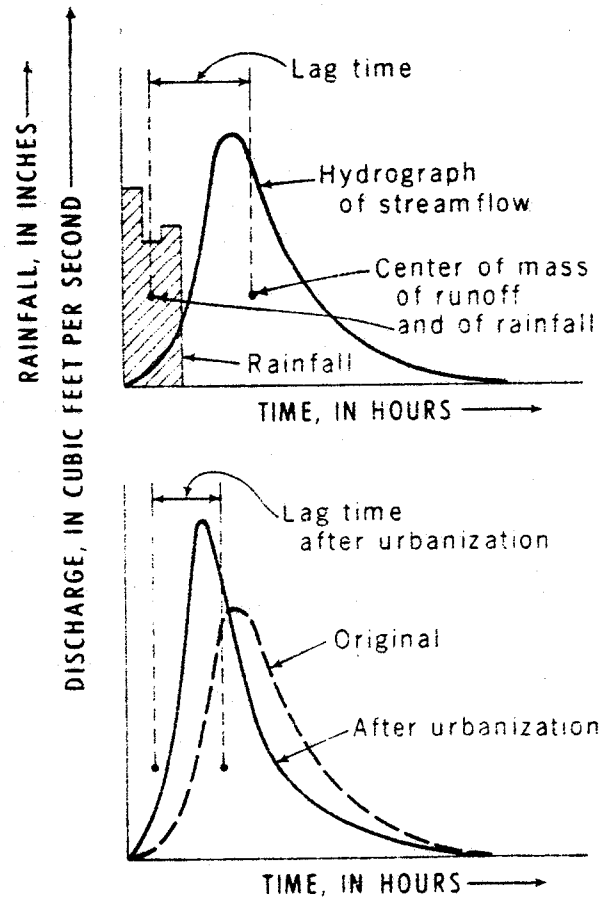


Figure 33. Hypothetical Unit Hydrographs Relating Runoff to Rainfall, with Definitions of Significant Parameters

Source: Leopold, 1968

and flood flows tend to pond against the north side of the canal banks, inundating areas that would not normally have been flooded. In times of storm flow, the canals are often forced to accept a portion of the runoff and this may result in an overtopping or breaking in areas along the canal banks. Thus, areas downstream or south of the canals that are not necessarily in the flood plain are subject to flooding. The raised canal banks and their design are features of human modification of the Phoenix environment that have resulted in increasing the vulnerabiltiy of some areas to flooding.

As urban sprawl continues, the vulnerability to floods and the resultant damages increases. Urbanization drastically changes basin characteristics and, consequently, the runoff regimen thereof. Land use planning affects the hydrologic systems of basin areas. Therefore, future land use plans, including those for flood control, must be developed and evaluated in terms of hydrologic parameters.

CHAPTER III - HUMAN ADJUSTMENT TO FLOODING

FLOODING -- A UNIVERSAL PROBLEM

Throughout the world, floods periodically have caused enormous economic losses and untold human misery and suffering. Flooding is a universal problem; loss of life, damage to property, and displacement of individuals occurs wherever floods invade land occupied by man. Exemplary of the global concern for dealing with floods and their continuing severity is the fact that a seminar under the aegis of the United Nations was held in the fall of 1969 to discuss flood loss management. The breadth of the seminar was significant as stated by White:

> This was the first seminar, however, which systematically brought together a consideration of the whole range of devices which man can use in coping with flood hazard. It surveyed not only the complete array of engineering measures, but problems of hydrologic forecasting, flood fighting and flood warning systems, methods of flood-proofing buildings, design of flood plain regulations, and the opportunities for using insurance and relief as means of distributing flood losses (White, 1970).

During the seminar several aspects of flood loss management were put in global perspective. Generally, evidence shows flood losses continue to mount throughout

the world. One important factor in the increase of flood losses is the urban growth in flood prone areas coupled with the inability of most countries to invest large sums of money for flood control. Thus, in many cases world-wide the flood hazard increases and the necessity for a comprehensive approach to flood loss management becomes apparent.

White points out that a few countries have instituted such a program. For example, on the island of Cyprus any new development in the flood plains is subject to licensing. Also, a land use planning program in Malaysia evaluates proposed development of the flood plains by weighing the estimated productivity against the flood hazard. Although all twenty-eight countries attending the seminar share problems of flooding, most lack a comprehensive method for coping with the hazard (White, 1970).

In the United States the far-reaching impact of floods is implicit in a statement which appeared in a 1966 bulletin of the Environmental Science Services Administration:

> The transformation of a tranquil river into a destructive flood occurs hundreds of times each year, in every part of the United States. Every year, some 75,000 Americans are driven from their homes by floods; on the average, 80 persons are killed each year. These destructive overflows have caused property

> damage in some areas estimated at more than $1,000,000,000. Floods are also great wasters of water, and water is a priceless national resource (U. S. Environmental Science Service Administration, 1966).

Floods, which account for most of the natural disasters in Arizona, have caused an increase in the magnitude of damages from natural hazards. Annual flood damage in Arizona is estimated at $22 per capita with projections of $45 per capita by the year 2020. Figure 34 depicts the average annual flood damages at 1965 development levels for subregions of the Lower Colorado River Region. In 1965 average annual damages were $38 million and projections show damages increasing to $66 million by 1980, $135 million by 2000 and $278 million by 2020. The distribution of annual flood damages indicates an increase in damages to residential and commercial properties between 1965 and 2020. This distribution is shown in Figure 35.

In 1965 the $22 annual per capita flood damage figure for Arizona residents was slightly lower than the national estimate of $23 for the average annual direct property loss from all natural hazards (White and Haas, 1975). From these statistics it can be inferred that the average annual per capita damage figure for all natural hazards is greater for Arizonans than for the nation as

Figure 34. Average Annual Flood Damages Are Increasing, Especially in the Gila River Subregion, Which Includes the Santa Cruz and Salt Rivers, Phoenix and Tucson Metropolitan Areas, Arizona

Source: Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, 1971

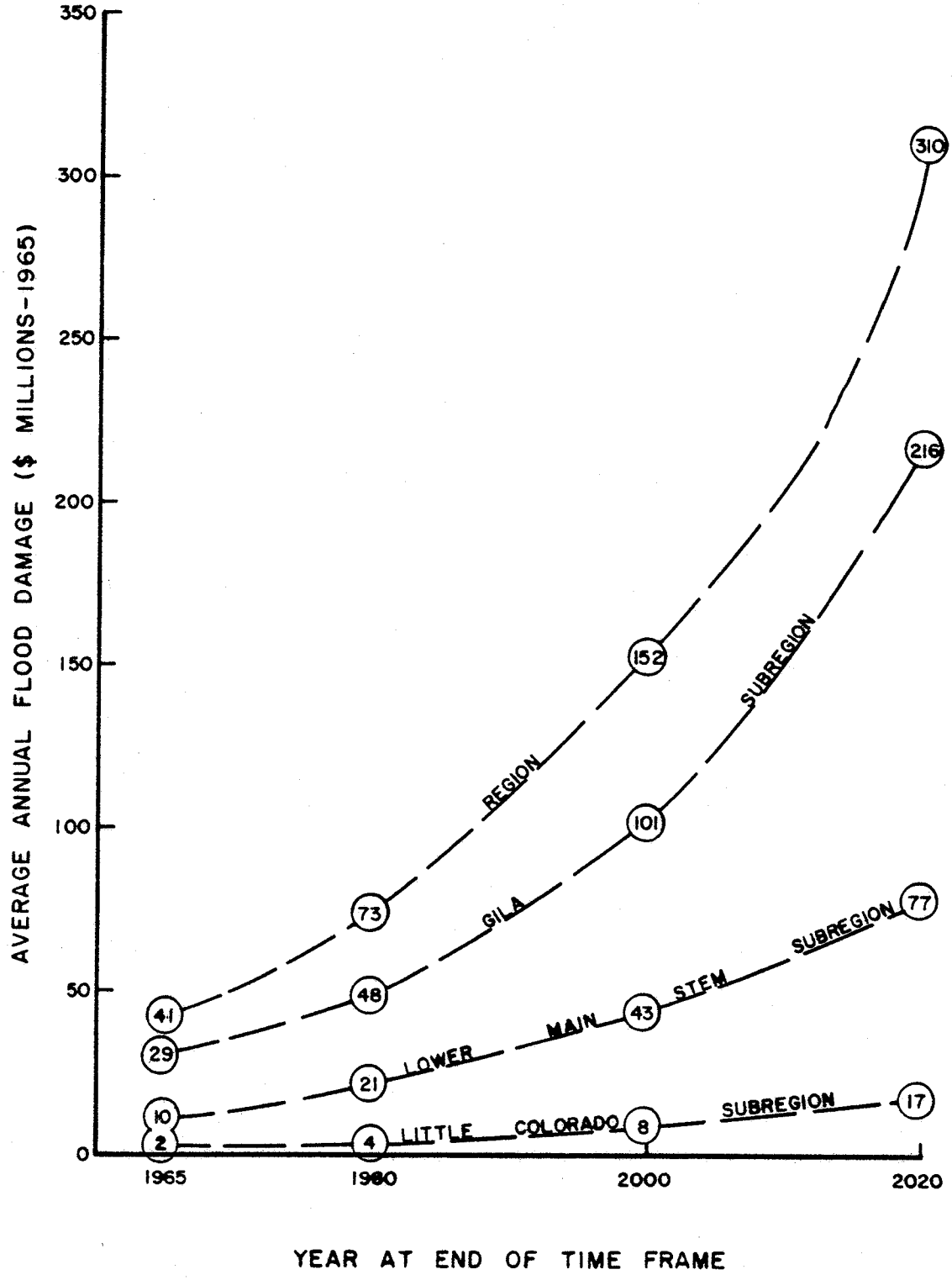
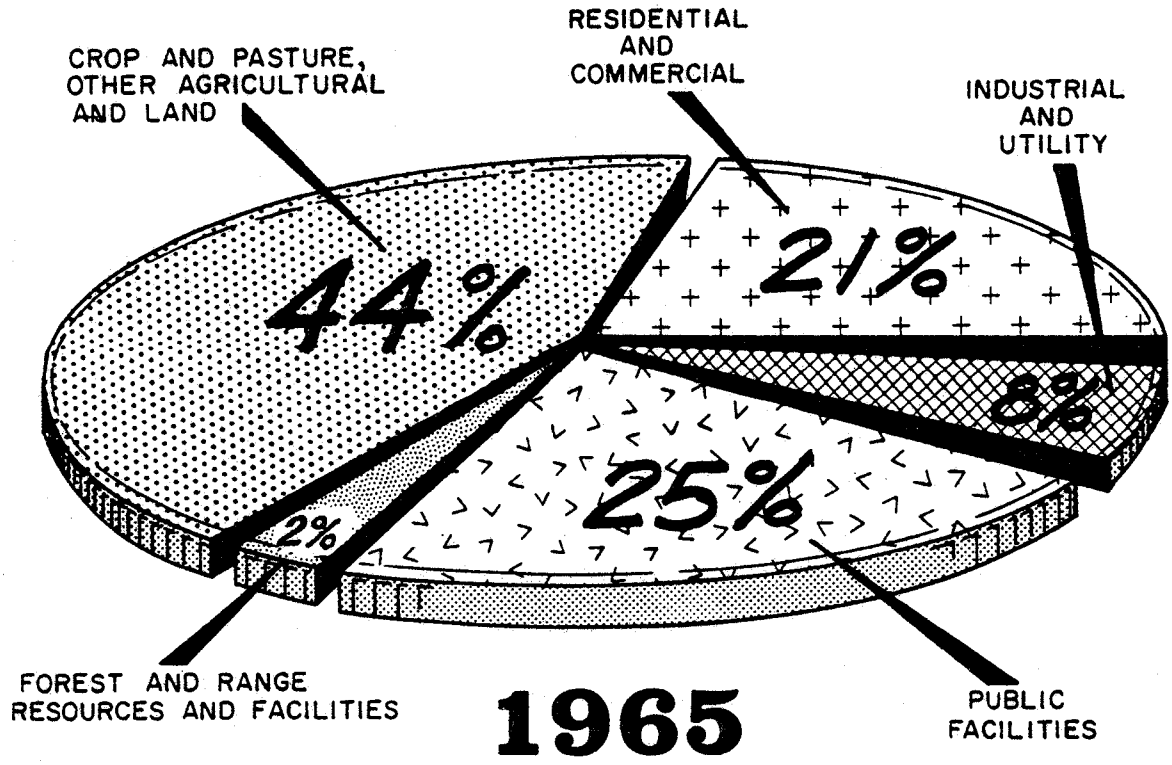
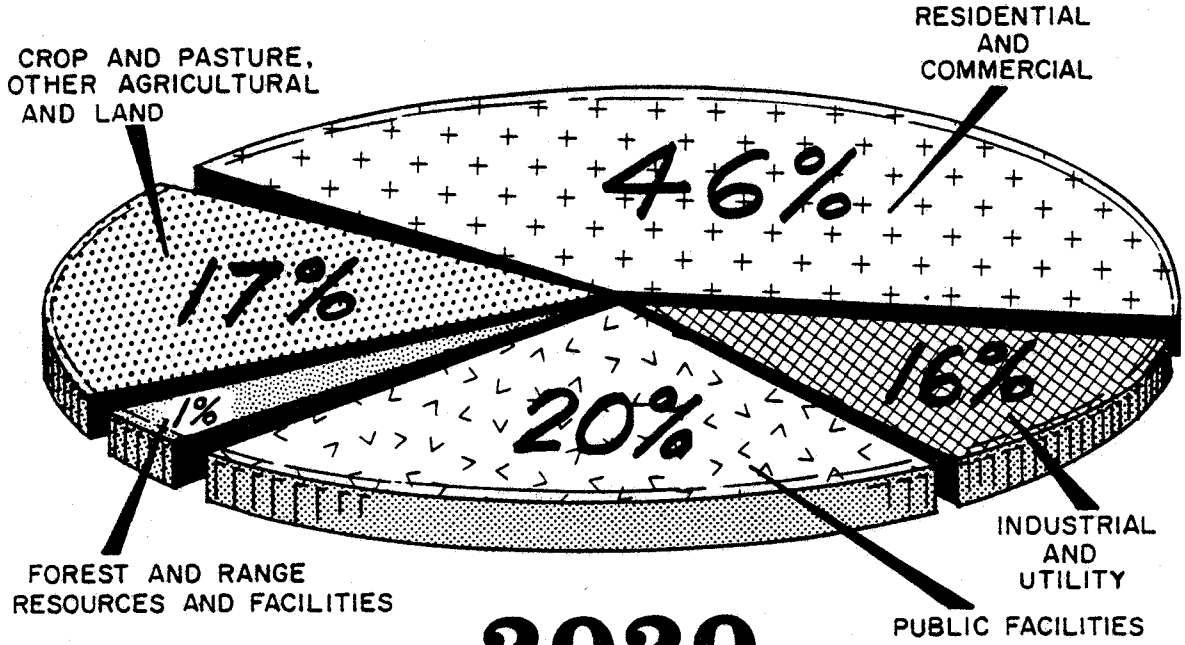

350
300
250
200
150
100
50
0
AVERAGE ANNUAL FLOOD DAMAGE ($ MILLIONS-1965)
1965
1980
2000
2020
YEAR AT END OF TIME FRAME
REGION
GILA
SUBREGION
LOWER
MAIN
STEM
SUBREGION
LITTLE
COLORADO
SUBREGION
41
29
10
2
73
48
21
4
152
101
43
8
310
216
77
17

Figure 35. Distribution of Annual Flood Damages in Arizona

Source: Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, 1971


CROP AND PASTURE, OTHER AGRICULTURAL AND LAND
RESIDENTIAL AND COMMERCIAL
INDUSTRIAL AND UTILITY
44%
21%
8%
25%
2%
FOREST AND RANGE RESOURCES AND FACILITIES
PUBLIC FACILITIES

1965


CROP AND PASTURE, OTHER AGRICULTURAL AND LAND
RESIDENTIAL AND COMMERCIAL
46%
17%
16%
20%
1%
INDUSTRIAL AND UTILITY
FOREST AND RANGE RESOURCES AND FACILITIES
PUBLIC FACILITIES

2020

a whole.

The Division of Emergency Services (Arizona State, c.1978) graphed the impact of a disaster in terms of a continuum of effects ranging from direct to indirect (Figure 36). Generally, indirect and direct disaster losses are equivalent (White and Haas, 1975).

As the facts and figures above imply, flooding is the single most significant natural hazard threatening Arizona. Kohler (1972) points out that the incidence of flash floods is higher in Arizona than any mountain or west coastal state. The magnitude and frequency of floods in the state bears the potential for continued damages to nearly every aspect of community life. A Civil Defense official noted the significant impact of floods: "Except for an earthquake, of all the things that can happen to a community, water is the worst" (U.S. News and World Report, 1973).

Flooding is not a new phenomenon. Floods have always occurred, but it was not until man occupied the flood plains that serious damages associated with flooding became a reality. Prior to development of the flood plains, floods were usually viewed as beneficial. The flood plains were composed of silt deposited in the valleys and the fertile, relatively flat land was considered

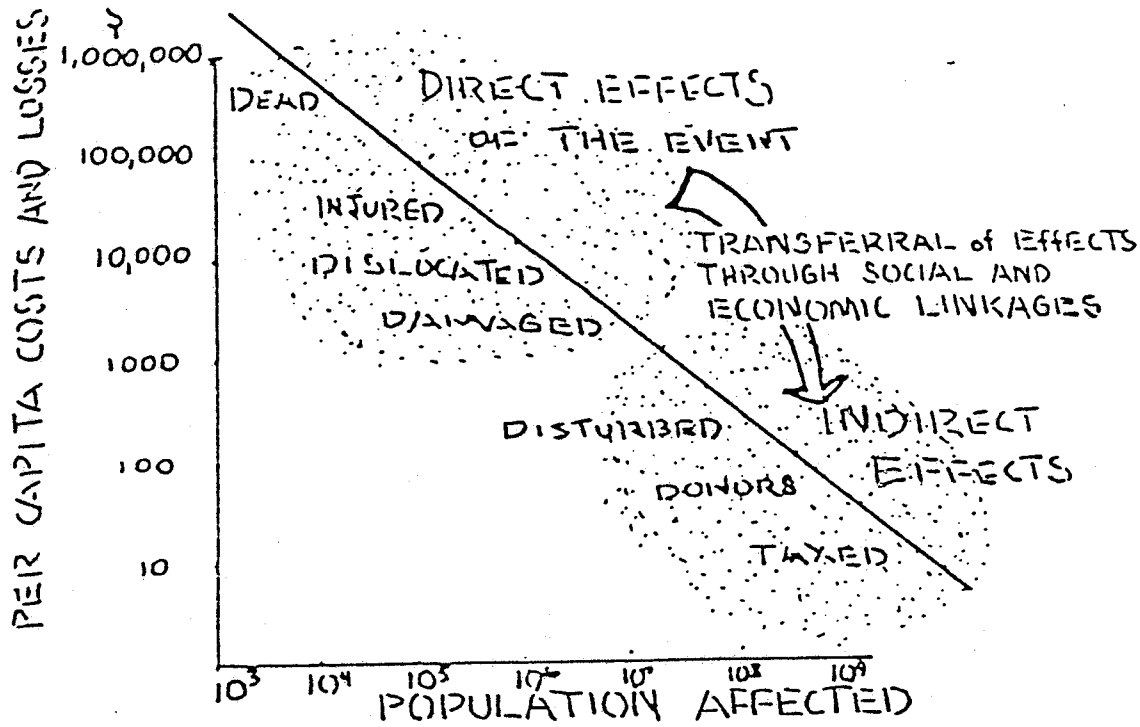


Figure 36. The Impact of a Disaster in Terms of a Continuum of Effects Ranging from Direct to Indirect

Source: Arizona State, Department of Emergency and Military Affairs, Division of Emergency Services, c.1978

valuable for cultivation. Urbanization was also attracted to the flood plains, which afforded accessibility to a water supply and a means of transportation. The occasional incidence of flooding seemed to be outweighed by the advantages of the flood plain site (Tennessee Valley Authority, 1961).

As the size and population of communities grew and more intensive agricultural practices ensued, the flood plains were further encroached upon. Property values rose and the impact of floods, which previously caused only minor inconvenience, was several times greater. Man has thus denied nature the area she has reserved for use during heavy flows in the river and man must suffer the consequence of such actions (Figures 37 through 40).

Flood problems of varying degrees exist upon every few miles of the thousands of streams in the United States. Each year floods of various magnitudes occur somewhere in this country and the resultant damages are generally commensurate with the development level of the flood plain (Barrows, 1948).

The flood problem, as viewed by Gilbert White (1942), consists of four basic elements: flood hazard, environmental features of the flood plain, human occupance of the flood plain, and adjustment of human occupance to

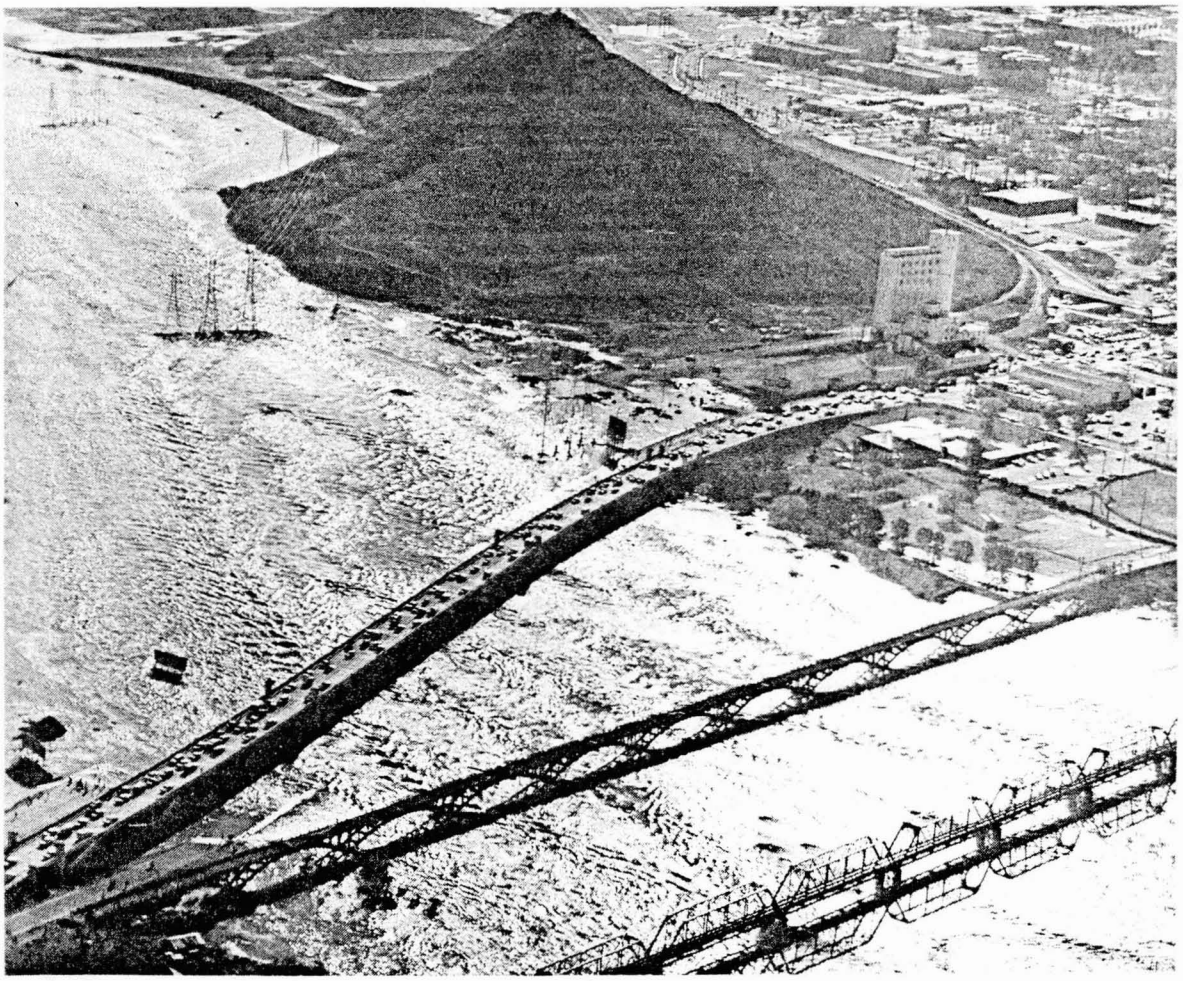


Figure 37. Lacelike Patterns of Floodwaters and Bridges Create Scene of Beauty as Well as of Destruction During December 1965-January 1966 Flood in Tempe, Phoenix Metropolitan Area, Arizona

Source: U. S. Army Corps of Engineers, 1975c

Figure 38. Public Facilities Encroaching onto the Flood Plain, Salt River in the Vicinity of Sky Harbor International Airport, Phoenix Metropolitan Area, Arizona

Source: Landis Aerial Surveys and Photography, 1978

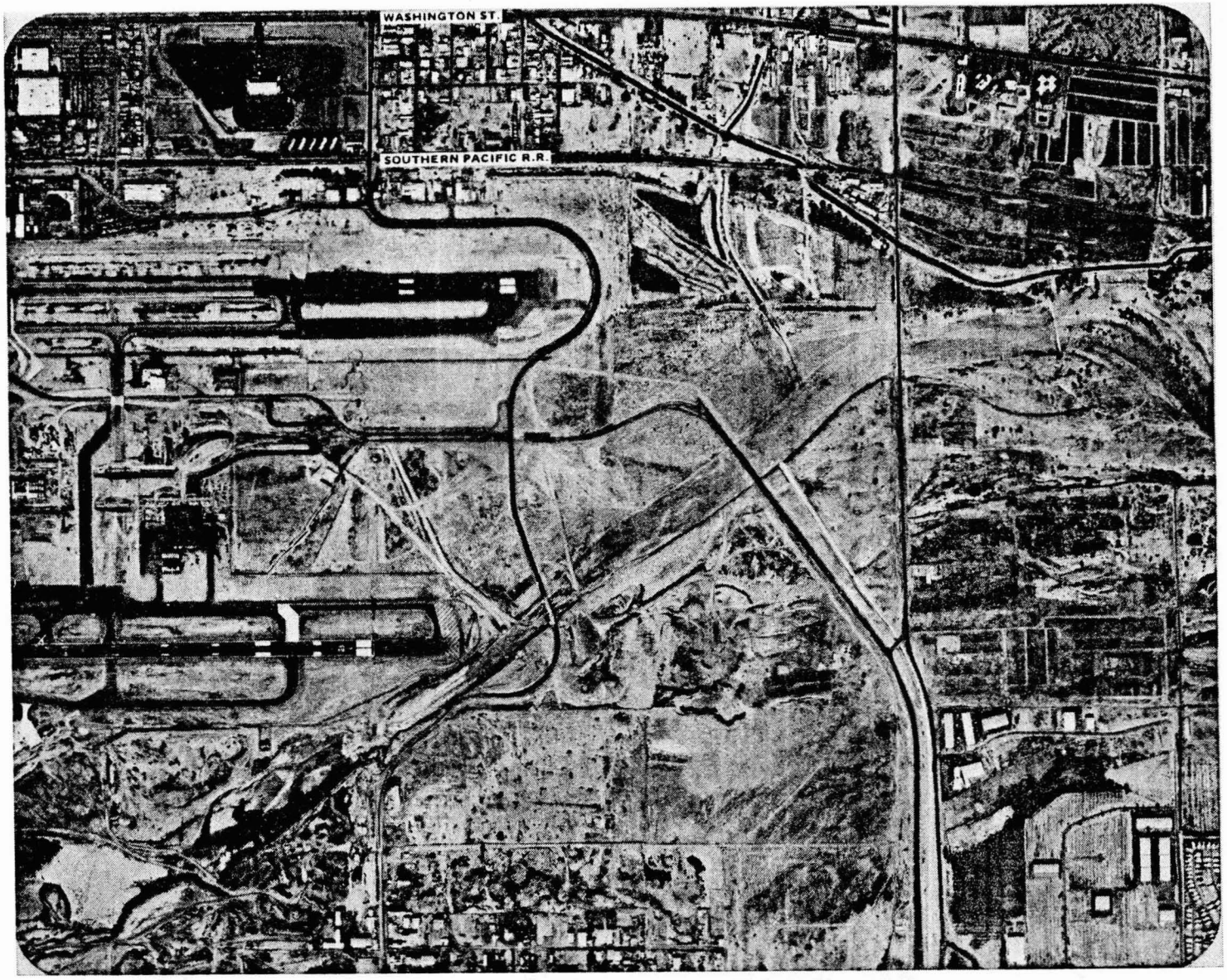

WASHINGTON ST.
SOUTHERN PACIFIC R.R.

Figure 39. Urban Encroachment onto the Flood Plain, Salt River between 7th and 24th Streets, Phoenix Metropolitan Area, Arizona

Source: Landis Aerial Surveys and Photography, 1978

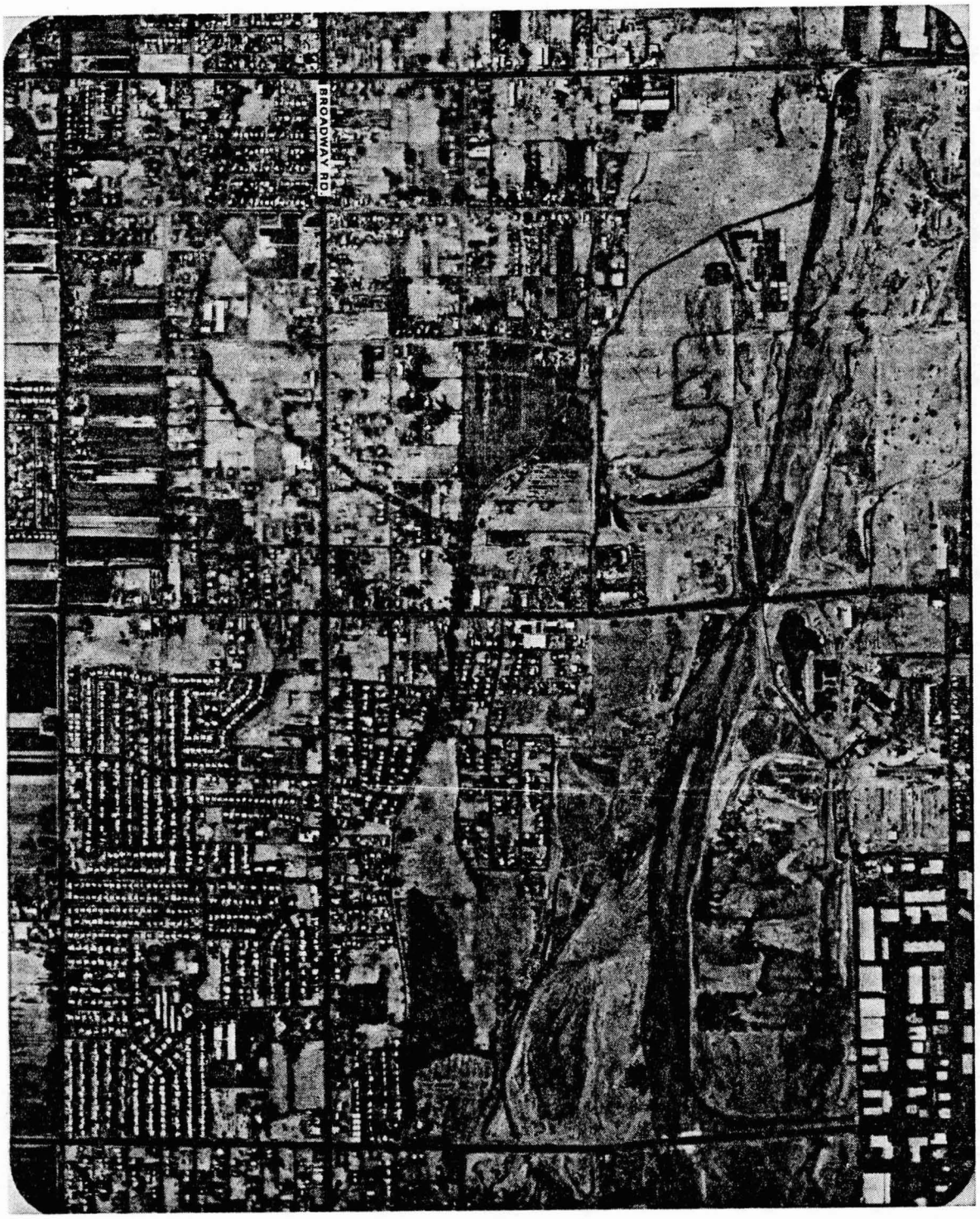

BROADWAY RD.

Figure 40. Agricultural Encroachment onto the Flood Plain, Salt River in the Vicinity of 76th Avenue, Phoenix Metropolitan Area, Arizona

Source: Landis Aerial Surveys and Photography, 1978

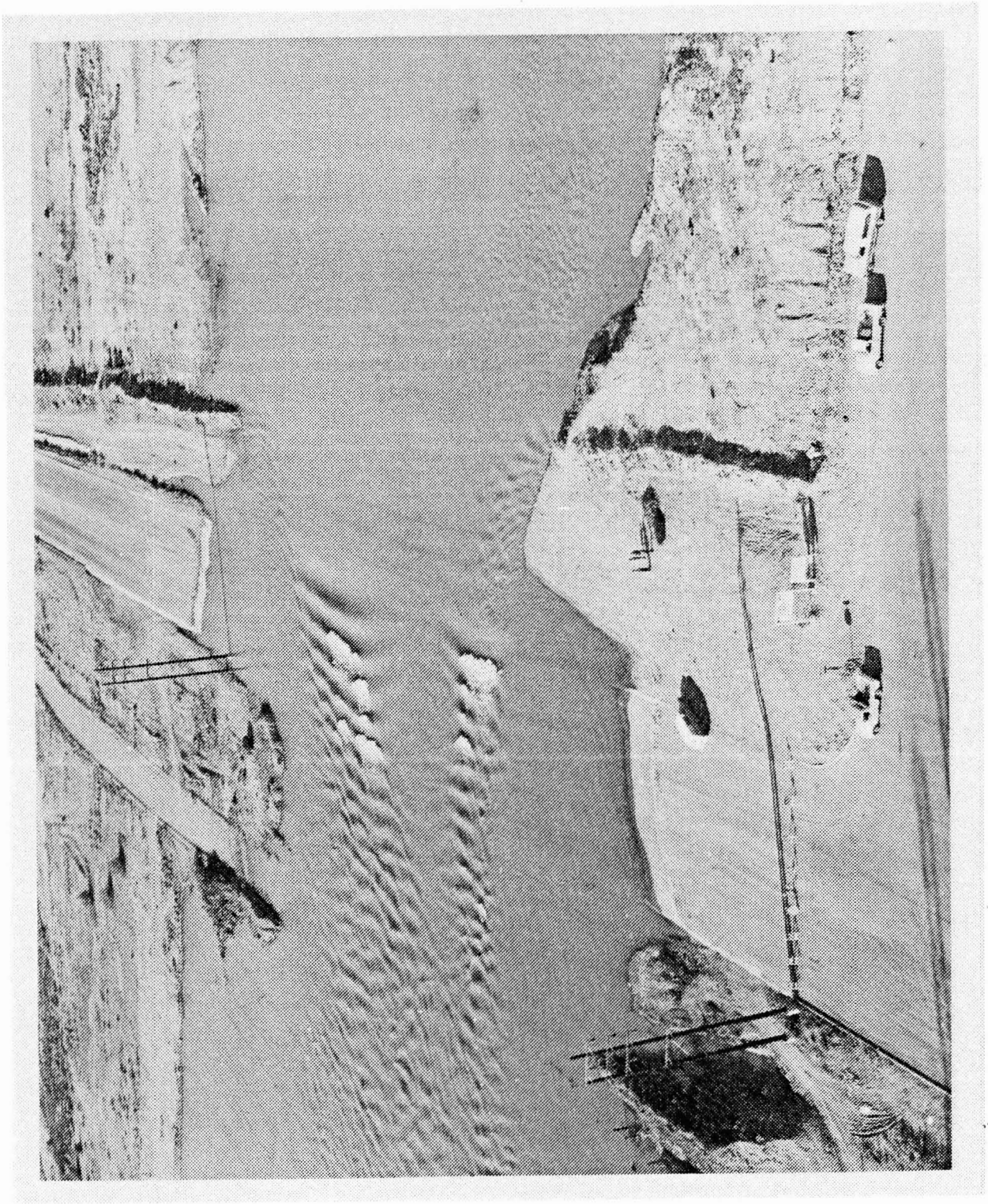
67TH AVE.
SOUTHERN AVE.

the flood hazard. The first element, the flood hazard is often underestimated by residents of flood prone areas. This stems from several factors including the infrequency of major floods, an unwillingness to recognize or admit the possibilities of the recurrence of damaging floods, and ignorance of the flood hazard. Floods impact communities in four ways. Damage to physical property is the most obvious and widespread impact. Physical damage occurs to buildings, contents, crops, livestock, and removal of topsoil. The second type of impact of floods on community life is the disruption of public services and transportation (Figure 41) and the temporary closing of businesses and industries. The third type of impact on a community is the loss of life and menace to health. Fourth, communities warned of a forthcoming flood often remove belongings and families to minimize losses, but return to the flood plain after the flood waters have passed.

The environmental features of the flood plain are the second element of the flood problem. Despite the recurring losses suffered by flood plain dwellers, man continues to occupy these flood prone areas. Initially, man was attracted to the flood plains by the water, rich soil and flat land--features of the environment suitable for agricultural purposes. However, even after urbaniza-

Figure 41. Disruption of Transportation Due to 1973 Flooding of Salt River, Phoenix Metropolitan Area, Arizona

Source: U. S. Department of Interior, Bureau of Reclamation, E. E. Hertzog



tion has encroached onto the flood plains and the inducements which had prompted early settlement had lost meaning, man continues to inhabit flood prone regions. The increased use of the flood plains has resulted in increasing the flood hazard.

Human occupance of the flood plain represents the third element of the flood problem. The damaging impact of human occupance of flood zones has steadily mounted over the years. At the same time, expenditures for flood protection works have also increased. When a flood strikes, those occupying the flood plain suffer losses commensurate with the magnitude of the flood. Their neighbors also suffer losses, although indirectly, for they must help finance the cost of emergency services and disaster relief. As long as the flood plains are occupied losses will continue.

The fourth element of the flood problem is the adjustment of human occupance to the flood hazard. The damaging effects of habitation of the flood plains can be minimized through careful land use which takes into consideration both the beneficial and detrimental aspects of human occupance of the flood plain. Adjustments to the flood hazard can take one or a combination of several forms. Such adjustments include construction of dams and

reservoirs, channel improvements, levees and floodwalls, evacuation, flood forecasting, watershed management, flood proofing, tax incentives, flood insurance, and flood plain management.

The four basic elements cited above are common to every flood problem in some degree. Solutions to the flood problem in any area should be premised on a thorough understanding of the problem and the alternative adjustments available.

ALTERNATIVE SOLUTIONS TO THE FLOOD PROBLEM

"Floods are 'acts of God.' But acts of man cause flood damage" (U. S. Army Corps of Engineers, 1974b). Basically, there are two methods for reducing flood damages: (1) control or structural works and (2) management or nonstructural practices. Man-made structural solutions are designed to retain and control flood flows "so as to insure a relatively harmless flow of flood waters past an area" (U. S. Army Corps of Engineers, 1967c). Elements of control works include floodwalls or levees, channel improvements, upstream dams and detention reservoirs, drainage and conservation practices, or some combination of the above. Characteristically, structural solutions represent costly engineering endeavors for which federal funds are often available to assist the local communities.

Nonstructural methods, commonly referred to as land use controls or flood plain regulations, "do not attempt to reduce or eliminate flooding but are designed to mold the flood plain development in such a manner as to lessen the damaging effects of floods" (U. S. Army Corps of Engineers, 1967c). Tools applicable in flood plain management include zoning, subdivision regulation, building and housing codes, administrative or development policies regarding the extension of utilities and public services, or a synthesis of the above. These land use alternatives for future flood plain development are not as costly in terms of dollars and do not entail extensive alteration or transformation of the natural flood plain.

Views and attitudes regarding the most effective techniques for handling flood hazards have been altered through time in both Arizona and the nation as a whole. These attitudinal changes, reflected in the adoption of various flood reduction solutions, have occurred gradually and will continue to mature as public officials and private citizens alike become more familiar with the flood problem, the risk involved, and the numerous options available to them for flood control and prevention.

Structural Solutions

Structural solutions rely on physical alterations of the channel or flood plain to control the river in order to reduce the overflow area downstream. Types of structural flood protection works include dams and reservoirs, levees or floodwalls, and channelization.

Dams and Reservoirs. Dams and reservoirs provide flood protection by retarding excessive runoff and, thereby, reduce the flood height (Figures 42 and 43). The reservoirs are empty most of the time but temporarily store flood waters until the threat of damage has passed and the waters can be gradually released.

Existing: Within the Phoenix metropolitan area, a number of dams currently exist. Six of these are operated by the Salt River Project and are located on the Salt and Verde Rivers. These dams are designed and operated primarily for water conservation and power generation, and only secondarily for flood control. Therefore, their effectiveness as flood control structures is limited.

The Soil Conservation Service has constructed numerous flood retarding structures which affect flood control in the study area. These structures are generally designed to protect localized rural areas and the

Figure 42. Roosevelt Dam on the Salt River, Maricopa County, Arizona

Source: Salt River Project

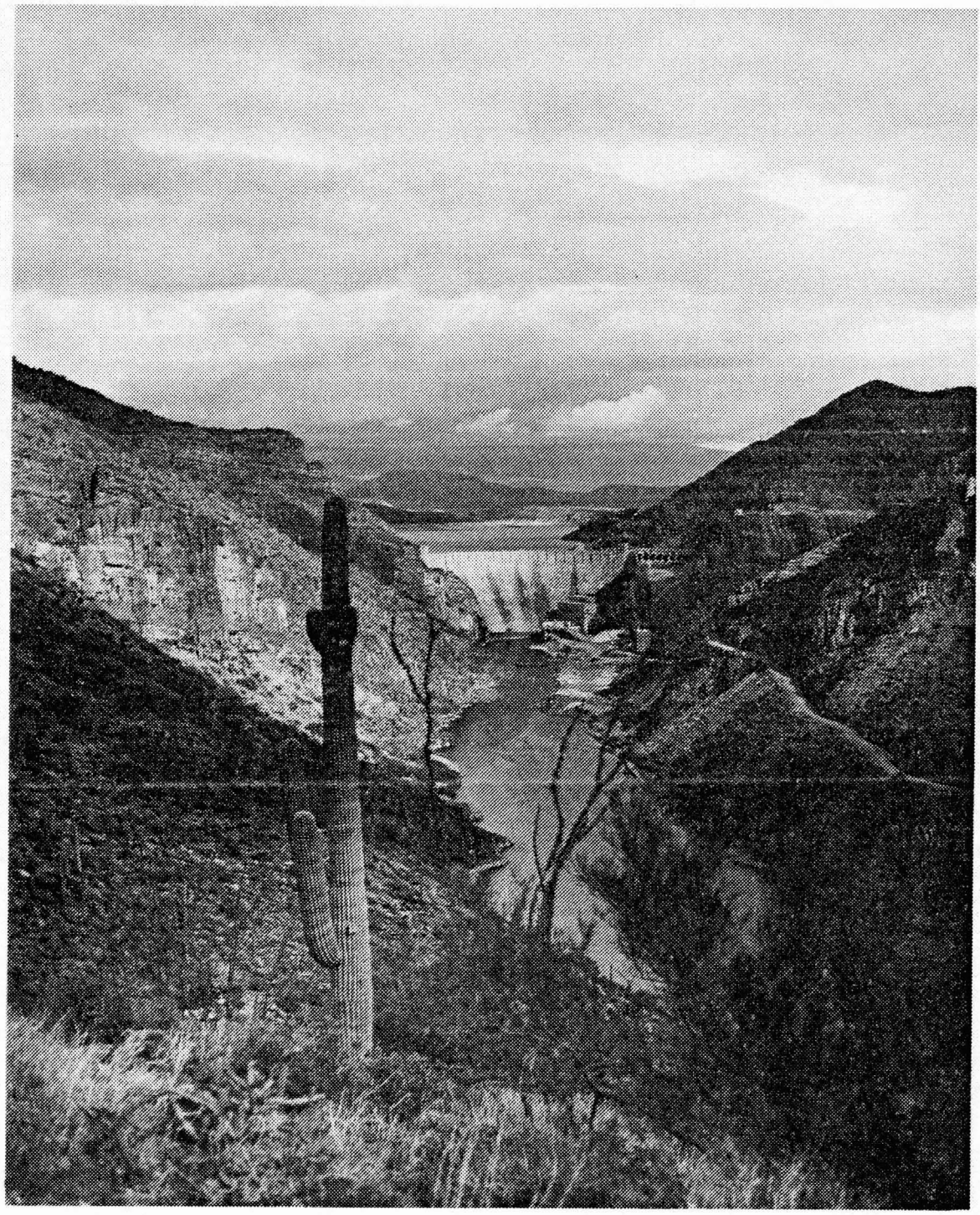
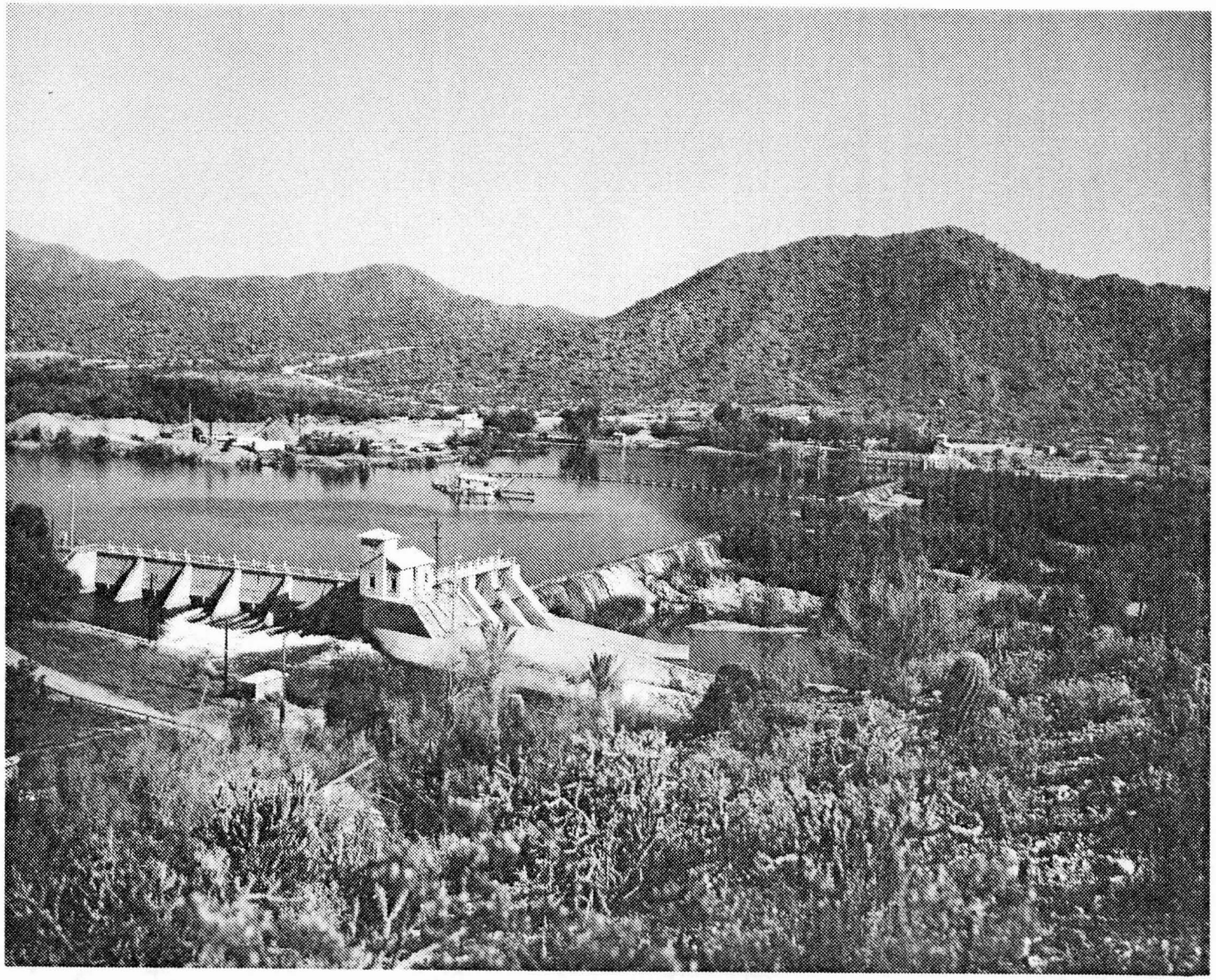


Figure 43. Granite Reef Diversion Dam on the Salt River, Maricopa County, Arizona

Source: Salt River Project, Ed Toliver



communities on the periphery of the metropolitan area.

The U. S. Army Corps of Engineers has contstructed three dams which provide flood protection to certain areas. The smallest of these structures, Dreamy Draw Dam, was designed to provide flood protection to approximately 1,750 acres of urbanized land in the northeastern portion of the City of Phoenix. Whitlow Ranch Dam on Queen Creek is about forty miles southeast of Phoenix and provides flood protection to a large, intensively irrigated area. McMicken Dam, a ten-mile long structure on Trilby Wash, was designed to provide flood protection to Luke Air Force Base. In so doing it also provides protection to several smaller communities.

Coolidge Dam with San Carlos Reservoir was constructed on the Gila River by the Bureau of Indian Affairs primarily to provide water conservation. This is a large reservoir which also provides some flood protection to the Phoenix area.

Cave Creek Dam completed in 1923 provides some protection to the area along Cave Creek Wash which traverses the central portion of Phoenix. The Cave Creek flood plain is highly urbanized and includes the State Capitol.

Carl Pleasant and Waddell Dams, located on the

Agua Fria River, were constructed by the Beardsley Irrigation District to provide water conservation. However, they also provide some flood protection. While the areas protected are predominantly rural, protection is provided to some densely populated areas in the western portion of the study area.

Proposed: The Salt River Project is investigating the feasibility of constructing additional dams on the Salt and Verde Rivers and their tributaries. Although these dams would be designed primarily for water conservation and power generation, they would have some flood control benefit.

The Bureau of Reclamation is studying alternative sites for a terminal storage reservoir for the Central Arizona Project. A number of their proposals call for multi-purpose water conservation and flood control reservoirs to be located on the Salt, Verde, or Agua Fria Rivers. Some of the proposals on the Salt and Verde Rivers would provide critically needed flood protection to the urbanized area.

The Soil Conservation Service has proposed the construction of several flood control structures to the east and southeast of the Phoenix metropolitan area. They are currently constructing the Spook Hill Flood Retarding

Structure and Outlet which is scheduled for completion in 1980 and is designed to protect eastern Mesa and surrounding agricultural lands. In addition to this structure, several other flood retarding structures and floodways are planned to provide protection to the same area. Additional protection for the southeastern area is to be provided by the Roosevelt Water Conservation District Floodway which is scheduled to be completed in six sections between 1979 and 1984. In 1980 the Soil Conservation Service plans to complete a flood retarding structure along Queen Creek.

Several flood control dams to the north and northwest of Phoenix have been authorized by Congress for construction by the Corps of Engineers. Cave Buttes Dam, located approximately 0.7 mile downstream of the existing Cave Creek Dam, is currently under construction and is scheduled for completion in late 1978. Adobe Dam on Skunk Creek in the vicinity of 35th Avenue and Deer Valley Drive would be started in 1979. New River Dam on New River would begin construction in 1980. All three dams would be earthfilled structures and would provide protection to downstream areas from a standard project flood.

The Corps is also studying the feasibility of

providing flood control to the greater Phoenix area through the construction of additional dams on the Salt and Verde Rivers or by increasing the height of existing dams. Concurrently, the Corps is working with the Salt River Project to determine the feasibility of increasing flood protection to the Phoenix metropolitan area by modifying the operation of the existing Salt River Project dams.

Levees or Floodwalls. Levees or floodwalls are designed to protect against flooding by acting as barriers between the floodway and development. Levees are usually earth embankments, while floodwalls are concrete. These structures are constructed in the flood plain and confine excessive flows within a restricted floodway zone.

Existing: Examples of levees can be seen along Indian Bend Wash in Scottsdale, Arizona. Berms are located in the area of the inlet to the wash just north of McDonald Drive and on the west side of the wash between Thomas and Indian School Roads. These berms allow encroachment onto the fringes of the flood plains by redirecting the lateral limits of the floodway.

Another example of a levee in the Phoenix area is the system of detention dikes (Figures 44 and 45) being

Figure 44. Aerial View of Paradise Valley Detention Dikes, Central Arizona Project, Phoenix Metropolitan Area, Arizona

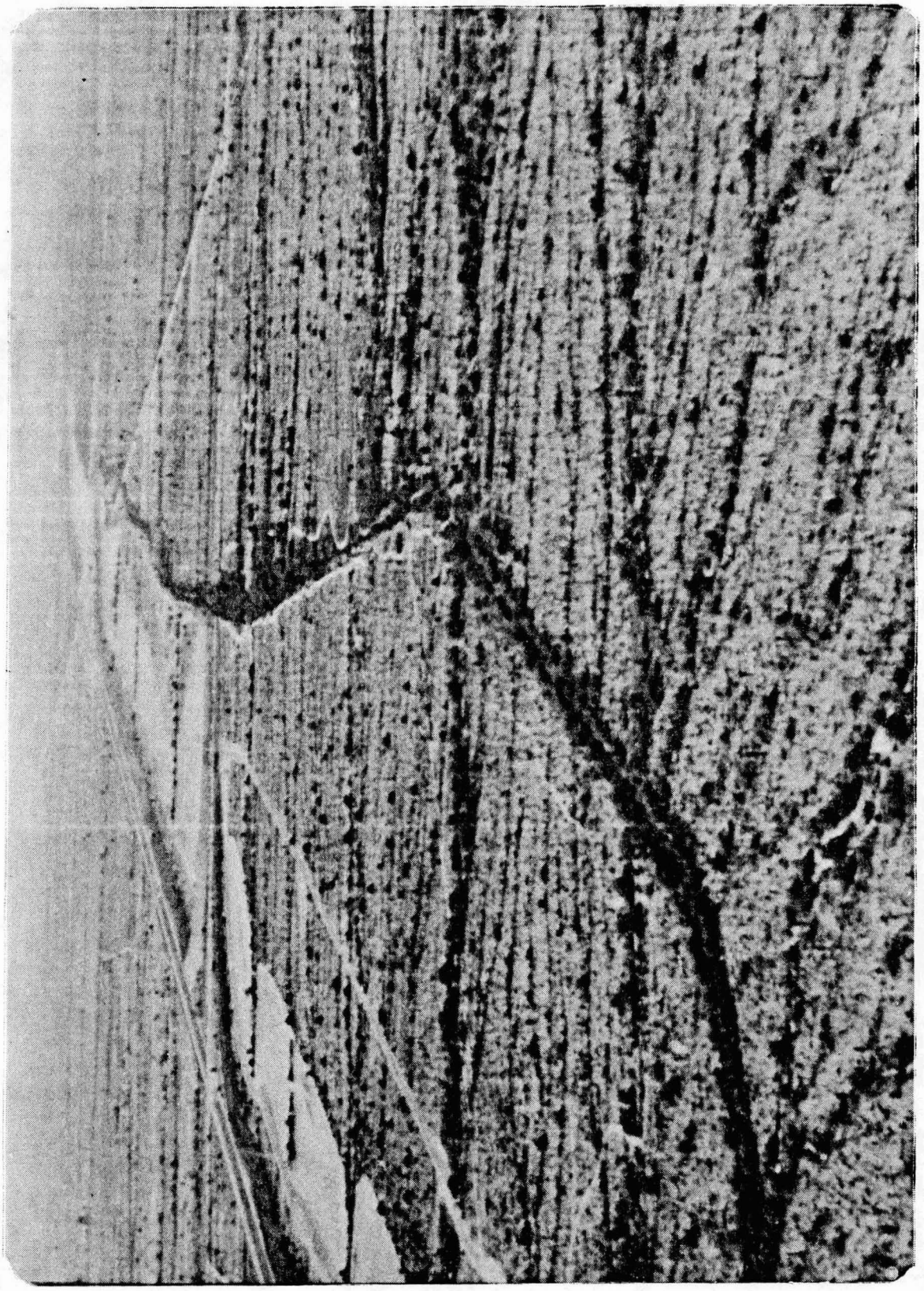


Figure 45. Ground View of Paradise Valley Detention Dikes, Central Arizona Project, Phoenix Metropolitan Area, Arizona

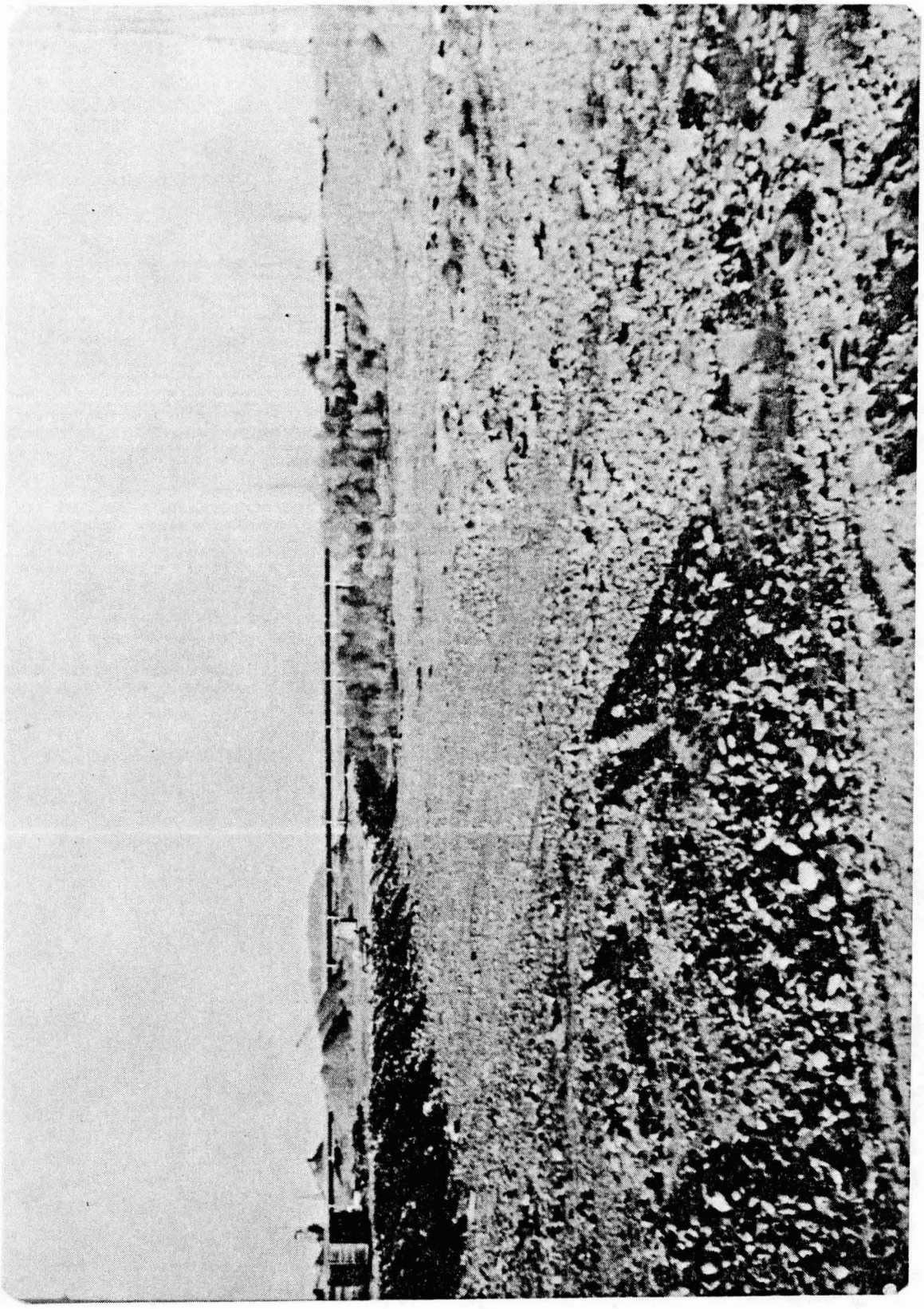
constructed by the Bureau of Reclamation as a feature of the Central Arizona Project. The dikes are designed to protect the Granite Reef Aqueduct from 50-year flood waters and, consequently, provide some protection to the urban areas downstream.

Along the Salt River in Tempe, Arizona, a levee has been constructed to protect the Arizona State University parking lot. The levee was constructed by the Flood Control District of Maricopa County.

Proposed: The Corps of Engineers has been authorized to construct several levees along portions of the Agua Fria River. These levees, in conjunction with some channelization, will confine a 100-year flood within the channel. The Corps is also studying the use of levees to provide flood protection along the Salt River.

Channelization. Flood control can be achieved by improving channel conditions which increase the carrying capacity of the stream (Figure 46). Methods that can be employed to improve conditions within the channel include: channel straightening to remove bends; deepening or widening to increase the size of the floodway; clearing to remove trees, brush, or other obstructions; and lining with concrete to increase channel efficiency.

Figure 46. Channelization of the Salt River, Phoenix Metropolitan Area, Arizona



Existing: The Corps of Engineers has constructed approximately six miles of channelization in conjunction with the McMicken Dam project. This channelization is designed to convey flood releases from the detention basin to the Agua Fria River.

The flood plain along Indian Bend Wash through Scottsdale and Tempe has been extensively modified by the Corps of Engineers, the Flood Control District of Maricopa County, and the cities of Scottsdale and Tempe. Upon completion of channel improvements, scheduled for 1981, Indian Bend Wash will provide 100-year flood protection to the urban areas adjacent to the wash.

The Flood Control District of Maricopa County was responsible for channelizing portions of the Salt River in the vicinity of Arizona State University in Tempe, Arizona.

The Flood Control District and several communities within the metropolitan area are channelizing the upper portion of Indian Bend Wash. When completed the channel will safely carry flows from a 100-year flood through portions of Phoenix, Paradise Valley, and Scottsdale.

The Indians, under the supervision of the Bureau of Indian Affairs and with funds provided by the U. S. Geological Survey, cleared a twenty-four-mile reach of

the Gila River in the San Carlos Indian Reservation. The clearing was undertaken for prototype evaluation of water salvage and also provided flood control.

Proposed: Channel improvements along selected reaches of the Cave and Skunk Creeks and the New and Agua Fria Rivers have been authorized for modification by the Corps of Engineers as part of the New River and Phoenix City Streams flood control project. Another feature of this project is a diversion channel paralleling the north side of the Arizona Canal for about seventeen and one-half miles, from 40th Street to 75th Avenue. The diversion channel is designed to intercept and convey flood flows from east and central Phoenix to Skunk Creek. The New River and Phoenix City Streams project is designed to provide flood protection to the central and western portions of the Phoenix metropolitan area.

In 1958 the Corps was authorized to clear and channelize portions of the middle Gila River from the proposed Camelback Dam site to fifty-four miles downstream of the dam site. The project was halted by court injunction in 1970. Upon completion of the required environmental impact statement in 1973, the injunction was removed. Since that time, the local sponsor has withdrawn support for the project.

Another authorized Corps of Engineers' project which is in a deferred category due to lack of required local assurances is the Pinal Creek channel improvements project. This project was authorized in 1962 to provide standard project flood protection to the residential and commercial areas in and near the town of Globe, Arizona.

In 1960 the Corps was authorized for channelization and construction of levees for portions of the Salt and Gila Rivers from Granite Reef Diversion to Gillespie Dams. The project was designed to provide standard project flood protection to most of the City of Tempe and part of the City of Phoenix, as well as downstream agricultural areas. In 1974 the project was placed on a deferred status pending receipt of assurances of local cooperation from the Flood Control District of Maricopa County. That same year the Flood Control District reaffirmed its desire for flood control improvements along the Gila River from 91st Avenue to Gillespie Dam. The Arizona Game and Fish Commission has passed a resolution supporting further study of channelization provided the alternatives considered protect existing wildlife habitat. The Corps of Engineers is currently studying channelization along the Salt River between Granite Reef Dam and the confluence of the Gila River as part of the Phoenix Urban Study.

Channel improvements along the Gila River in the southeastern portion of the study area have been studied by both the Corps of Engineers and the Soil Conservation Service. Because of the determination that no federal interest exists in this project, the Flood Control District of Maricopa County and the effected local communities are proceeding with plans for local channel improvements.

Nonstructural Solutions

Nonstructural solutions attempt to encourage wise use of the flood prone lands to mitigate the damaging impacts of floods (Figure 47) rather than trying to eliminate flooding. Some nonstructural methods of flood control include: watershed management, flood plain management, flood proofing, flood forecasting, evacuation, tax incentives, and flood insurance.

Watershed Management. In non-urban areas watershed management incorporates the treatment of land, usually over a small area, to enhance the absorption of rainfall by the soil. Techniques include contour stripping, terrace construction, crop rotation, and selective planting or reforestation. In urban areas watershed management involves the on-site detention or retention of flood waters.

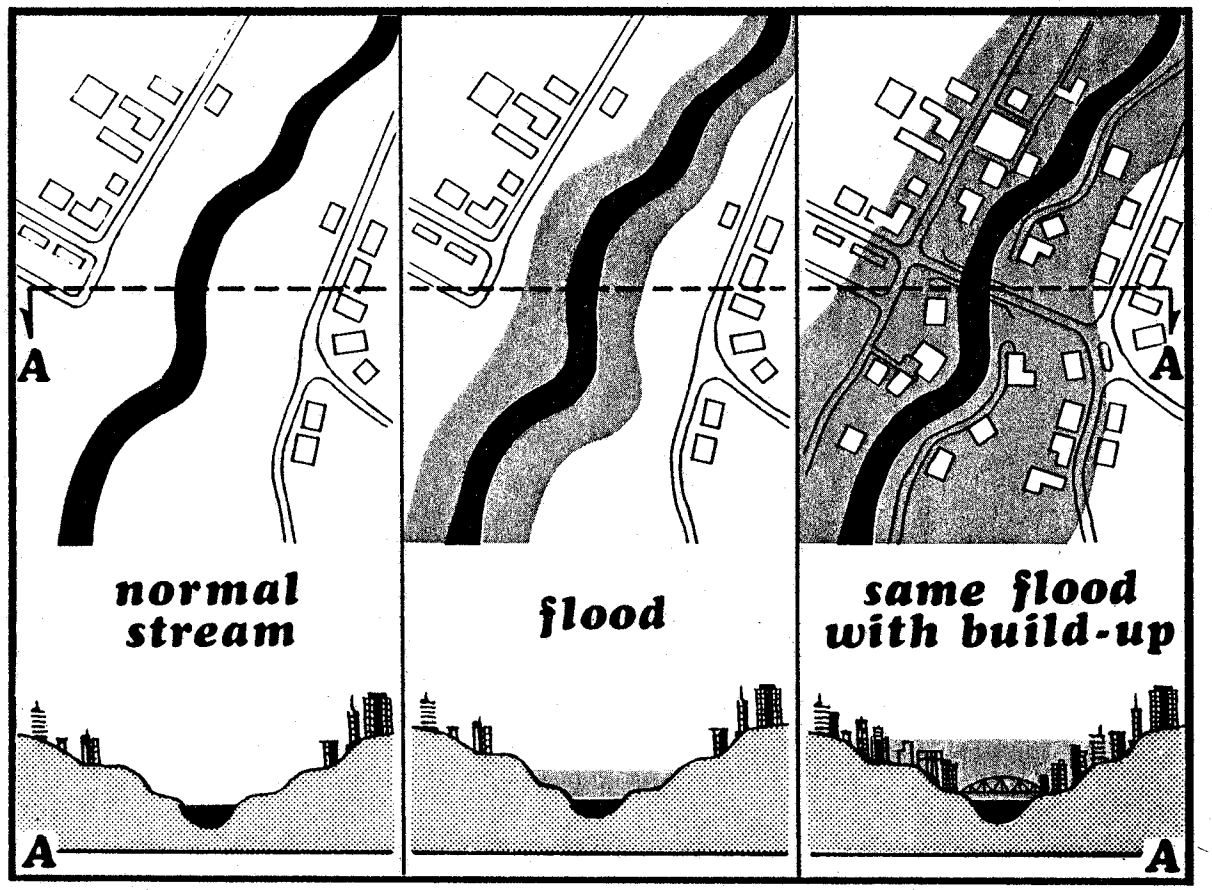


Figure 47. Building in the Flood Plain Can Make Floods Wider and Deeper.

Source: Phippen, 1974

Several agencies within the Phoenix metropolitan area are involved in watershed management practices for non-urban areas. The U. S. Forest Service conducts programs of fire fighting and reforestation to protect the watershed. They also modify the watershed characteristics through a program designed to control the density of the underbrush. The Soil Conservation Service employs erosion control techniques to protect the watershed. The Salt River Project institutes programs designed to increase the runoff from the watershed. Each of these programs affects the characteristics of the watershed. However, some of these increase the flood potential while others decrease it.

Within the urban areas watershed management takes the form of on-site detention or retention of storm waters. This is accomplished either on individual lots through the use of depressed yards or in small subdivisions by the employment of detention basins. These programs are enforced by individual cities through ordinances.

Flood Plain Management. Flood plain management regulates land use and future development in flood prone areas by utilizing legal tools within the purview of communities. Flood plain management may include designated floodways

and encroachment lines, zoning, subdivision regulations, and building codes.

Designated Floodways and Encroachment Lines: The portion of the channel and adjacent flood plain necessary to carry flood waters is the designated floodway. Encroachment lines are the lateral boundaries of the floodway. Encroachment lines on each side of the river delineate the area in which construction should not be permitted (Figure 48).

Zoning: Zoning, a legal tool for regulation of land use, can be effectively utilized to prohibit development in the designated floodway and to insure optimum use of flood prone areas outside of the floodway.

Subdivision Regulations: Subdivision regulations may be used by local governments to specify the way in which land may be divided for the purpose of sale or development. These regulations can minimize the impact of flooding by mandating the size of lots, elevation of land, width of streets, specifications for gutters and curbs, and the size of the floodway. By regulating future development in the flood plains potential losses can be reduced.

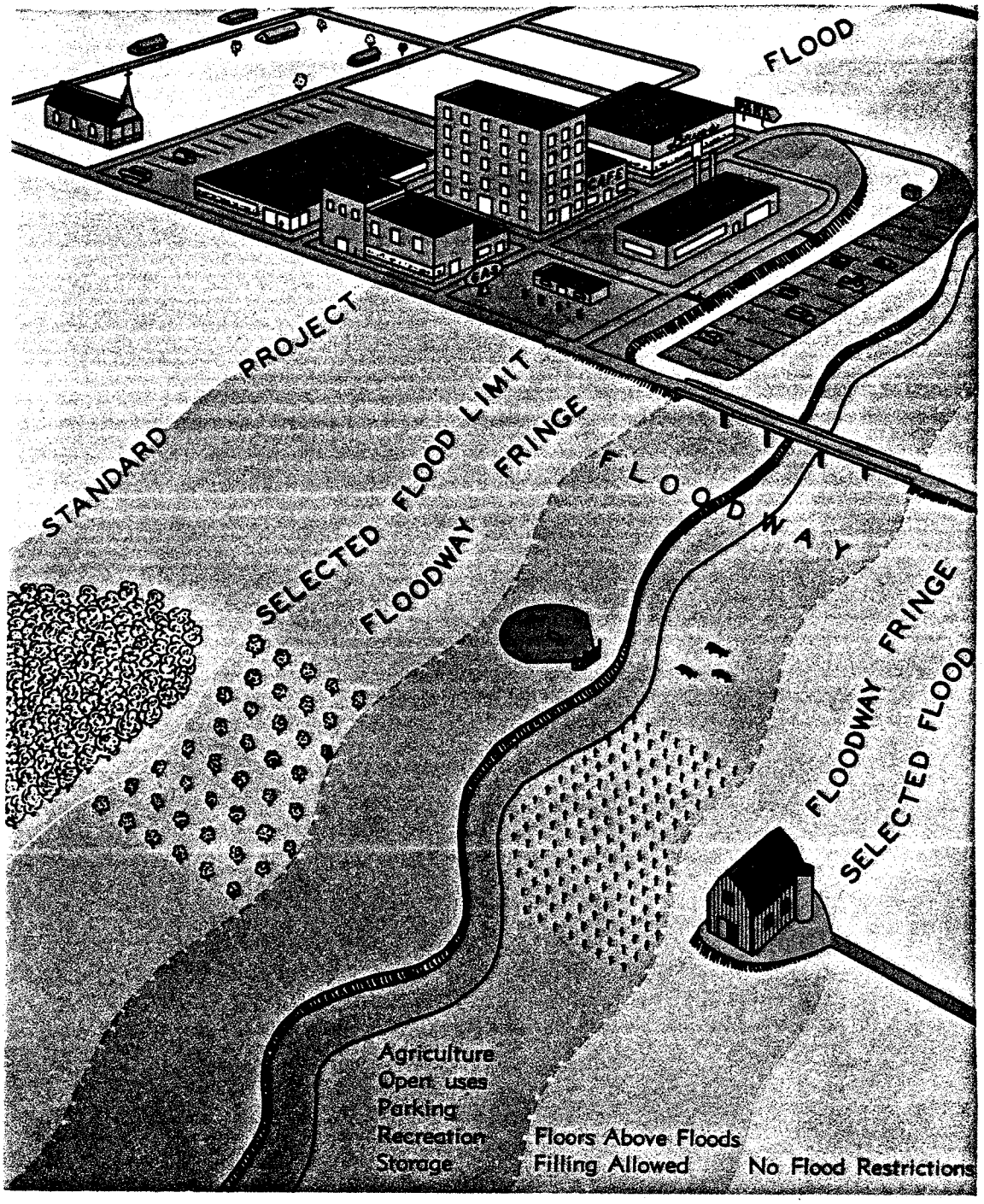


Figure 48. Regulated Use of the Flood Plain to Minimize Flood Damage

Source: Tennessee Valley Authority and U. S. Army Corps of Engineers, 1967

Building Codes: Building codes when adopted and enforced by local governments can reduce the damage to buildings located in the flood plain. The function of building codes is to protect the health, safety, and welfare of the populace by establishing construction standards for edifices in the flood plain. Flood damages can be reduced by enforcing building codes that require proper anchorage to prevent buildings from floating off their foundations, restrict the use of materials which deteriorate when exposed to water, set minimum first floor elevations in accordance with potential floods, require structural strength to withstand high water velocity and pressure, and prohibit equipment that could pose a threat to life when submerged.

Flood plain management practices vary from city to city. Regulations adopted at city, county, and state levels are discussed in Chapter IV. The effectiveness of these programs is limited by the varying levels of enforcement.

Flood Proofing: Flood proofing requires structural modifications and property adjustments to reduce flood damages. Items included in flood proofing measures are sewer adjustment, seepage control, protected openings (Figure 49), appliance protection, utility adjustments,

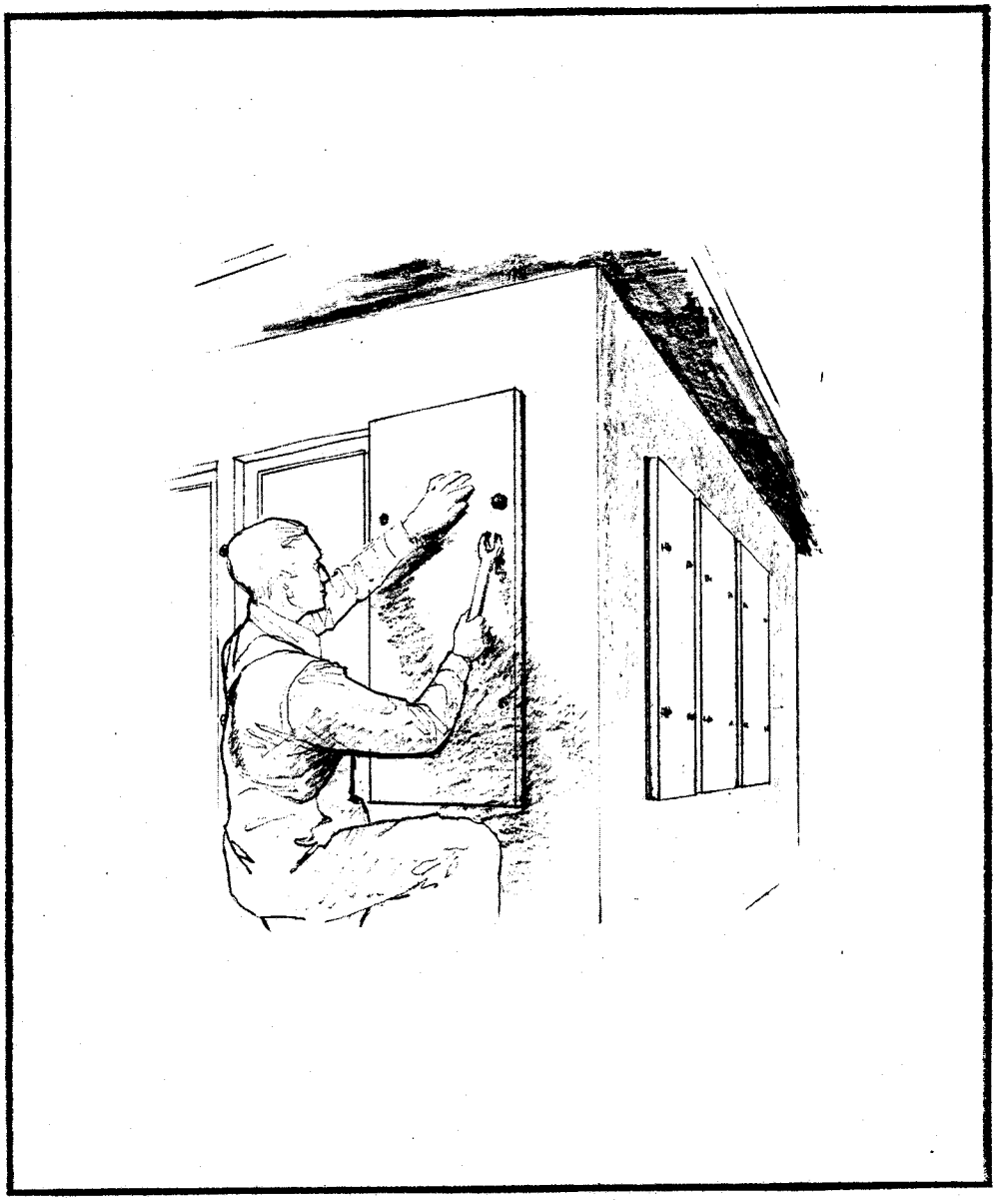


Figure 49. Flood Proofing by Protecting Openings

Source: Sheaffer, 1967

elevation (Figures 50 and 51), temporary removal, water-tight caps, underpinnings, structural design (Figure 52), and the like. These methods are more readily adapted to new construction, but can be applied to existing facilities. Flood proofing measures work the best in areas exposed to moderate flooding with low velocities and stages and of short duration.

Examples of the employment of flood proofing can be found in the metropolitan area (Figures 53 and 54), but are generally used on a rather limited basis.

Flood Forecasting: Flood forecasting can be used to warn residents of the coming of flood waters and allow time for evacuation of flood zones. The federal government through the Environmental Science Services Administration (U. S. Weather Bureau), Corps of Engineers, Bureau of Reclamation, and Tennessee Valley Authority has developed and operates the major forecasting system. Although many areas are included in the forecast network, most communities lack adequate means of disseminating information, assisting in evacuation methods, and dealing with temporarily displaced residents.

The responsibility for issuing flood warnings to individual property owners lies with the local governments. Unfortunately, not all of the communities possess

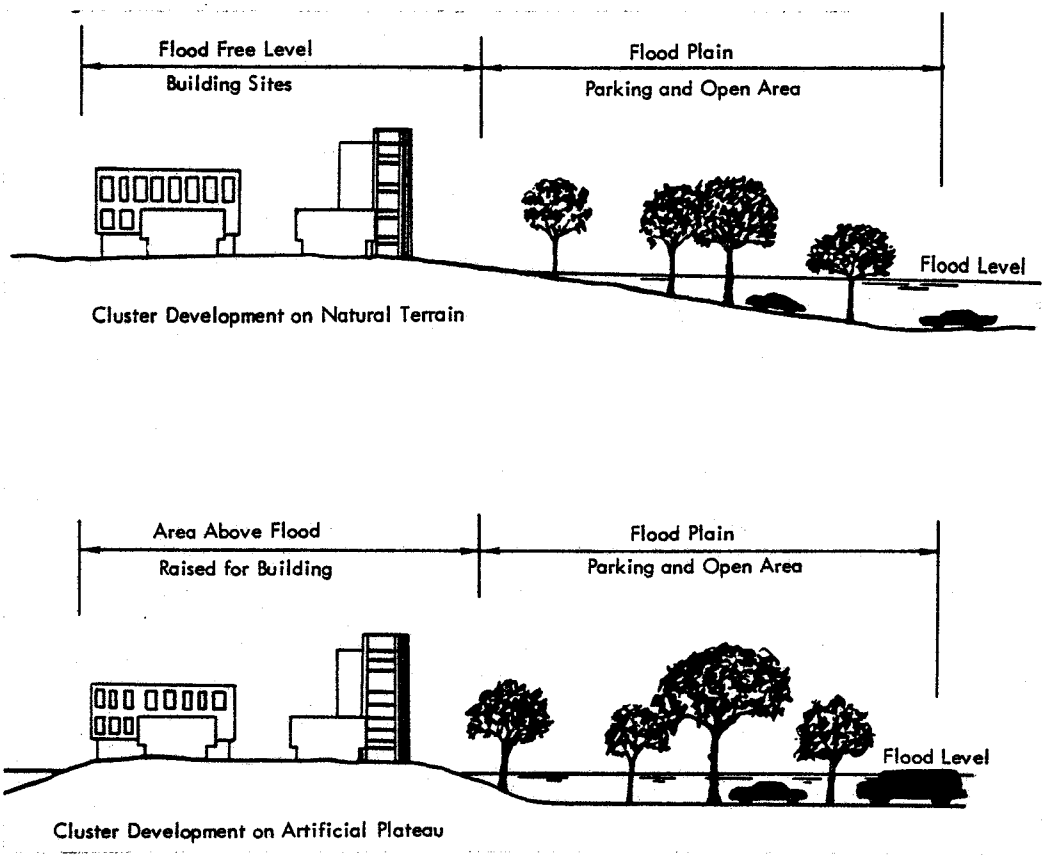


Figure 50. A Planned Unit Development on a Flood Plain Site. The Example at the Top of the Page Illustrates a Valley Location--with only a Part of the Site Subject to Flooding. The Lower Example Shows a Site Entirely Within a Pondage Area and Subject to Low Stage Flooding. In this Case, a Portion of the Site was Artificially Raised to be Above Flood Levels.

Source: Sheaffer, 1967

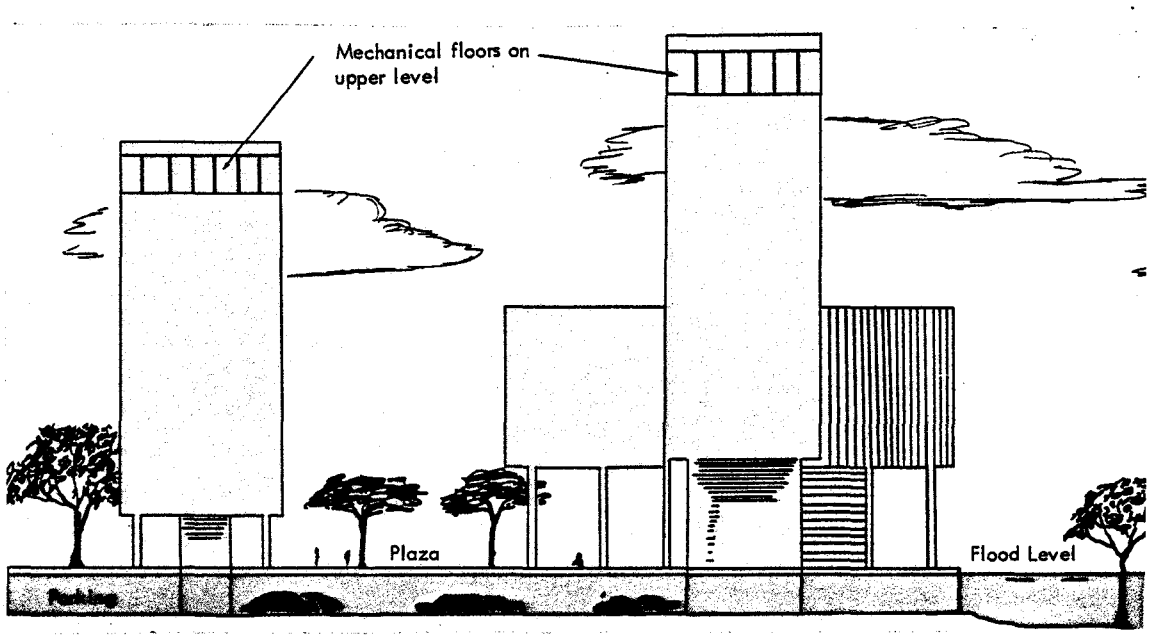
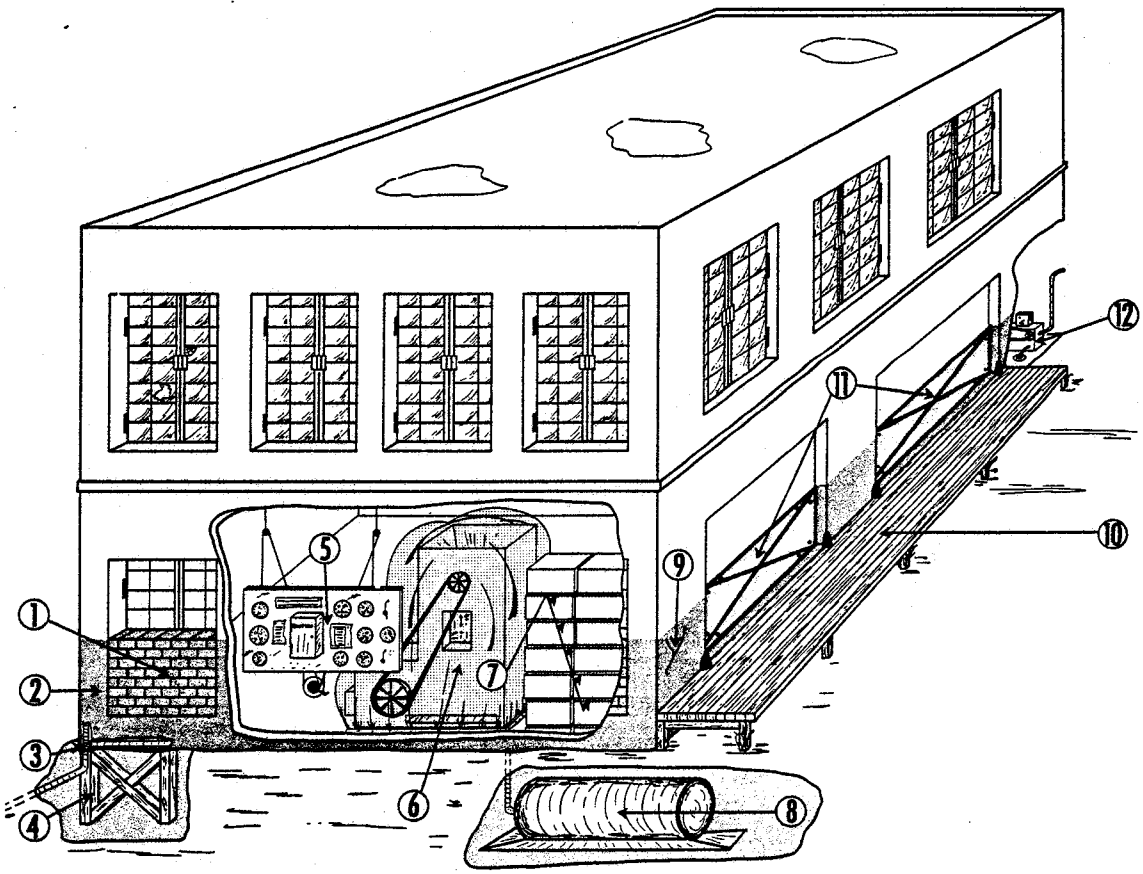


Figure 51. Urban Development that is Compatible with a Flood Plain Location. In this Development, the Uses of the Building Have Been Adjusted to Avoid Uneconomic Flood Losses.

Source: Sheaffer, 1967



EXPLANATION

1. Permanent closure of opening with masonry
2. Thoroseal coating to reduce seepage
3. Valve on sewer line
4. Underpinning
5. Instrument panel raised above expected flood level
6. Machinery protected with polyethylene covering
7. Strips of polyethylene between layers of cartons
8. Underground storage tank properly anchored
9. Cracks sealed with hydraulic cement
10. Rescheduling has emptied the loading dock
11. Steel bulkheads for doorways
12. Sump pump and drain to eject seepage

Figure 52. A Flood Proofed Structure. This Sketch Illustrates the Many Items That Must be Employed to Flood Proof a Structure.

Source: Sheaffer, 1967

Figure 53. Flood Proofing by Elevating Structures, Phoenix Metropolitan Area, Arizona

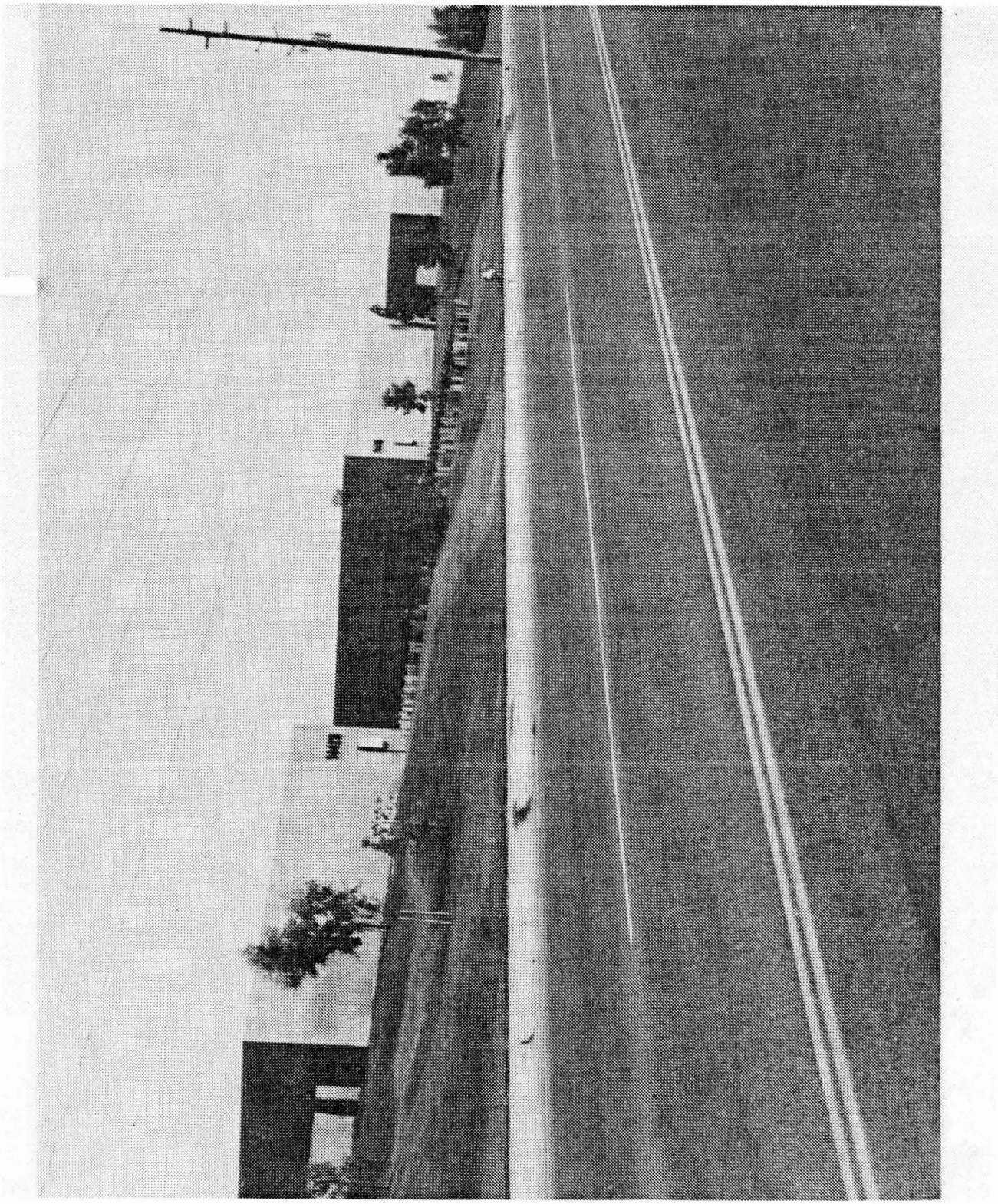
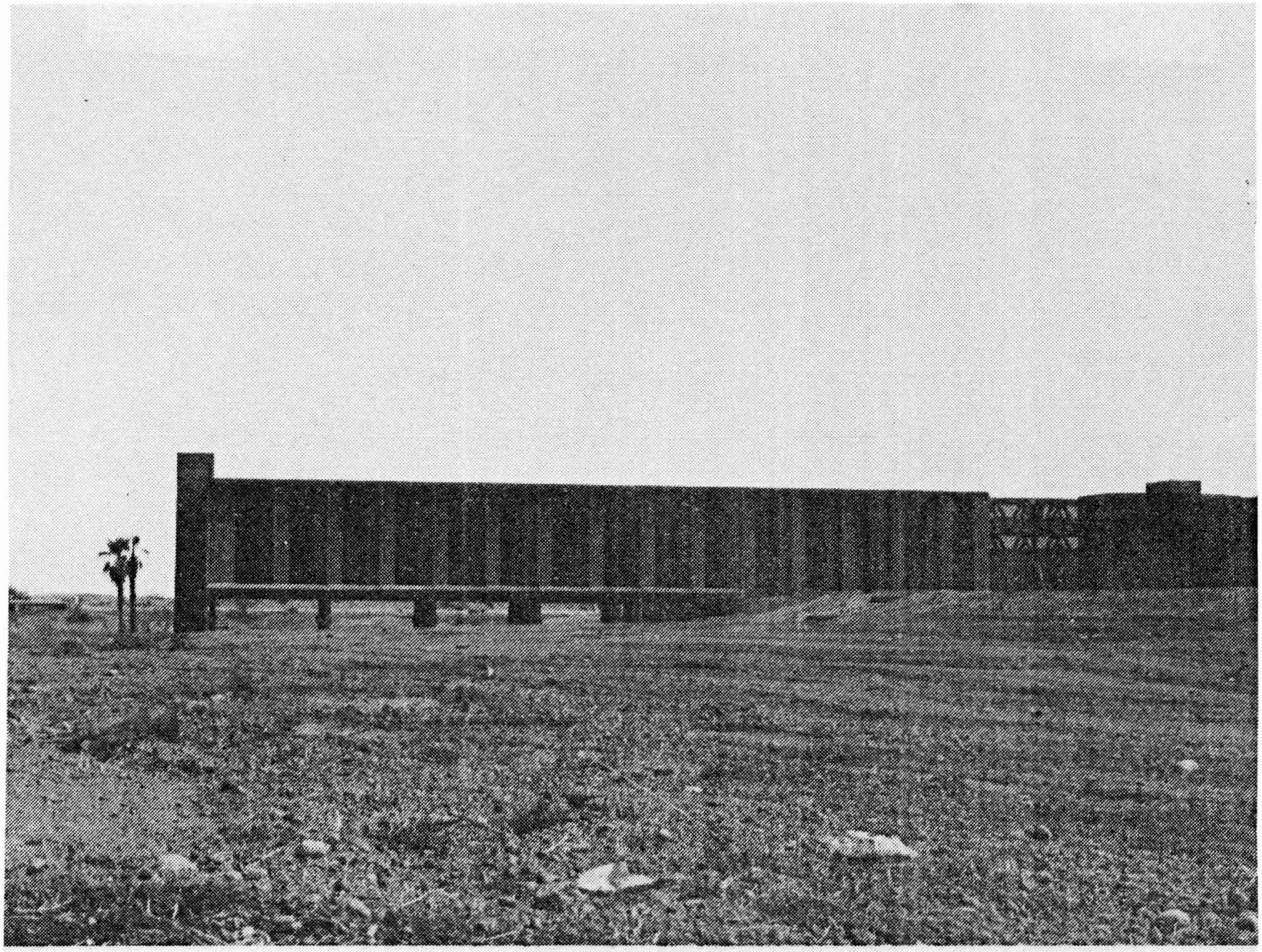


Figure 54. Flood Proofing of Radisson Resort by Elevating the Structure, Phoenix Metropolitan Area, Arizona



the necessary resources to issue timely warnings.

Evacuation: Flood losses can be reduced by the temporary or permanent evacuation of persons and property in the path of flood waters. Temporary evacuation consists of evacuating buildings, raising possessions above the expected flood height, undertaking emergency protective measures, and activating flood fighting and relief agencies. Permanent evacuation requires the purchase of properties, relocation of residents, and removal of improvements in the flood prone areas. The vacated lands can be used for open space or parks or some other use that would sustain relatively minor damages from floods.

The local governments are responsible for evacuating individuals from flood threatened areas. This includes both temporary and permanent evacuation.

Tax Incentives: Tax incentives can be employed to preserve floodways. In areas where floodways are used for agricultural, recreation, or other open space purposes, the influx of residential and commercial establishments onto the flood plains increases the land values and, hence, the taxes. By adjusting taxes local governments can prevent taxes on farmlands from rising so high that it is no longer profitable to continue farming. In other

cases, taxes are used to clear the flood plains. This is accomplished through a system of tax rebates, which reduce a property value to zero over a period of ten to twenty years.

No explicit uses of tax incentives to preserve the floodways are currently employed within the Phoenix metropolitan area.

Flood Insurance: Flood insurance was recently made available to flood prone communities through the National Flood Insurance Program, which is under federal aegis. Communities must adopt and enforce flood plain regulations in order to qualify for the low-cost insurance applicable to existing developments within flood prone areas.

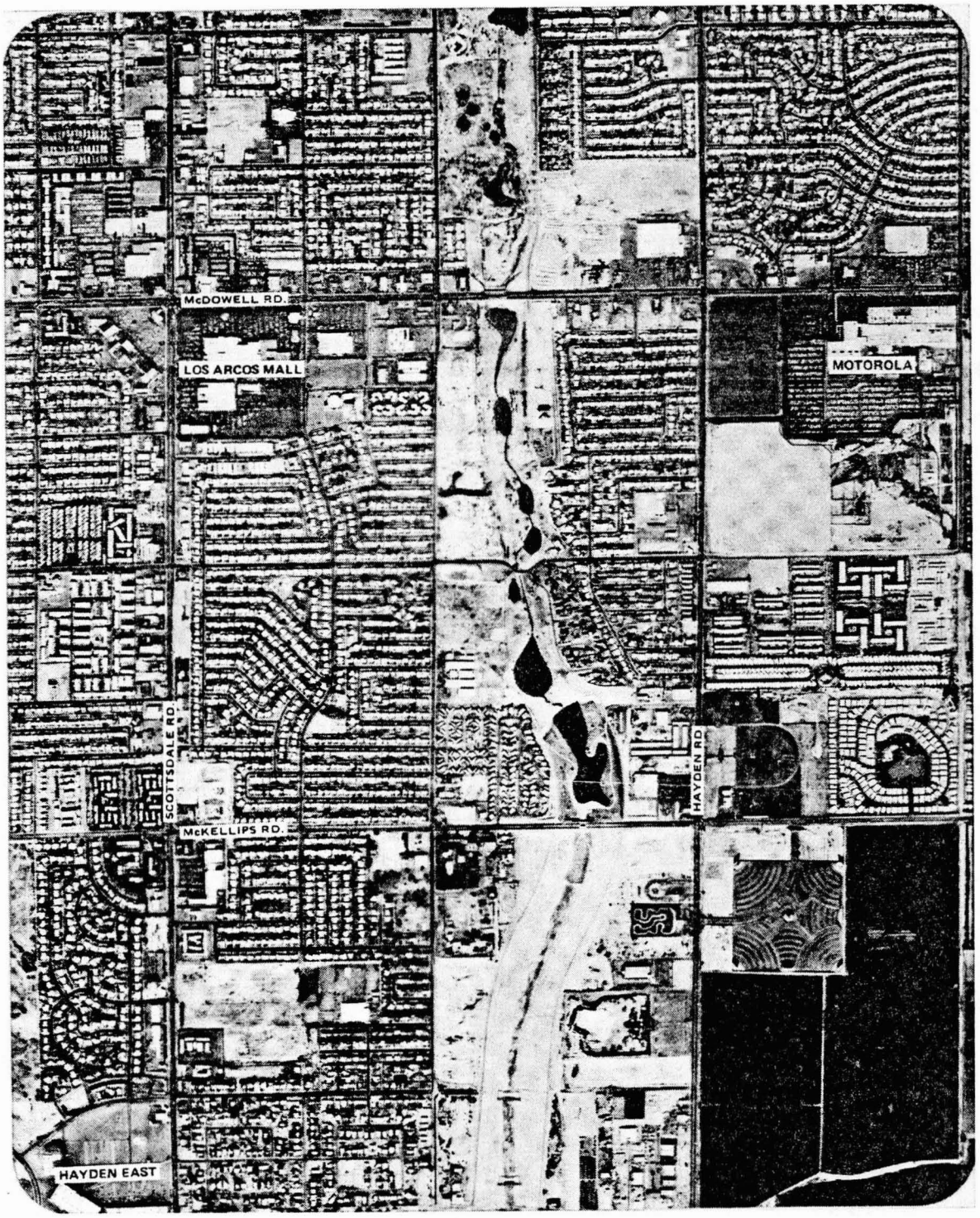
In the past flood protection expenditures have increased but flood losses have also mounted. This trend can be expected to continue as long as urban development occupies flood prone areas. The flood hazard, environmental features of the flood plain, human occupance of the flood plain, and the adjustment of human occupance to the flood hazard are the four elements which comprise the flood problem. Many alternative solutions are available to deal with a community's flood problem. These solutions include structural and nonstructural

measures or a combination of the two (Figure 55).

Special flood hazard boundary maps, delineating the 100-year flood plains, have been prepared for the communities and unincorporated areas within the Phoenix metropolitan area. Under the National Flood Insurance Program, it is the responsibility of each community to pass flood plain regulations to insure no future encroachment onto the flood plains. Within the metropolitan area most of the communities have complied with this requirement. Those who have not are working toward that end.

Figure 55. A Combination of Structural and Nonstructural Measures Were Utilized in the Design and Construction of Indian Bend Wash, Scottsdale and Tempe, Arizona

Source: Landis Aerial Surveys and Photography, 1978


McDOWELL RD.
LOS ARCOS MALL
MOTOROLA
SCOTTSDALE RD.
HAYDEN RD.
McKELLIPS RD.
HAYDEN EAST

CHAPTER IV - FACTORS OF CHANGE IN THE FLOOD HAZARD SYSTEM

Selection and implementation of methods to reduce flood losses have been inhibited in several ways. Many factors, affecting the evolution of a flood hazard system, are important to the decision-making processes. Several factors, including changing values, changing perceptions, changing flood risk, and acceptable level of risk have been instrumental in changing the flood hazard system in the Phoenix metropolitan area. When analyzing scenarios of alternative futures, the influence of the factors mentioned above should be kept in mind. These factors will be treated systematically below; however, it will become obvious that the factors do indeed overlap.

CHANGING VALUES

The cultural values of the nation are reflected in the development of communities. In the early days of settlement in the Salt River Valley, communities developed along the river banks because the river was the essence of life in the arid region. As the area was transformed from an agricultural community to an urban society growth occurred in every direction. After

World War II the rapid growth in the Valley changed the land use patterns in many areas. including the flood plains and flood prone areas. Flood prone sites that were once covered with wide spans of agricultural crops and a few buildings were transformed into intensively developed urban areas with residential, commercial, industrial, and public structures. Floods that in the past would have caused relatively minor property damages to agricultural lands, today would result in disastrous damages to the urbanized developments.

The new environmental awareness of the 1960's and early 1970's called attention to the heretofore unquestioned growth and the related environmental concerns. Environmental quality and the associated wise management of the flood plains became topics of discussion at all levels of government, among individual citizens and organizations, and in the news media.

On a national scale there was evidence of environmental planning and the impacts of such on development and flood plain management. Social and environmental, rather than solely economic, considerations have been employed in the development of alternative solutions to flood control programs. These alternatives include flood insurance, flood plain regulations, and other nonstructural

solutions.

Local examples that reflect the trend of changing values and attitudes toward reducing flood losses are the Indian Bend Wash experience in Scottsdale and the adoption of flood plain regulations and ordinances by the State of Arizona, the unincorporated areas of Maricopa County, and the cities and towns in the Phoenix metropolitan area.

CHANGING PERCEPTIONS

Changes in the flood hazard system have been reflected in part by changes in the inhabitants' perception of flooding as a natural hazard. Prior to discussing changing perceptions relevant to the flood hazard, "perception" must be defined and the variables or elements used to determine one's perception must be scrutinized.

Perception, a complex concept, can be defined as the social and cultural factors as they effect the cognitive structuring of man's physical and social environment. The perception of the environment varies with each individual and with his background and current attitudes, which are the sum of his needs, moods, values, expectations, memories, and social situations. Methods of measuring perception are difficult to assess because

it is hard to state explicitly that which one perceives. Often, views or ideas are implied in indirect actions rather than in overt articulations.

Perception of flooding as a natural hazard may be determined by examining some of the relevant constituents in relation to periods of flooding. As previously stated, these factors include: the approval or rejection of bond issues and laws or ordinances, the location and date of flood insurance purchases, and the frequency of sale of houses in flood prone regions. Each of the indices of perception will be discussed in further detail.

Bond Issues

One indication of how serious one considers a natural hazard to be is the rapidity or ease with which he parts with his money. Bond elections are called to determine whether or not the voters living within the political taxing division desire the issuance and sale of general obligation bonds. Numerous bond issues have been voted on by the residents in Phoenix. It would seem likely that the bond elections for flood control measures would be approved following a flood that wreaked havoc and misery to the occupants of the flood prone regions. Has this been the case in Phoenix?

Bond issues approved the construction of storm

drainage systems totaling $16 million in 1957 and 1961. Flooding had occurred in years preceding the bond elections. Following the severe rainstorms and consequent flooding in August and September of 1964, another bond issue was proposed. Due to inadequate flood control facilities storm damage centered along Van Buren Avenue between 28th and 48th Streets. Mayor Graham of Phoenix urged acceptance of the flood control bond, especially in Sunnyslope. In spite of the obvious need for improved protection works, the proposal was rejected. The same was true for the bond election in 1966 which was proposed after the December, 1965--January, 1966 flood. However, a bond issue allocating $37 million for the construction and improvement of sewers was passed when residents approved ten bond issues in the election on 21 August 1970. This election did not succeed a recent major flood. To avoid the delay and red-tape involved in bond elections the City Engineer of Phoenix incorporated a nearly $4 million storm drainage improvement program into the city ordinance passed in February, 1974 (Burris, 1976).

From the evidence presented it is difficult to accurately discern the perception of flooding as a hazard. Although bond issues proposed in 1964 and 1966 followed major floods in the vicinity, the rejection of the bonds

suggests that the residents either did not perceive flooding as a great hazard or did not think that floods of such magnitude would recur. The floods of 1970 and 1972 may have stimulated the acceptance of the 1974 city ordinance for Phoenix. Again, one must exercise caution when dealing with perception and, therefore, any concrete conclusions would be presumptuous at this time.

Laws and Ordinances

The widespread damages, both physical and social, accrued during the 21-22 June 1972 flood provided the impetus for legislation concerning flood plain management at the state, county, and city levels. Prior to this time there were no established guidelines or criteria regulating the development of the flood plains. In 1964 the U. S. Army Corps of Engineers initiated a campaign urging land use controls in areas susceptible to flooding. From that date to 1973 the only recourse the Corps of Engineers, as well as other federal, state, and local agencies, had was to disseminate information pertaining to the hazards of urban development in flood prone regions (Worthington, 1976). However, the impact of the 1972 flood seems to have been the turning point for the responsiveness of the citizens.

State. The State of Arizona House Bill 2010 of 1973 represented the avant-garde for regulating development in flood prone areas. As stated, the purpose of this legislation was to empower the state agencies, as well as assist and encourage the cities, towns, and counties, to establish appropriate regulations as an intrinsic component of a flood plain management program designed to:

> 1. Minimize flood damages and reduce the height and violence of floods which are caused by obstructions restricting the capacity of the floodways.
>
> 2. Prevent unwise encroachment and building development within flood plain areas.
>
> 3. Protect the life and property of citizens who have settled in flood plain areas.
>
> 4. Enhance property values of abutting flood plain lands.
>
> 5. Protect public health.
>
> 6. Reduce the financial burden imposed on the community, its governmental units and its citizens if such land is subject to flooding.
>
> 7. Enhance wildlife and recreation values where appropriate...(Arizona House of Representatives, 1973).

On 3 May 1973 the bill was passed and signed into law. The act proposed the establishment of a "Flood-plain Board" charged with the responsibility of adopting

flood plain regulations. Such regulations, defined as codes, ordinances, and other regulations relating to land use and construction within the channel and flood plain areas, would include zoning ordinances, subdivision regulations, building codes, housing codes, setback requirements, open area regulations, and other control methods pertaining to the use and development of flood prone areas. With the enactment of these regulations written permission or authorization from the Floodplain Board will be mandatory for the construction of any structure which would divert, retard, or obstruct the flow of water in any watercourse (Arizona House of Representatives, 1973).

County. Regulations at the county level were approved on 25 February 1974. This depicted the initial response of flood plain management at the county level. The regulations, cited as the "1974 Floodplain Regulations for the Unincorporated Area of Maricopa County," stated that any structure within the delineated flood plain must have the minimum floor elevation above the high water line of the one-hundred-year flood. Land uses permitted by law would be sanctioned provided: (1) the floor level is above the fifty-year flood elevation; (2) non-dwelling structures

are adequately flood proofed; or (3) it is determined by the Chief Engineer and General Manager of the Flood Control District of Maricopa County that the capacity of the flood plain channels will not be restricted by the use. Existing uses; areas in which construction is presently underway; subdivisions with approved final plats; areas in which the construction of bridges, dikes, etc., is necessary for the construction of roads or highways; and a few other special cases are exempt from the cited regulations. In addition to the criteria for flood plain management, factors to be considered in delineating flood plains and in flood proofing or otherwise protecting structures are enumerated (Maricopa County Board of Supervisors, 1974).

City. 25 February 1974 marked the adoption of the first flood plain regulations for the City of Phoenix. Other cities within the metropolitan area have adopted regulations similar to those of the City of Phoenix. The Phoenix ordinance designated the City Council as the Floodplain Board and the City Engineer as the Administrative Agent for the regulations. Enforcement of the following flood plain regulations was delegated to the Floodplain Board, through the office of the City Engineer. (1) The floodway capacity may not be obstructed, reduced, or diverted by

filling, dumping, or altering the width or course of the floodway. (2) If the City Engineer approves a request for a building permit prior to issuance by the Building Official, construction and development may take place within the floodway fringe (outer limits of the 100-year flood). The City Engineer requires the applicant to include appropriate flood proofing measures. These may be: provision of access during flooding; maintenance of electrical, sewer, and water facilities; construction of structures and foundations so as to withstand hydraulic loadings expected during the 100-year flood; and construction of doorways, windows, and openings so that the waters from the 100-year flood cannot enter through them. (3) With approval of the City Engineer development of facilities having low flood damage potential will be permitted within the floodway. (4) Existing land use is not affected by these regulations, but alterations exceeding reasonable limits will be considered new construction and must conform to regulations. (5) The flood plain area must be redefined within one hundred twenty days after the completion of any flood control project in that area. (6) Written authorization from the City Engineer must be obtained prior to the location or maintenance of any new building, structure, fill, excavation, or development

within the flood plain (Phoenix City Council, 1974).

The rules and regulations cited above testify that Arizonans are at last realizing that engineering endeavors alone are not adequate nor always feasible for reducing the threat of flood damage in urbanized sectors. Land use regulations are imperative in a rapidly expanding urban society to insure against further losses.

Flood Insurance

The National Flood Insurance Program was established in 1968. The purpose of this program is to make specified amounts of flood insurance, previously unavailable from private insurers, available under federal aegis. The program insures exisitng properties and requires state and local governments to adopt and enforce land use and control measures that will regulate land development in flood prone areas in order to avoid or reduce potential flood damage:

> The Congress recognized that Federal participation in the form of a subsidized insurance program alone would encourage the continued unwise use of flood hazard areas and result in greater expenditures of tax dollars to provide economic relief to the disaster victims. Therefore, the Congress authorized the subsidized insurance for those exposed to flood hazards, provided that future development would be guided to minimize losses (U. S. Department of Housing and Urban Development, 1972).

The Federal Insurance Administrator in the U. S. Department of Housing and Urban Development is responsible for the operation of the program. The program is a cooperative effort between the federal government and the private insurance industry, which is represented by the National Flood Insurers Association. Any insurance company licensed to write property insurance in a state is eligible for membership. A servicing committee is appointed by the National Flood Insurers Association on a statewide basis to disseminate information to the public and to insurance agents, to process insurance policies, and to handle the adjustment of claims for loss payments (U. S. Department of Housing and Urban Development, 1972).

For a community to qualify for the National Flood Insurance Program it must submit a written request to the Administrator to participate in the flood insurance program for the entire area under its jurisdiction. The checklist for prerequisites necessary to qualify for flood insurance includes submission of land use and control measures adopted in compliance with the program regulations (U. S. Deparment of Housing and Urban Development, 1972).

The advantages of land use regulations required before a community may file application to participate in

the flood insurance program are the allocation of unprotected lands to the most appropriate use and the prevention of private or public landowners from burdening others with costs incurred from losses due to the unwise use of regions prone to flooding.

Phoenix qualified for the National Flood Insurance Program in December, 1971. To date, the only insurance company offering flood insurance in Phoenix is AETNA Life and Casualty.

It is relatively easy to purchase flood insurance. To obtain a flood insurance policy, a homeowner may purchase the policy from any participating property and casualty insurance agent or broker licensed to do business within the state. No minimum amount of insurance is required and deductible clauses are included (U. S. Department of Housing and Urban Development, 1972).

It was believed that the purchase of flood insurance would be a reliable indication of the perception of flooding as a natural hazard. Theoretically, those persons who experienced losses due to floods or who lived in a flood prone region would invest in a flood insurance policy. But, Edward C. Brinley of Hartford Insurance Group stated that a majority of flood plain residents do not have flood insurance. Most do not realize that

their insurance policies do not cover floods. Without flood insurance the only aid would be if their area is declared a disaster area and is eligible for disaster relief. Although most homes can be insured against floods for less than one hundred dollars, many are "still alarmingly apathetic" (The Arizona Republic, 1974).

> O. M. Cleveland, the Hartford's regional office manager in Phoenix, said there are around 750,000 single-family dwellings in Arizona, yet only 5,463 flood insurance policies are now in force on those homes. Cleveland said 1,749 of these policies were taken out in the past year (The Arizona Republic, 1974).

Information regarding the addresses and purchase dates of flood insurance policy holders could not be obtained. Therefore, it was necessary to conduct an interview to discern whether many of those covered by flood insurance lived in the flood prone sectors of Phoenix. See Appendix C for a sample interview.

Analysis of the interview suggests that less than 10 percent of those located within the flood prone areas in 1973 had flood insurance coverage. This leaves approximately 90 percent of the population susceptible to floods wholly unprotected. The few families owning flood insurance policies had expensive homes with sunken living rooms. Only after their homes were invaded by waters from the 21-22 June 1972 flood did they invest in

a flood insurance policy. Once again, it appears that flooding is generally not considered much of a hazard or the residents are not aware of the risk involved.

Frequency of Sale of Houses

One may assume that the frequency of sale of houses in the flood prone regions would statistically be greater than the sale of equivalent residences in sectors not susceptible to floods. Data indicating the frequency of sale of houses was not readily available so it was included in the interview questionnaire.

The length of residence of the homes sampled ranged from one and one-half weeks to twenty-nine years. No average length of residency was calcualted as the application of quantitative methods would not be valid in this case.

The only empirical information concerning the frequency of sale of houses was obtained from Dr. Robert W. Durrenberger (1975) of the Department of Geography, Arizona State University. Before purchasing a home in 1972 Dr. Durrenberger mapped the location of the houses for sale. He noted a clustering effect in several areas and further investigation revealed that the clustering occurred in areas that had previously been inundated. Although no precise evidence can be provided at this time,

it appears that houses within flood prone areas change owners more frequently than houses not prone to flooding.

CHANGING FLOOD RISK

One factor in the changing flood hazard system has been the changing flood risk. Before World War II the flood prone areas were used for agriculture and there were relatively few buildings in the path of flood waters. Floods occurred prior to this time and they caused some damage, but not as much damage as those same floods would cause today. Newspaper accounts give an indication of damages from previous floods such as that of 1921 and 1943. If such floods as these were to occur now, damages from the 1921 flood, which was estimated to have a frequency of occurrence of once in one-hundred years, would total approximately $63 million; and the 1943 flood, equivalent to a 25-year frequency flood would cause damages estimated at $20 million. In a statement of May, 1967 delivered to the Maricopa County Board of Supervisors and the Phoenix City Council, Fred Glendening, the Phoenix Public Works Director at that time, addressed the changing flood risk, particularly that along Cave Creek. He showed the change from farmlands in 1943 to the densely populated, built-up urban areas in 1967.

He noted that an additional 95,000 people, 30,000 dwellings, 1,700 commercial establishments, and 36 schools had located in the flood prone areas during that time (Glendening, 1967). In 1972 Mr. Glendening, then Deputy City Manager for Operations for the City of Pheonix, again exemplified the serious and changing flood risk:

> Somehow the word has to get over to the hundreds of thousands of people in the urban areas who could have their property seriously damaged and perhaps even lose their lives in the case of a major flood. If the heavy rains of June 22, 1972 had been concentrated over the Cave Creek watershed instead of over the Indian Bend Wash watershed, damage would have been many times greater than that which occurred along the Indian Bend Wash; the reason being that the bed of Cave Creek has been completely obliterated and filled with people south of the Arizona Canal to the Salt River (Glendening, 1972).

Further changes in the flood risk of the Phoenix metropolitan area are expected as a result of the recently adopted flood plain regulations and ordinances. These regulations are designed to restrain future development in the flood plains and to restrict rebuilding of existing structures in those areas. Consequently, if the regulations are effectively enforced, it can be assumed that the areas vulnerable to damage in the flood plain will gradually diminish.

Other factors that can potentially alter the flood risk are the current plans and proposals for flood

control. These include proposals in various stages of planning and development for both structural and non-structural solutions for mitigating flood losses. Presently, plans are being pursued by the U. S. Army Corps of Engineers, the Soil Conservation Service, and the Bureau of Reclamation. All of the plans of these federal agencies are in concert with the plans of the Flood Control District of Maricopa County.

The pendulum of the changing flood risk may be on the downswing. The Phoenix metropolitan area has always experienced flooding of its rivers. Damages have been commensurate with the type and degree of development in the flood prone regions. Damage figures have mounted from the agricultural era to urban days; they can be expected to stabilize if flood plain regulations and management practices are exercised and enforced; and damages should decrease after completion of the proposed flood control programs.

ACCEPTABLE LEVEL OF RISK

Despite the numerous reports, newspaper articles, and public presentations pertaining to the flood hazards and their possible solutions, the residents of the Phoenix metropolitan area have been largely inactive and apathetic

toward flood control and flood plain management. The only exception to this trend has been immediately following storms that have caused damages to life and/or property and have inconvenienced residents. Reaction in the Valley has been similar to that expressed by Ericksen (1975) regarding the Boulder, Colorado experience: "Without serious exposure to the physical event, decision-makers simply ignored or misunderstood technical advice, and channelled concern into more obvious, everyday social programs (streets, sewerage, water)."

The probabilistic situation of flooding is often difficult for the residents of the flood prone areas to handle. Frequently, one hears statements to the effect that the 100-year flood only occurs once every hundred years. This statement is not only misleading, but exudes a false sense of security in the present situation by implying that flood hazards do not require immediate rectification or action because there is plenty of time in which to act before the next 100-year flood strikes. This ignorance of the flood risk teamed with "the 10 to 20-year investment philosophies of the entrepreneurial private managers," largely explains why development of the flood prone areas was allowed to continue unquestioned for so many years (Ericksen, 1975).

The change from an agricultural to an urban community demands a change in the acceptable level of risk. An urbanized society can no longer tolerate floods that cause damage in terms of lives lost and/or money lost from damages to items such as property, utilities, and roads. One example depicting change in the acceptable level of risk is storm drainage. The range of frequencies of storms used in the engineering design for storm drains reflects the degree of protection of life, safety, and nuisance communities are willing to accept and pay for. In residential areas storm sewers are commonly designed to accommodate storms of a 2- to 15-year frequency; in commercial and high-value districts 10- to 50-year designs are the norm; and for flood protection designs are for 50-year or greater storms (Yost and Gardner, 1970).

CHAPTER V - SUMMARY AND CONCLUSIONS

One aspect of natural hazard research has been striving to understand why people occupy flood plains and what impact active public participation to reduce the flood damages would have on the national economy and local land use. The historical evolution of flood control policies and practices must be understood before analysis and implementation of the best alternative solutions to flood protection can be pursued.

In the preceding pages the circumstances and conditions that have influenced the evolution of flood control programs in the Phoenix metropolitan area were discussed. Chapter I dealt with the basic problem of flooding in the desert region. Phoenix has experienced floods in the past and future floods are likely to cause more damage as the urbanized area continues to expand. Prior to the writing of this paper there was no comprehensive account of the historical evolution of the flood policies and practices in the Phoenix area. The significance of such an account detailing the process by which policies are instituted and the factors involved in the process is that it would provide the background and basic

knowledge necessary to assist the decision-makers in formulating, selecting, and implementing effective future programs.

Chapter II described man's intervention in the natural systems. Meteorology and surface hydrology are the natural physical elements of the flood problem. As the Phoenix metropolitan area changed from an Indian settlement to an agricultural community to an urbanized society the flood problem worsened. Man has modified the landscape by such acts as constructing canals perpendicular to the natural drainage patterns, obliterating drainage patterns first by agricultural pursuits and later by urban development, and locating within flood prone areas. He changed the basin characteristics which in turn altered the runoff regimen and increased the problems associated with flooding. The current flood hazard was discussed and it was pointed out that future land use plans must take into consideration related hydrological impacts.

Human adjustments to the flood hazard were discussed in Chapter III. Flooding has historically been a universal problem. Flood losses have continued to increase despite the fact that flood control expenditures have also increased. The magnitude and frequency

of floods spells potential danger for many residents of the Phoenix metropolitan area. Alternative structural and nonstructural methods of dealing with the flood hazard have been defined. Techniques utilized to cope with flood problems tended to be structural until recent years when nonstructural methods or land use controls gained greater emphasis. The selected solutions to the flood hazard hinge on the knowledge of the decision-makers and the public with regards to the flood problem, the risk involved, and the options available to them. Thus, a campaign to educate the residents of the Phoenix area on the three topics mentioned above is a necessary element of sound decision-making. The need exists for a comprehensive program of flood plain management.

The factors of change in the flood hazard system were explained in Chapter IV. Fluctuations in the system are caused by changing values, perceptions, flood risk, and acceptable level of risk. Values regarding environmental and social indices have changed leading to more consideration for nonstructural methods as the Indian Bend Wash case and passage of flood plain regulations and ordinances demonstrated. Factors indicative of changes in perception included bond issues, laws and ordinances, location and date of flood insurance purchase,

and frequency of sale of houses in flood prone areas. In general, the changes identified in these realms revealed changes in the perception of the flood hazard. Transition from an agricultural to an urbanized society increased the potential for damage by flood waters. Long range projections indicate that the recent flood plain regulations and ordinances, if effectively enforced, will tend to diminish the number of homes threatened by flooding. When completed, current plans, consisting of both structural and nonstructural flood control measures, will decrease the number of homes currently subject to flooding. Data dealing with the acceptable level of risk revealed that residents of the Phoenix region have been generally inactive and apathetic in matters concerning the flood situation. The exception to this statement has been soon after a severe flood has caused damages to property and/or life. The acceptable level of risk changed as Phoenix transformed from an agricultural to an urbanized community. An urban population simply cannot tolerate the high damages associated with flood waters. The definition of these factors which describe the changing flood hazard system are important for the analysis of future alternatives.

The data presented herein give evidence that a

serious flood problem exists in the Phoenix metropolitan area and that a comprehensive flood plain management program is needed to decrease the potential of danger to people and property. The process by which flood control policies and practices have been established and the factors involved in the process have been discussed. It is hoped that an understanding of this evolution will provide governmental decision-makers with the background from which to formulate, select, and execute the best alternative solutions for flood protection and mitigation of losses.

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APPENDIX A - TOPOGRAPHIC CHARACTERISTICS OF THE MAJOR WATERWAYS DRAINING THE STUDY AREA

The U. S. Army Corps of Engineers (1976b) has described the topographic characteristics of the study area and of some of the streams therein:

> The area pertinent to flood problems in Phoenix and vicinity is in Maricopa and Yavapai Counties in the central part of Arizona . . . , and comprises approximately 2,730 square miles. The area is roughly oval, with a maximum length and width of approximately 90 and 45 miles respectively. Elevations range from 190 feet at the confluence of the Agua Fria and Gila Rivers to 7,000 feet in the mountains near the headwaters of the Agua Fria River. The topographic characteristics of the major watercourses draining the project area are described in the following subparagraphs.
>
> a. Agua Fria River. The Agua Fria River originates about 7,000 feet above sea level in the mountains of central Arizona and flows southward for about 130 miles before emptying into the Gila River, 15 miles west of downtown Phoenix, at elevation 910 feet. The course of the stream is nearly equidistant between two parallel mountain ranges, the Black Hills-New River Mountains and the Bradshaw Mountains, that form the eastern and western boundaries of the drainage area. The gradient of the Agua Fria River ranges from about 300 feet per mile in the headwaters to about 10 feet per mile at the Gila River.
>
> b. New River. New River, the major tributary of the Agua Fria River, has its headwaters in the New River Mountains, roughly 40 miles north of Phoenix. New River flows generally southward for about 40 miles to its confluence with the Agua Fria River, about 15 miles west of Phoenix. The drainage area of New River at its mouth is

340 square miles, of which approximately one-third is mountainous. Elevations in the basin range from a little over 5,000 feet in the New River Mountains to about 1,040 feet at the confluence with the Agua Fria River. The stream gradient ranges from 370 feet per mile in the mountains to 10 feet per mile in the valley.

c. Skunk Creek. Skunk Creek, the major tributary of New River, rises in the New River Mountains about 35 miles north of Phoenix and flows generally southwestward for about 30 miles to its confluence with New River about 15 miles northwest of Phoenix. The drainage area of Skunk Creek is 110 square miles, of which about 20 percent is mountainous. Stream gradients on Skunk Creek decrease from 650 feet per mile in the mountains to 20 feet per mile near its confluence with the New River.

d. Cave Creek. Cave Creek has its source in the New River Mountains to the north of Phoenix, where elevations rise to as high as 5,000 feet. The stream then descends to the alluvial fan near the community of Cave Creek and flows south for 13 miles to Cave Creek Dam, which controls the 175 square mile drainage area upstream from the dam. Cave Creek then flows across an alluvial fan which is undergoing urbanization between Cave Creek Dam and the Arizona Canal. Flood flows on Cave Creek exceeding the freeboard capacity of the Arizona Canal flow directly through metropolitan Phoenix to the Salt River. The total drainage area of Cave Creek at the Salt River is 311 square miles. The stream gradient ranges from 500 feet per mile in the mountains to 25 feet per mile near the Arizona Canal.

e. Dreamy Draw. Dreamy Draw, a tributary of Cave Creek, rises in the Phoenix Mountains and flows generally southwestward for about 5 miles to its confluence with Cave Creek in Phoenix. Dreamy Draw Dam controls 1.3 square miles of the 2.0-square-mile drainage area above the Arizona Canal. (U. S. Army Corps of Engineers, 1976b).

Information pertaining to Cudia City Wash and the Salt River was also described by the U. S. Army Corps of Engineers (1976a):

> CUDIA CITY WASH
>
> Cudia City Wash, with a drainage area of 4.9 square miles above the Arizona Canal, rises in the Phoenix Mountains northeast of Phoenix and upstream from the Arizona Canal. The main stem of the wash starts at about 2,100-foot elevation and drops to the valley floor at 1,400-foot elevation in approximately 1 mile, and to the Arizona Canal at about 1,250-foot elevation in approximately 3 miles.
>
> SALT RIVER
>
> The Salt River, a major tributary of the Gila River, flows in an east-west direction through Phoenix. Although this report does not give detailed consideration to the Salt River, the latter now serves as the outlet for Cave Creek and other relatively minor washes (U. S. Army Corps of Engineers, 1976a).

APPENDIX B - MAJOR FLOODS OF THE PHOENIX METROPOLITAN AREA

Floods have occurred in the Phoenix area in 1891, 1897, 1905, 1916, 1918, 1919, 1921, 1922, 1935, 1936, 1943, 1951, 1954, 1956, 1957, 1959, 1963, 1964, 1965-66, 1967, 1970, 1972, and 1973. The frequency of flooding in the region coupled with the unprecedented rate of urban growth explicitly spell continued disaster and raise consequential flood damage accordingly.

To exemplify the gravity of this natural hazard and the impact of urbanization one need only view some of the past floods in the area.

FLOOD OF FEBRUARY, 1891

One of the earliest known floods in the Phoenix metropolitan area was borne of two storms in the Gila River Basin in February, 1891. One storm lasted from the 15th to the 19th and the other occurred from the 22nd to the 25th. The storms originated in the Pacific Ocean and caused extensive flooding in California, as well as Arizona. Heavy precipitation and melting snow yielded the greatest floods of record on the Salt and Gila Rivers. On the Salt the peak discharge was

approximately 300,000 cubic feet per second (cfs) at the Arizona Dam, which was situated in approximately the same site as the Granite Reef Dam. Average discharges for the Salt River at the Arizona Dam appear in Table 4. The Gila River endured peak discharges estimated at 102,500 and 250,000 cfs at Florence and Gila Bend, respectively. Yuma was flooded by the raging Colorado River carrying about 250,000 cfs (U. S. Army Corps of Engineers, 1957).

Table 4. Selected Discharges for Salt River at Arizona Dam, Gila River Basin, From the Flood of 1891

Date	Average Discharge (Cubic Feet Per Second)
17 February	835
18 February	154,000
19 February	276,000
20 February	69,100
22 February	14,890
24 February	300,000[a]
26 February	15,000

Notes: a. Given as a maximum discharge

Source: U. S. Army Corps of Engineers, 1957

Newspaper (The Arizona Republic, various dates) excerpts gave accounts of the flood and the associated problems:

> February 19. * * * At 2 o'clock this morning word was received from the Arizona Canal Dam, by telephone, that the water of Salt River stood 16 feet upon the dam, the highest at any time during the great flood of last spring. * * *

February 20, Phoenix, Ariz. * * * Between five and six o'clock the height of the flood seemed to be reached and after remaining nearly stationary several hours the water began slowly to recede about 8 o'clock last night. * * *

* * * Contrary to the general opinion, but little of the flood water came from the Verde. That stream is said to have not reached its limit of last year and has fallen very rapidly since Thursday. Judging from the quickness with which the flood came and subsided it is thought that most of the water was delivered to Salt River by Tonto Creek, which draws the eastern slope of the Mazatzals and a large portion of the Mogollons. * * *

February 22 paper gave a review of events of the flood for the 19th. * * * The water at the Arizona Canal Dam had fallen 4 feet 6 inches by 6 P.M. yesterday, and the tendency was still downward. * * *

February 24. It was stated that on Saturday and Sunday bulkheads were being built in the consolidated Maricopa and Salt River Valley canals.

* * * The precaution was well taken as the steady rain began to tell and the water, which had fallen to but two feet and eight inches over the Arizona Dam at 4 o'clock Sunday afternoon, began to show an increase. At 8 P.M. it was up to four feet, and at 9 o'clock yesterday morning the register indicated eight feet. At 12 it had increased to ten and one-half feet, thus showing a rise of nearly one foot an hour. * * *

* * * Reports from the head of the Arizona Canal showed the following stage of water over the dam at the hours named. At 12 o'clock noon, 10 feet 6 inches; 3:15 P.M., 12 feet 6 inches; 5:30 P.M., 13 feet 6 inches; 8:30 P.M., 14 feet 9 inches; 10:40 P.M., 15 feet 3 inches; 1:40 A.M., 17 feet; 2:40 A.M., 17 feet 1 inch. * * *

February 25. * * * Finally, at 2:40 yesterday morning, the faithful watchman at the dam reported

> 17 feet 1 inch of water, the height reached at the last flood, and the river still rising. * * * The river continued to rise until it reached the unprecedented height of 18 feet 2 inches over the dam. * * * About 10:30 news came from the dam that the river had begun falling and each succeeding message was but a repetition of the good news. * * *
>
> February 26, Phoenix, Ariz. * * * After the water began to recede around the city, Tuesday night, it sank back towards the river almost as fast as it had risen. * * *(The Arizona Republic, various dates).

Brief accounts of the great flood of 1891 were given in Wagoner's Arizona Territory: A Political History (1970) and Corle's The Gila: River of the Southwest (1951). Wagoner mentioned the sudden onslaught, flooded areas, and short duration of the flood waters in the following excerpt:

> Torrential rains, in February of that year, brought the deluge; the Salt overflowed its banks, washed away the Tempe railroad bridge near Hayden's Butte (See Photograph), and damaged houses as far north as Jackson Street in downtown Phoenix. As usual, the waters receded and rushed on to the Colorado River as quickly as they had risen (Wagoner, 1970).

In his ventilation of the trials and tribulations of Jacob Walz, the famed discoverer of the "Lost Dutchman's Mine," Corle made reference to the 1891 flood:

> Pouring down from the mountains came a tremendous torrent, the result of a great storm, flooding the Gila, flooding the Salt, and wiping out towns and ranches, dikes, ditches, and farms.
>
> At two in the morning the house of Jacob Walz was completely washed away, and the roaring waters of the Salt River carried a good third of the town of Phoenix along with it (Corle, 1951).

Residential and business properties suffered damages estimated at $70,000. Miles of canal and all diversion structures and canal heading, except the Arizona Diversion Dam, were washed out. In Tempe the raging Salt River demolished the railroad bridge and trestle, interrupting rail traffic for about three months. For nine days there was no telegraph communication between Phoenix and the East. Of the 11,000 Maricopa County residents, one hundred families lost their homes and five people died (U. S. Army Corps of Engineers, 1957).

The 1891 flood inundated an extensive portion of Phoenix and smaller communities located adjacent to the riverbed. Erosion of the banks, and the flat topography, coupled with the heavy stream discharges, were responsible for the severity of flooding and the resultant damages. The overflow areas were delineated by the United States Geological Survey and calculations indicated that a recurrence of such a flow would approach the magnitude of the standard project flood (U. S. Army Corps of Engineers, 1957).

FLOOD OF 1905

The U. S. Army Corps of Engineers (1945) described the floods of 1905:

The year 1905 was productive of exceptionally heavy run-off from the Gila River drainage area. There were severe floods during January, February, March, and April. The flood of November 1905 was even more important. A protracted period of light precipitation during the early part of the month and a fairly heavy storm from November 21 to 23 served to prime the soil and to provide a moderate snow cover. A second storm, which had originated over the Pacific Ocean, passed over the drainage area between November 25 and 28. Precipitation intensitites apparently were high although quantitative records are not available. In addition to the direct run-off which it produced, this rainfall melted a considerable portion of the snow on the ground, causing a very severe flood. Plate 12 is an isohyetal map showing areal distribution of the precipitation which occurred between November 25 and 28. The heaviest rainfall was in the areas tributary to Hassayampa, Agua Fria, and Verde Rivers. Secondary centers were located in the Pinal and Santa Catalina Mountains. Floods were especially severe on San Francisco, Salt, Verde, and San Pedro Rivers. Quantitative records are not available for Agua Fria and Hassayampa Rivers, but these streams were reported to have been in flood. Records of peak discharge are not available on the upper reaches of Gila River. However, the 30-day run-off volume of 110,000 acre-feet recorded near Cliff indicates high discharges. Farther downstream near San Carlos, flood flows were extremely severe. Some authorities have estimated the peak discharge at this point to be 150,000 cubic feet per second, which however, may be high. Although the flood was one of the most severe recorded near the mouth of Gila River, estimated values are slightly less than those for the March 1905 occurrence. In some respects the November flood on Salt and Verde Rivers was equal to or greater than any flood during the period of record since 1905. Records do not indicate a large flood on upper Santa Cruz River. Observations or estimates of discharge are available for the following locations within the Gila River drainage area: Gila River near Cliff, near San Carlos, and near Dome; San Francisco River near Alma; San Pedro River near its mouth; Santa Cruz River

at Tucson; Salt River at Roosevelt and at McDowell; and Verde River near McDowell (U. S. Army Corps of Engineers, 1945).

FLOODS OF 1916

January 1916

Two general winter storms, occurring within the Gila River watershed, established January, 1916 as the wettest month on record since 1891 when the Arizona climatological service was instituted. The first storm, prevalent from the 15th to the 21st, enveloped a large geographical area and produced the larger flood. The second storm lasted from the 25th to the 30th.

Gillespie Dam and McDowell Dam site recorded precipitation of 3.5 and 4.9 inches during the first storm and 1.3 and 2.7 inches for the second, respectively. In both cases about one-half of the precipitation fell within a twenty-four-hour period. Severe ground conditions were accentuated by snow cover and heavy, continuous rains. Discharges in the Gila River and tributaries were high with peaks of 230,000 cfs and 155,000 cfs, respectively, at the mouth of the Gila River (U. S. Army Corps of Engineers, 1957).

An estimated $305,000 in property damage was sustained by residents of the Gila and Salt River Valleys.

Losses were heaviest on agricultural lands, bridges, and irrigation networks. "The rock-and-gravel plants in the Salt River channel, the Phoenix sewage disposal plant, and Riverside Park at the north end of Central Avenue bridge were severely damaged" (U. S. Army Corps of Engineers, 1957). In addition to the physical property damages and the suspension of transportation and other services, four lives were lost.

September 1916

The uplands bordering the Salt River Valley received excessive rainfall on 8 and 9 September. Flood waters from the Cave Creek watershed drained into the Arizona Canal and the excessive runoff, estimated to be eight times the capacity of the canal, broke through the banks and inundated large areas to the south. Glendale and Phoenix were flooded when the Arizona, Grand, and Maricopa Canals were breached (The Arizona Republic, various dates). Damage to the canal system totaled approximately $10,000. Losses to farmers were great because the rain and flood waters washed away many of the newly planted crops and damaged the hay and cotton.

FLOOD OF AUGUST, 1921

The U. S. Army Corps of Engineers (1976a) briefly

highlighted the flooding along Cave Creek in 1921:

> During the August 1921 storm it was reported that 4 inches of rain fell on the Cave Creek watershed and the resulting runoff at the location of the now existing Cave Creek Dam has been variously estimated at 20,000 to 25,000 cfs. The runoff flooded a large area in west Phoenix and, according to newspaper accounts, caused "over a million dollars" in damages. (Under present, 1975, conditions of development and price levels, damages would be in the neighborhood of $175 million.) In addition to flood damage to homes and businesses, the floodwaters covered the first floor of the State Capitol Building. Because of this storm, immediate steps were taken to prevent a recurrence of the flood by construction of Cave Creek Dam in 1922 and 1923 (U. S. Army Corps of Engineers, 1976a).

The magnitude of the 1921 storm has a frequency of occurrence about once every one hundred years. Some excerpts from The Arizona Republic on 22 August 1921 exemplify the conditions wrought by the storm:

> ...the entire western end of the city and thousands of acres of farm lands to the north (were) covered with water ranging from a few inches to several feet in depth.... It was Cave Creek's second rampage in three days....
>
> ...two feet of water crossed the first floor of the statehouse... (in the vicinity of the capitol) ...a solid sheet of water extended from Fifteenth to Nineteenth Avenues, reaching a maximum depth of five feet, and beyond the railroad tracks, between Nineteenth and Twenty-second Avenues, there was another unbroken sheet... the submerged area extended from the state fairgrounds to the southern limits of the city.
>
> ...it was coming over the Grand Canal, its channel being about a mile wide, from Seventh Avenue west. Central Avenue, meanwhile, had

> been covered with water for some distance, but the spread eastward was checked quickly (The Arizona Republic, various dates).

The resultant damages totaled approximately one million dollars. Most of the area suffering losses was farmland.

FLOOD OF AUGUST, 1943

The 4 August 1943 flood occurred after the existing Cave Creek Dam was constructed subsequent to the 1921 flood. It put about 9000 cubic feet per second down the "God-made but man-ignored Cave Creek floodway between the Arizona Canal and the Salt River" (Glendening, 1972). A concise description of the flood was provided by the Corps of Engineers (1976a):

> The August 1943 flood, resulting from heavy thunderstorm precipitation north and east of Phoenix, caused several breaks in the south bank of the Arizona Canal, one of which was in the Cave Creek area. This break released water that ultimately caused nine breaks in the Grand Canal. If all the numerous peaks along the Arizona Canal occurred at the same time, the total peak inflow into the canal would have been about 30,000 cfs. The peak flow in Cave Creek upstream from the Arizona Canal was estimated at 9,000 cfs. Total damages are not known but under present (1975) conditions of development and price levels, they could amount to about $60 million (U. S. Army Corps of Engineers, 1976a).

Excerpts from The Arizona Republic of 4 August 1943 give another account of the flood:

> Flood waters, ... invaded 1,000 or more homes in the Phoenix and Salt River Valley area yesterday.
>
> Three breaks in the Arizona Canal and a break in the Grand Canal poured walls of water into the area of north and northwest of Phoenix and into Northwest Phoenix itself (The Arizona Republic, various dates).

FLOOD OF AUGUST, 1954

A brief statement regarding the Queen Creek flood of 1954 appeared in a Corps of Engineers (1976a) report:

> The August 1954 storm and flood was the most severe on record within the Queen Creek drainage area approximately 50 miles east and southeast of Phoenix. An estimated 140 square miles of area had over 5 inches of precipitation and approximately 850 square miles had over 1 inch of precipitation. Peak discharge at the gaging station on Queen Creek at Whitlow Ranch Damsite near Superior, Arizona (drainage area 144 square miles) was estimated at 42,900 cfs. No estimate of runoff is available for the study area (U. S. Army Corps of Engineers, 1976a).

The 1954 thunderstorm, which was centered over the Queen Creek drainage area to the southeast of Phoenix, "was determined to be the local storm with the most severe flood peak producing relationship between rainfall, depth, area, duration and isohyetal pattern that may reasonably be expected to occur over the central portion of Arizona" (U. S. Army Corps of Engineers, 1976a). This storm has often been used as the standard project flood for design and economic analysis for dams within the

Phoenix metropolitan area.

FLOOD OF AUGUST, 1963

The 17 August 1963 flood centered in the Glendale-Maryvale area. Approximately five inches of rain fell, producing heavy local flooding. As much as three to four feet of water stood in residential and commercial establishments during the peak flow and the community suffered three million dollars in damages.

> Glendale has a long history of flooding. The 1963 flood was apparently the most damaging flood of record, and caused ponding along the north side of the railroad tracks to a depth of 2 to 3 feet. Almost all businesses along a six mile reach were flooded. In Maryvale, water ponded along the Grand Canal resulting in flooding to a depth up to 3 feet in a concentrated residential area. Damages from this flood amounted to $2,900,000 in the Glendale-Maryvale area. This would be equivalent to approximately $4,900,000 in terms of today's dollars. There is not sufficient data available to determine the frequency of this flood (U. S. Army Corps of Engineers, 1975a).

FLOOD OF DECEMBER, 1965 - JANUARY, 1966

Several damaging floods have occurred along the Salt River. The 1965-66 flood was discussed by the U. S. Army Corps of Engineers (1975a):

> The 1965-66 flood with a peak discharge of 67,000 cubic feet per second at Granite Reef Dam caused damages to business and residential

properties, feed lots, sand and gravel operations, street crossings, bridges, agricultural properties, irrigation works and utilities. Fourteen of the 17 street crossings were washed out.

The Sky Harbor Airport, the main airport in Phoenix sustained considerable damages when 2,600 feet of the runway was inundated. Considerable damages occurred to a number of sewage oxidation ponds resulting in the discharging of raw sewage into the river; however, no real threat to human health occurred. The total damages along the Salt River from this flood amounted to about $5,800,000 measured in 1966 dollars, or $9,315,000 in 1975 dollars (U.S. Army Corps of Engineers, 1975a).

FLOOD OF DECEMBER, 1967

The flooding along New River and Skunk Creek in December 1967 primarily affected the residences and agricultural lands in the Glendale rea:

The December 1967 storm and flood set new December precipitation records at several Arizona stations, including 3.92 inches at Phoenix. The month's entire precipitation fell within the 10-day period from December 12 to 21, with the heaviest daily precipitation falling on December 19th. The New River-Skunk Creek system produced a peak of 19,800 cfs near Glendale. Damages to property are not known (U. S. Army Corps of Engineers, 1976a).

FLOOD OF SEPTEMBER, 1970

Tropical storm Norma located in the Pacific Ocean south of Baja, California triggered a movement of warm

moist air toward southern Arizona in early September, 1970. Numerous thunderstorms developed and resulted in heavy precipitation in the southern portion of the state. Orographic precipitation increased as a cold front from the northwestern states moved toward the Phoenix area. Flooding occurred throughout much of the metropolitan area with damages estimated near $600,000:

> Damage estimates were arrived at through actual records of individuals and agencies or by noting the nature of damages in the field and applying unit costs later. It is highly probable that the total estimate of approximately $600,000 is lower than that actually incurred as there is always a certain percentage of damage that goes unreported, as in the commercial damage that was unreported to the Small Business Administration.
>
> Damage in Phoenix was slight when compared with the havoc wrought in the rest of Maricopa County and the State as a whole. Maricopa County damage estimate was $5,803,342 with eight lives lost due to drowning. When you consider that the largest concentration of population, with the greatest potential for damage loss in the County, sustained only 10% of the total damage some credit should be given to the Phoenix Storm Drainage System.
>
> With the sketchy data available, it is difficult to assign a recurrence interval of this storm. The maximum intensity over a 3 hour period (the time of concentration for our largest sewers) was no more than a 5 year storm. In total rainfall it was more than a 100 year storm. There can be no doubt that it was a major storm in the Phoenix area, and both the above and below ground drainage systems functioned well (Attebery, 1971).

FLOOD OF JUNE, 1972

On the evening of 21 June and the morning of 22 June 1972, Phoenix received heavy rains. From 6:00 a.m. to 12:00 a.m. on 22 June torrential rains fell in northeast Phoenix. Rainfall intensities ranged as high as 5.25 inches in two hours to 3.85 inches in one hour and twenty minutes. Only a small area of land was directly affected by the intense part of the storm (U. S. Army Corps of Engineers, 1972a).

The area that received most of the rainfall lies in the Gila River Basin. It is partly mountainous, but predominately rolling desert plain with elevations ranging from 1000 feet at the Salt River to 3000 feet in the North Phoenix Mountains.

The tremendous volume of precipitation received from the 21-22 June storm induced relatively high discharges on the south slopes of the Phoenix Mountains and a record discharge on Indian Bend Wash (U. S. Army Corps of Engineers, 1972a).

Flood damage which consisted of physical damages; emergency costs resulting from evacuation, relief, flood fighting, and use of alternative facilities; and business losses due to delays, lost income, and increased costs of

operation, were extensive. Damages occurred mainly along: a fourteen-mile-long reach of Indian Bend Wash; sixteen miles of the Arizona Canal from Cave Creek to Indian Bend Wash; breaks in the Arizona Canal from Cave Creek to Indian Bend Wash; breaks in the Arizona Canal at 23rd Avenue, Central Avenue, 7th, 12th, 16th, 20th, 32nd, and 40th Streets; eight miles of the Grand Canal from 15th Avenue to 44th Street; and breaks in the Grand Canal at 12th Avenue, Central Avenue, 7th Street and Longview Avenue. The overflow from Indian Bend Wash, Arizona Canal, and Grand Canal affected several population centers: Phoenix along Indian Bend Wash, Arizona Canal and Grand Canal; Scottsdale and Tempe along Indian Bend Wash and Arizona Canal; and Paradise Valley along Indian Bend Wash. Flood damage to the Phoenix metropolitan area totaled $10,558,000. These and other cities were decreed disaster areas by the President (U.S. Army Corps of Engineers, 1972a).

The impact of inundation by flash flooding in a metropolitan area can have far-reaching and often tragic results. The following excerpts from a local newspaper typify the emergency situations reported in Phoenix:

> A man suffered a heart attack in the 56th Street and Shea Boulevard area--and police were unable to reach him.

> A tornado funnel danced across McDowell Mountains in the northeastern part of the Valley, then vanished.
>
> Flood waters near Phoenix Country Day School washed away a panel truck. The driver jumped out--just in time.
>
> An invalid woman was trapped in bed and police rescued her.
>
> Fire station at 1330 N. 32nd Avenue was flooded out.
>
> A car with people inside was seen washing away in the 3700 block of East Elm, fate undetermined.
>
> Water waist-deep gushed through various intersections on Seventh Street from Maricopa Freeway to the bridge over the Southern Pacific tracks.
>
> Mountain Bell switching offices in the Valley converted to emergency power.
>
> Water rose to four feet in depth at 40th Street and Camelback.
>
> Garbage was washed throughout entire neighborhoods and sanitation trucks were having difficulties in making pickups (The Phoenix Gazette, 1972).

The list is endless, but the point is made.

FLOODS OF 1973

Water releases in 1973 from the Salt River Project's dam system on the Salt and Verde Rivers resulted in flows in the Salt River for several months. Many viewed these releases as a flood:

> In 1973, with an extensive snowpack condition in the higher mountains, the Salt River experienced a continuous flow condition from 21 February through 29 May (except for 7 days), with a maximum flow at Granite Reef Dam of 22,000 cubic feet per second. This flow caused damages to sand and gravel

mining operations and several street crossings and resulted in the closing of several crossings. No estimate of monetary damages from this event is available (U. S. Army Corps of Engineers, 1975a).

APPENDIX C - INTERVIEW QUESTIONNAIRE OF PERCEPTION OF FLOODING IN THE PHOENIX METROPOLITAN AREA

INTERVIEW

Ruth Bajza is a graduate student in the department of geography at Arizona State University. She is currently working on a research project concerning residential development within the flood-prone regions of the Phoenix Metropolitan Area. The following anonymous questionnaire, randomly distributed, will provide the necessary information for the completion of her research. Your cooperation would be greatly appreciated. If you have any further inquiries as to the nature or purpose of this research, please call or write Ms. Bajza, Department of Geography, Arizona State University, Tempe, Arizona 85281.

Address: _____

How long have you lived in this house? _____

Who developed the land? _____

Do you have flood insurance? Yes No

If so, when did you purchase it? _____

Do you consider yourself to be in an area susceptible to floods? Yes No

Why or why not? _____

If yes, did you believe this before you purchased your house? Yes No

Who informed you of this? _____

BIOGRAPHICAL SKETCH

Esther Ruth Bajza was born in Kingsville, Texas on the twenty-sixth of July, 1951. She attended public school for elementary and secondary education in Kingsville and graduated from H. M. King High School in May, 1969. She attended Texas A & I University in Kingsville from 1969 to 1973 and graduated Summa Cum Laude in May, 1973 with a Bachelor of Arts Degree in geography and a minor in mathematics. In May, 1973 she also was awarded a teaching certificate for secondary education in the State of Texas. While at Texas A & I University she served as President, Cap and Gown Women's Scholastic Society; Vice-president, Alpha Chi National Honorary Scholastic Fraternity; Secretary, Gold Jackets Honorary Service and Scholastic Society; Secretary, Explorers and Travelers Club sponsored by the Department of Geography; and Texas A & I Distinguished Student. She enrolled in the graduate program in the Department of Geography, Arizona State University, in August, 1973 and received a graduate teaching assistantship for the 1973-74 academic year, and a graduate research assistantship for 1974-75. She also received a scholarship from the Department of Geography for the summer of 1974. In May, 1974 she began a part-time, temporary position with the U.S. Army Corps of Engineers in Phoenix. In June, 1975 she was hired as a permanent employee of the Corps of Engineers, Phoenix, Arizona, with the title of Geographer and has worked full-time since that date. She is a member of American Association of Geographers, American Association of University Professors, Arizona Parks and Recreation Association, and National Recreation and Parks Association.