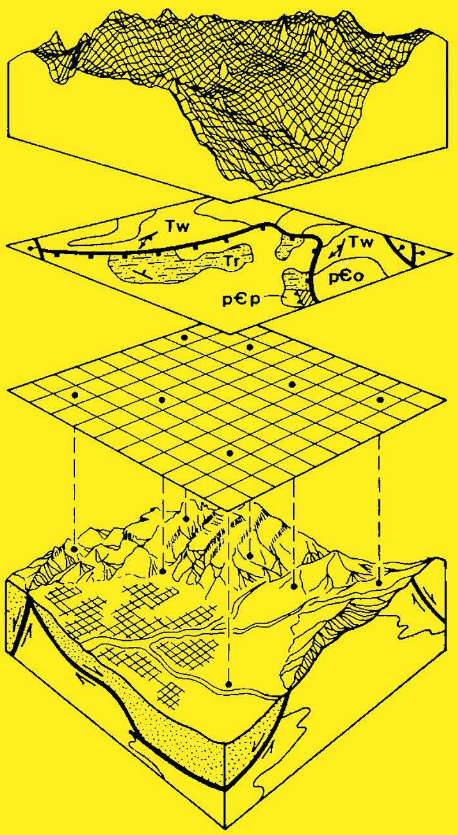
FRONTIERS IN GEOLOGY AND ORE DEPOSITS OF ARIZONA AND THE SOUTHWEST

Arizona Geological Society and the University of Arizona 1986 Symposium



FIELD TRIP GUIDEBOOK
12

Geologic Hazards of Tucson

March 22, 1986

Leader: E. McCullough (U. of A.),
M. Pearthree (Pima Co.) and G.
Rodzenko (U. of A.)

ARIZONA GEOLOGICAL SOCIETY
TUCSON, ARIZONA

Cover preparation by Beverly Morgan, modified from J. Mehulka and P. Mirocha, AGS Digest Volume XVI

ARIZONA GEOLOGICAL SOCIETY
P.O. BOX 40952, UNIVERSITY STATION
TUCSON, ARIZONA 85719

To: Field Trip Participants

Welcome to Arizona and the 1986 Arizona Geological Society Symposium "Frontiers in Geology and Ore Deposits of Arizona and the Southwest." As field trip chairman I would like to wish you an enjoyable and informative conference and a worthwhile field trip experience.

The field trip committee set out many months ago to provide field exposure to a broad spectrum of geological disciplines. The results include trips to recent precious-metal discoveries, areas of new and developing stratigraphic and structure concepts, industrial mineral resources, lithologic features significant to the petroleum potential in the Southwest, geologic hazards in the community, and an opportunity to attend trips from previous Arizona Geological Society meetings. We hope you find your chosen field trip as exciting as we intended.

At this time of very limited support from industry, it is especially important to acknowledge the personal efforts of so many. I include in those the planning and follow through of the field trip committee, the many hours of preparation by the trip leaders, and the commitment of the trip coordinators to a smooth-running trip. A special thanks goes to Maggie Morris of the University of Arizona Conference Department for the transportation, lodging, and meal arrangements.

Please enjoy the Southwest and remember this week of field trips and meetings as a step toward the frontiers of the future.

Best regards,

Parry D. Willard
Field Trip Chairman

Field Trip Committee

Annon Cook
Norm Lehman
Beverly Morgan
Jon Spencer
Erick Weiland
Joe Wilkins Jr.
Jan Wilt

ITINERARY

FIELD TRIP 12

GEOLOGIC HAZARDS OF TUCSON

Leaders: E. McCullough (U of A), M. Pearthree (Pima County), G. Rodzenko (U of A)

Saturday, March 22, 1986

7:00 am	Depart from University of Arizona, front of Student Union
7:30 am	Stop 1. Martinez Hill
8:45 am	Stop 2. Los Reales detention/retention basin
11:00 am	Stop 3. Energy dissipator on channelized west branch of Santa Cruz River
12:00 noon	Lunch* stop at energy dissipator
1:45 pm	Stop 4. Rillito River and Orange Grove Road
4:30 pm	Stop 5. South bank of Rillito River at First Avenue—River-front Village
6:00 pm	Return to University of Arizona

*Included in fees.

Drivers: G. Rodzenko
N. Colburn

FIELD TRIP 12

GEOLOGIC HAZARDS OF TUCSON

March 22, 1986

Leaders: E. McCullough (University of Arizona),
M. Pearthree (Pima County),
G. Rodzenko (University of Arizona)

GEOLOGIC HAZARDS IN TUCSON

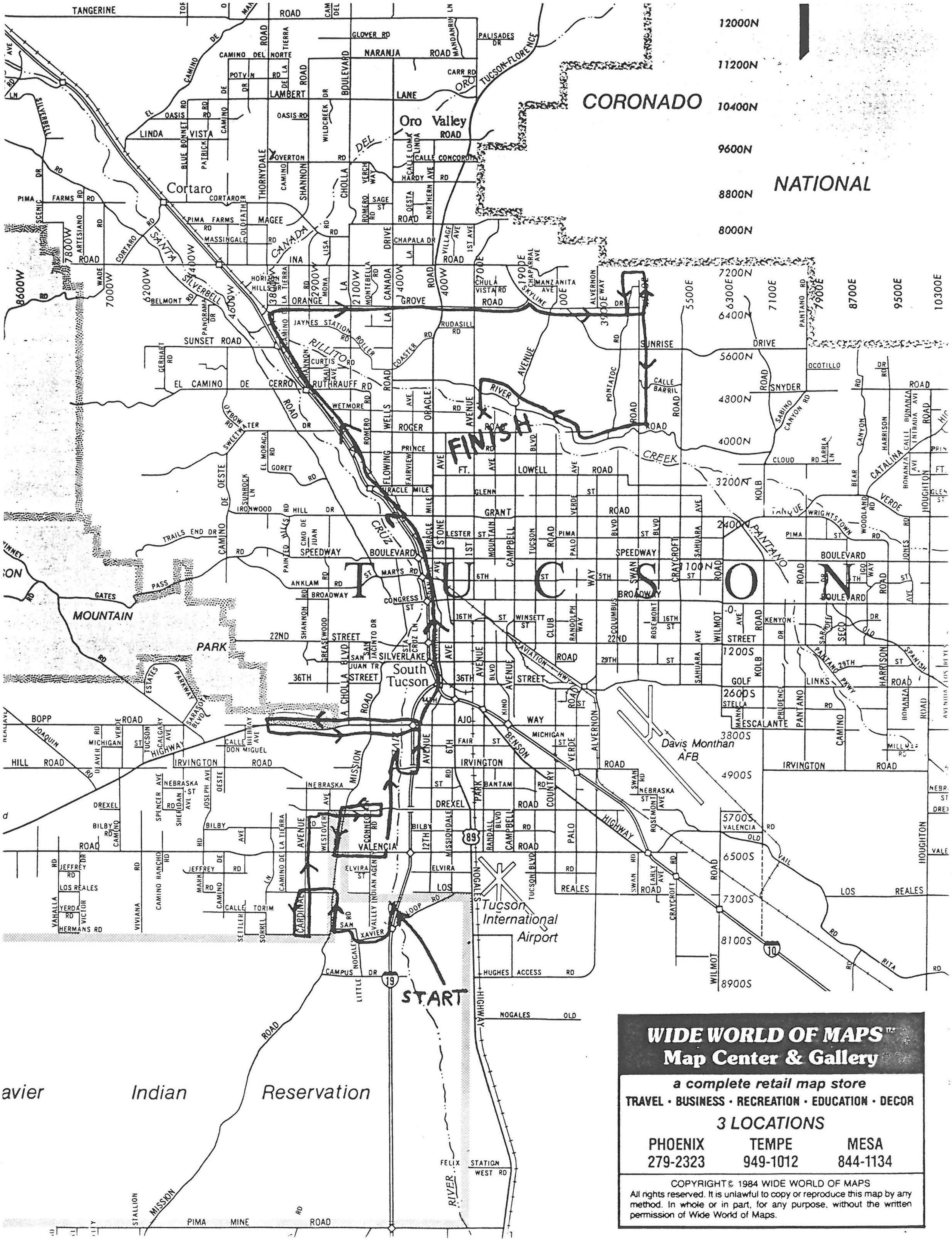
E. McCullough, G. Rodzenko[1], M. Pearthree[2]

Geologic hazards are geologic processes which, because of their proximity to human development, threaten that development. In the semiarid Tucson basin, the major geologic hazards are bank erosion and flooding along the rivers, ground water contamination from solid waste, septic tanks, and chemical waste, subsidence due to ground water withdrawal and shrink-swell soils, rockfalls, and the potential failure of earthen dams ("dams").

Erosion and flooding along the rivers is the most serious geologic hazard in Tucson. Frequent changes in the morphology and position of alluvial channels of ephemeral streams create planning difficulties for floodplain management in the semiarid southwest. Population pressure and the economic necessity for low cost housing are at odds with the mandate of government agencies to protect the public from flood hazards.

[1]Department of Geosciences, University of Arizona, Tucson, AZ 85721

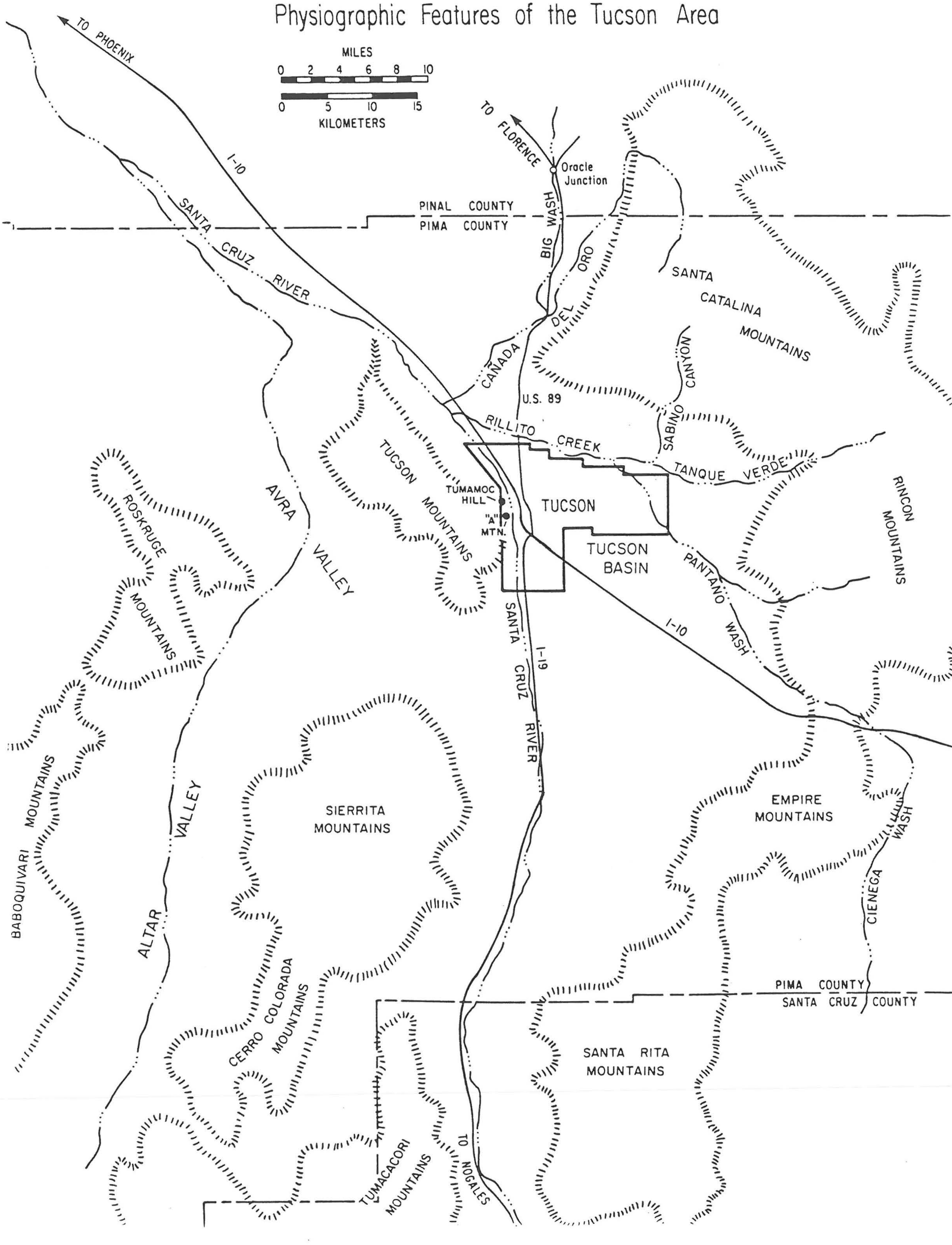
[2]Pima County Department of Transportation and Flood Control District, 1313 S. Mission Road, Tucson, AZ 85713

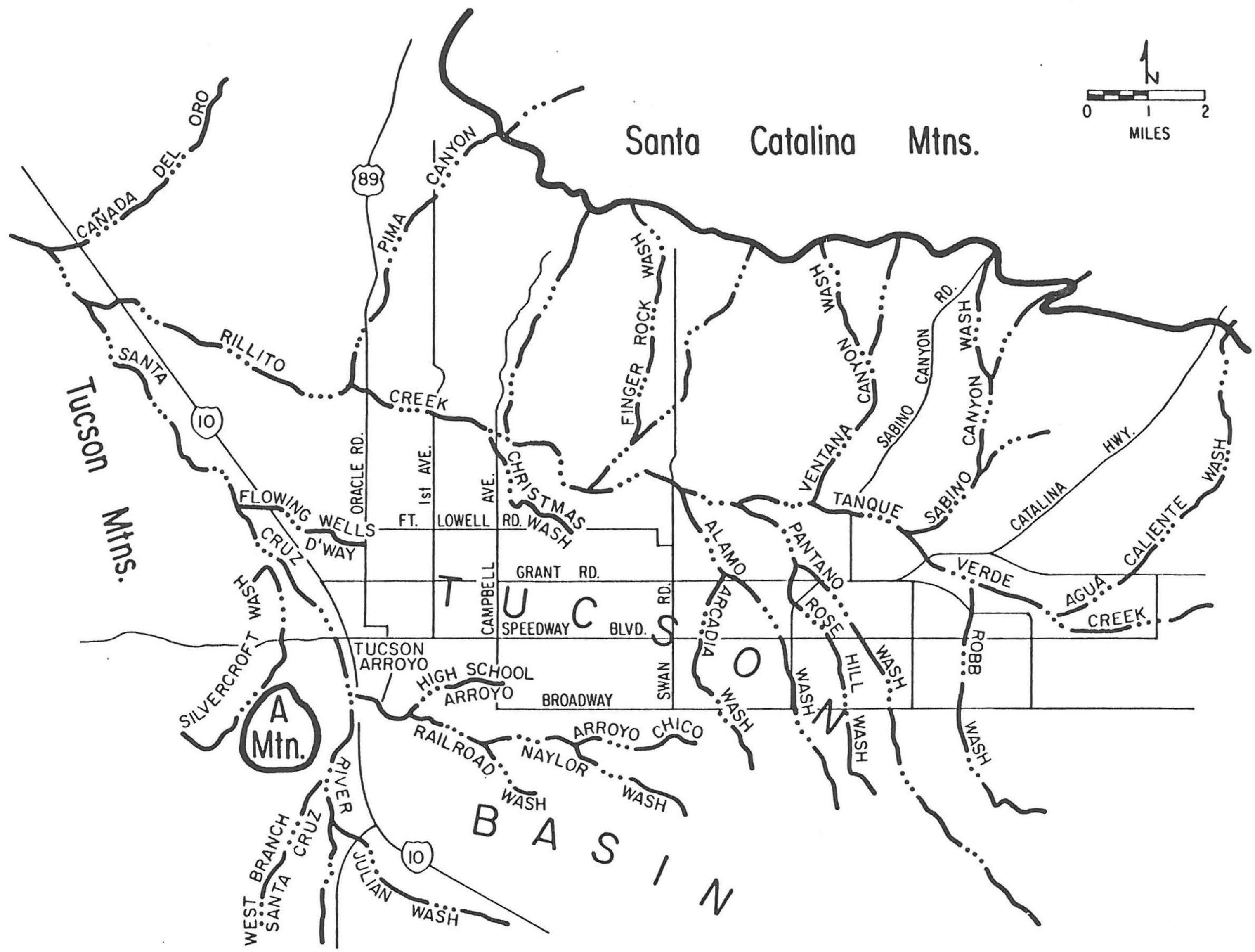


WIDE WORLD OF MAPS™
Map Center & Gallery
a complete retail map store
TRAVEL • BUSINESS • RECREATION • EDUCATION • DECOR
3 LOCATIONS
PHOENIX 279-2323
TEMPE 949-1012
MESA 844-1134

COPYRIGHT © 1984 WIDE WORLD OF MAPS
All rights reserved. It is unlawful to copy or reproduce this map by any method. In whole or in part, for any purpose, without the written permission of Wide World of Maps.

Physiographic Features of the Tucson Area





Major drainages of the Tucson Basin.

GEOLOGIC HAZARDS IN TUCSON

E. McCullough, G. Rodzenko,[1] and M. Pearthree[2]

Road Log

Mileage Cum.	Interval	
0.0	0.0	San Xavier Road/I-19 exit ramp. Turn right ("U-turn"), head north on unpaved frontage road.
0.3	0.3	STOP. Channel bank abuts road.
0.6	0.3	U-turn. Walk back to bridge. Right turn on San Xavier Road.

Erosion Hazards

Definition

Frequent changes in the morphology and position of alluvial channels of ephemeral streams create uncertainties for floodplain management in the semiarid Southwest. Rainfall and/or snowmelt generate flows of widely varying magnitude and duration in the local river systems. The channels are usually dry for long periods of time or convey occasional low flows. Infrequent high flows may either be fully contained within entrenched channel reaches or may exceed channel capacities and locally overflow onto adjacent floodplains. Because the stream systems are formed in unconsolidated sediments, cross sectional channel geometries and stream patterns frequently change.

Significance

Channel bank erosion and lateral channel migration have posed greater hazards than overbank flooding to the Tucson metropolitan area, at least since the 1960s. Encroachment of urban development onto the floodplains of local watercourses has resulted in widespread erosional damage to roads, commercial/industrial structures, and private residences.

The main stream systems of eastern Pima County are the Santa Cruz River and tributaries, the Rillito Creek system, comprised mainly of Rillito Creek, Pantano Wash, and Tanque Verde Creek, and the Canada Del Oro Wash. The present channel systems exhibit wide, sandy channels with near vertical banks.

[1]Department of Geosciences, University of Arizona, Tucson, AZ 85721

[2]Pima County Department of Transportation and Flood Control District, 1313 S. Mission Road, Tucson, AZ 85713

This form began to evolve in the late 1800's and early 1900's when arroyo-cutting, prevalent throughout the Southwest, initiated channel entrenchment (Cooke and Reeves, 1976). Meandering, sinuous, and braided channel patterns may be found within each system.

Examples

Channel bank erosion and lateral channel migration of alluvial ephemeral streams constitute very real hazards to the southwestern United States. In addition to the loss of millions of dollars in property damage, frequent changes in the position of such stream channels create uncertainties for floodplain management in this region. Federal floodplain management regulations form the basis for local floodplain management. These regulations address flooding on a national basis, but, do not consider southwestern semi-arid stream channel behavior such as bank erosion and lateral channel migration.

The first stop of this field trip illustrates the erosional problems associated with alluvial stream channels. Historical photos of the Santa Cruz River from 1941 to October 1983 at this location, illustrate typical changes in channel width, pattern, and position over time of this stream channel and numerous other alluvial channels of the Southwest. Interstate Highway 19 (I-19) is in danger of being washed away by the Santa Cruz River at this location. The Arizona Department of Transportation (ADOT) has responded to the problem by constructing several levels of bank protection over the period 1965-1972. The bank protection consists of posts and tetrahedrons within the present low flow channel, and wire rock with rails along the edge of the channel.

The U.S. Geological Survey has operated a continuous recording gauge at the Congress Street crossing of the Santa Cruz River from 1915 to 1981, and one at the Cortaro Road crossing further downstream since 1940. A summary of the annual peak flows measured at Congress Street are presented in a following diagram. The largest flows of recent years occured in October 1977 and October 1983 as a result of tropical storms from the Pacific Ocean. The flood of October 1983 caused widespread damage to public works, utilites and private property along the river. The majority of the damage was caused, not by overbank flooding, but by the process of local bank erosion, streambed scour, general channel widening, lateral channel migration, and formation of new channels by a process termed avulsion (Pima County Department of Transportation and Flood Control District, 1986). Total failure of the San Xavier Loop bridge and the northbound portion of the I-19 bridge occured in October 1983 at Martinez Hill as a result of channel bank scour and migration of the southern/western bank of the river to the southwest. The aerial photograph taken in October 1983 shows flow impinging on the northern bank of the river upstream of I-19 and then being deflected to the southern bank at the locations of the two bridges. Note the extensive width of the channel through this reach of the Santa Cruz River. Further downstream the channel narrows to 10 per cent of its upstream size.

As a result of the erosion of the October 1983 event, the bridges have been rebuilt and their abutments have been stabilized with soil cement. Soil cement stabilization , constructed at various locations along the Santa Cruz

River and its tributaries, proved to be a highly effective form of erosion control during the October 1983 event (Pima County Department of Transportation and Flood Control District, 1986).

Studies of historical channel change have been conducted along all three stream systems (Pearthree, 1982; Gordon, 1984; Hays, 1984; Betancourt and Turner, in press). Investigation of the Rillito Creek system (Pearthree, 1982), a stream system typical of the semiarid Southwest, revealed that channel change since 1941 has been characterized by prolonged periods of channel narrowing interrupted by abrupt episodes of locally severe channel bank erosion, general channel widening, and lateral channel migration. In December of 1965 and 1978, extreme channel bank erosion of as much as 680 feet (107m) and 190 feet (57m) respectively, occurred along Rillito Creek and Tanque Verde Creek from flow events estimated to have recurrence intervals ranging from 16 to 27 years (Aldridge, 1970). The largest increases in channel width were produced by erosion of concave banks of channel bends, which migrated in the downstream direction.

The greatest amounts of channel bank erosion and lateral channel migration seen to date along the Santa Cruz River, Rillito Creek system, and Canada Del Oro Wash occurred on October 1 and 2, 1983. This flow event was provisionally estimated to have a recurrence interval in excess of 100 years along the Santa Cruz River, 50 to 100 years along Rillito Creek, 10 to 50 years along Tanque Verde Creek, and 10 to 25 years along Pantano Wash (Hjalmar Hjalmarson, U.S. Geological Survey, verbal communication, 1985). It should be noted that recurrence interval estimates and associated magnitudes of flow are a matter of considerable debate within the scientific community.

Bank erosion was the most severe hazard produced along the more incised, unstabilized stream channel reaches, although some overbank flooding also occurred. Maximum widening of the Canada Del Oro Wash channel locally measured 330 feet (100.7m). Channel bank erosion along the Santa Cruz River and Rillito Creek followed existing meander patterns and alternated between stream banks along those reaches without bank protection (soil cement) (Baker, 1984). Lateral channel migration of the Santa Cruz River during this event ranged from 200 to 2400 feet (61m to 732m) (Pima County Department of Transportation and Flood District, in preparation). Severe bank erosion also occurred at the downstream end of protected channel banks. Unfortunately, intermittent reaches of bank protection concentrate erosion at the ends of the protection, along with maintaining the bank. Erosion was also noted at the upstream ends of protected channel reaches at several locations.

Many of the effects of the October, 1983 flood repeated the experiences of previous floods. In eastern Pima County, 28 bridges, nine flood control projects, and numerous residential, commercial, and industrial developments were damaged by channel bank erosion in 1983 (Pima County Department of Transportation and Flood Control District, 1985). Power lines were damaged when their support pads were undermined by channel bank erosion or streambed scour, and major utilities were washed out (Saarinen et al, 1984). Erosional damage also occurred at several active and abandoned sanitary landfill sites and at wastewater treatment facilities. The total cost of flood repair and selected flood protection works has been estimated at 105.8 million dollars by the Pima County Department of Transportation and Flood Control District (1985).

Additional Features of Interst, Stop 1:

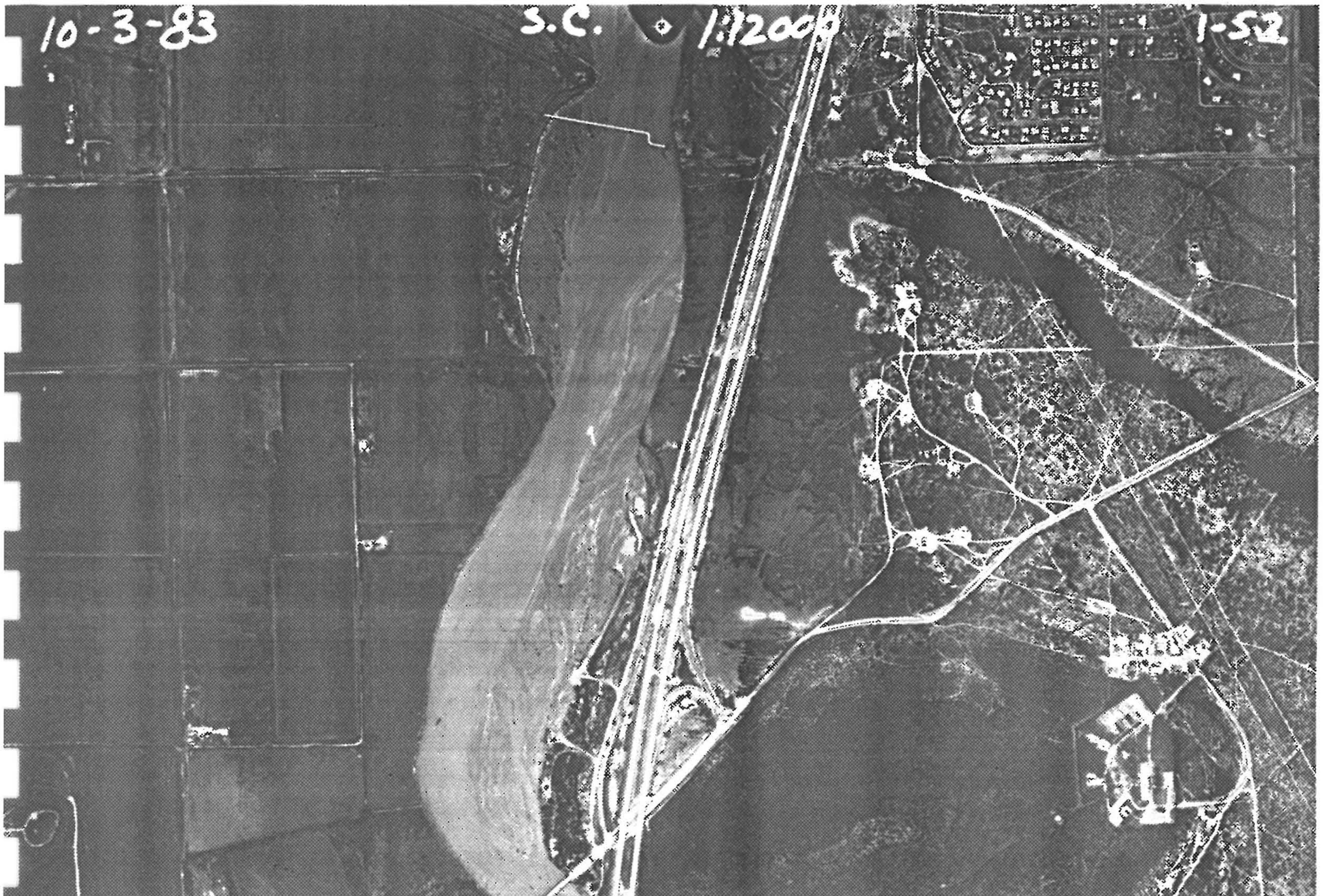
1. El Paso Natural Gas Company pipeline crossing the Santa Cruz River downstream of Martinez Hill: high pressure transmission line consisting of two (2) pipes 26 inches and 30 inches in diameter. This line transports natural gas from Texas and Oklahoma to southern California for sale to the gas industry, and has been in existence in various forms since the 1940s. At one time the transmission line was buried beneath the river bed. It has since been relocated several times above ground on piers as the river channel has changed its course. Additional support for the current transmission line is provided by a set of support piers buried in the channel bank between I-19 and the river, in the event that the channel migrates toward I-19. The current channel geometry and alignment is monitored by a grid network located between I-19 and the river.

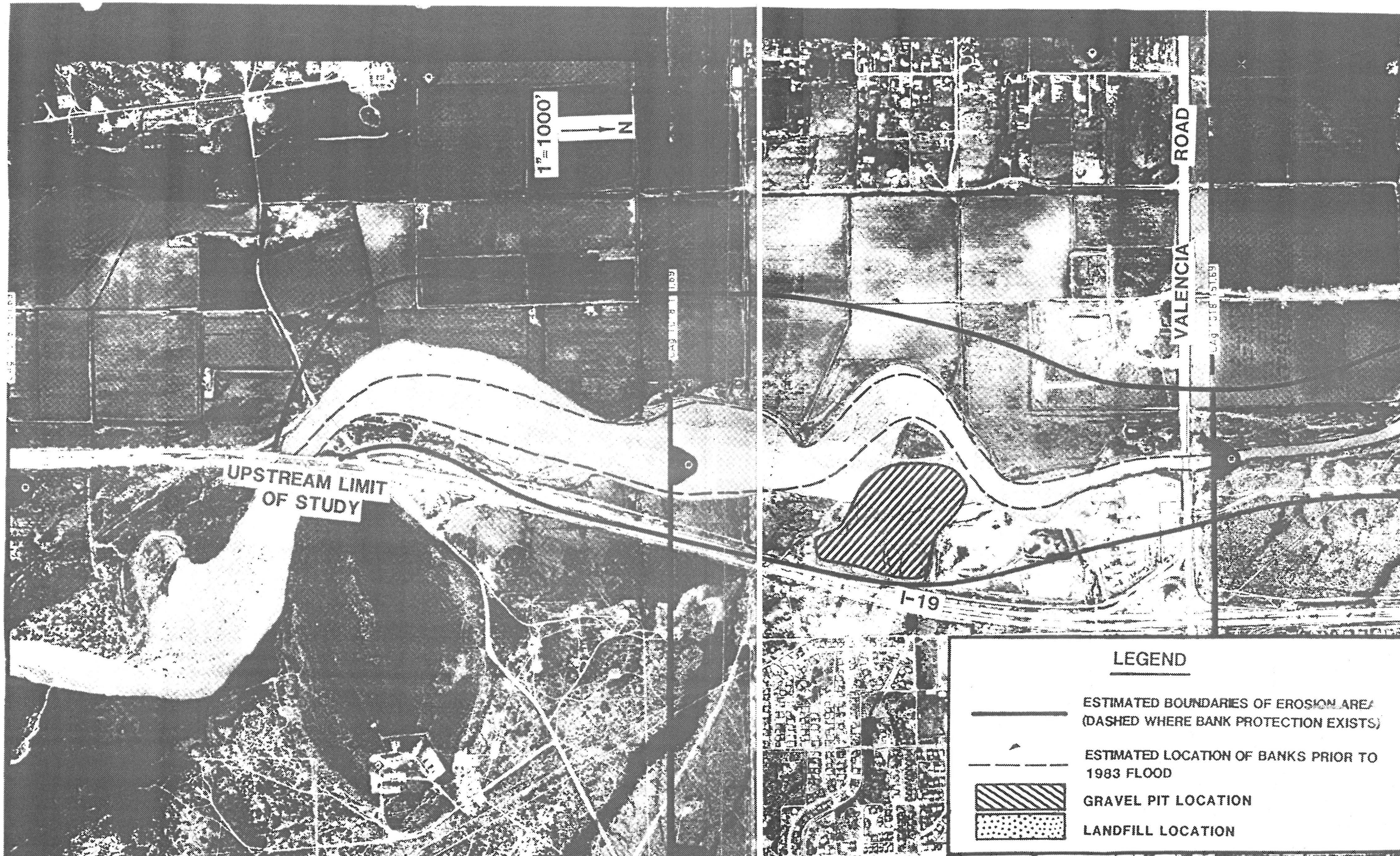
2. Sand and Gravel Operations

Two sand and gravel operations currently exist north of Martinez Hill adjacent to the Santa Cruz River and within its channel. The primary extraction of sand and gravel in this area is through open pit mining conducted by San Xavier Rock and Materials. This company has several pits located on the eastern and western floodplains of the river. A smaller operation is also in existence to the south within the limits of the San Xavier Indian Reservation.

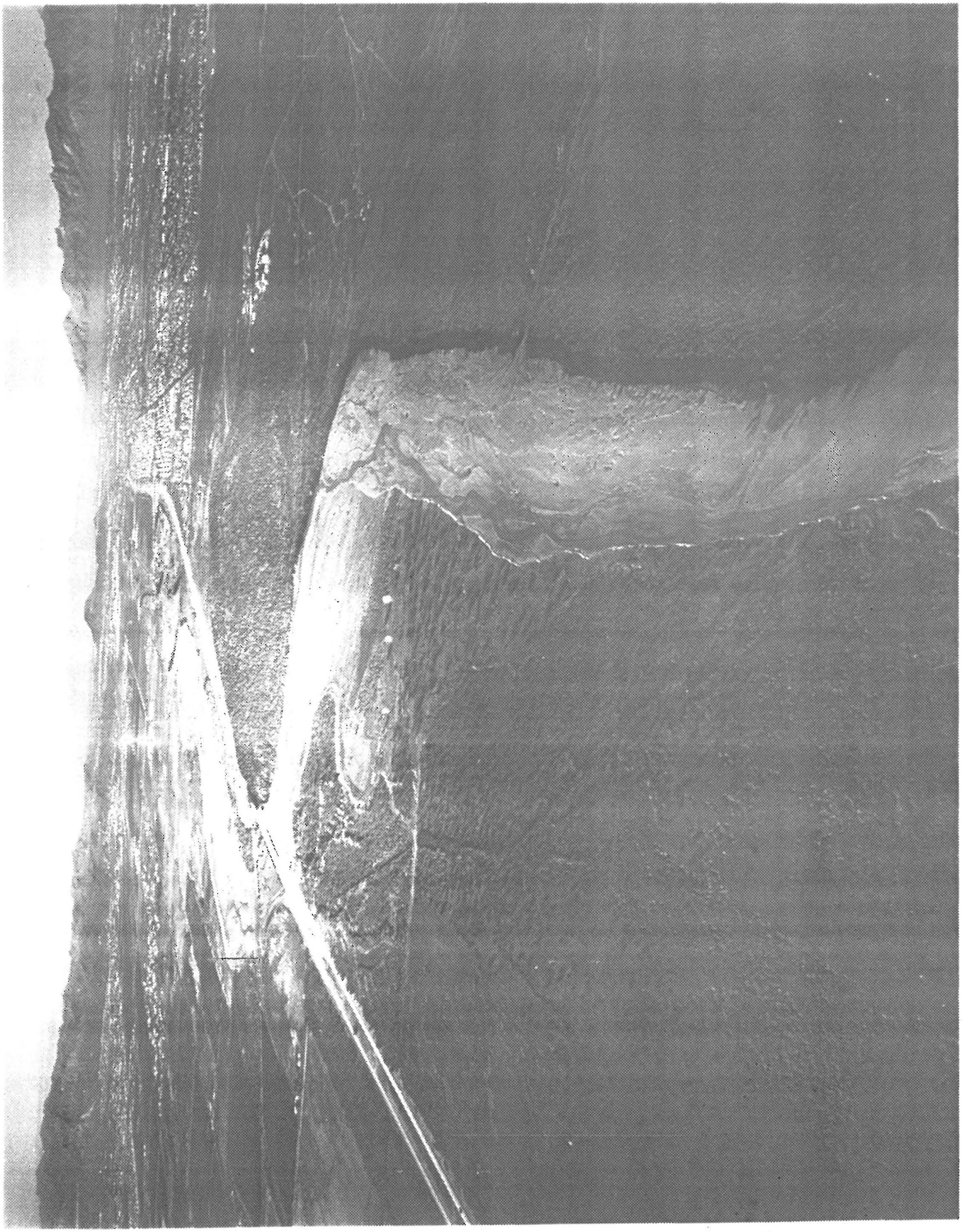
The policy of local governmental agencies has been to restrict sand and gravel mining within flood hazard areas in more recent years. In-stream mining is currently discouraged, and floodplain mining is typically required to be set back a minimum distance of 500 feet from the banks of a major stream channel such as the Santa Cruz River. Excessive sand and gravel mining from the a river channel can endanger the stability of the river system, bridges and other flood control structures by inducing general streambed degradation and headcutting (Pima County Department of Transportation and Flood Control District, 1986). These processes also occur in floodplain areas where sand and gravel pits are located, but are generally limited to overbank flooding conditions.

Erosion of floodplain pits can encroach on adjacent properties or endanger nearby structures. An additional concern is the potential for erosion and failure of a dike or buffer zone that separates a pit from an active stream channel when flood waters spill into the pit. Local channel morphology and sediment transport rates can be altered by such an occurence and adversely impact reaches of the stream channel both upstream and downstream of the pit.


10-3-83
S.C.
1:12000
1-52



1"=1000'
N
UPSTREAM LIMIT OF STUDY
VALENCIA ROAD
I-19
LEGEND
ESTIMATED BOUNDARIES OF EROSION AREA (DASHED WHERE BANK PROTECTION EXISTS)
ESTIMATED LOCATION OF BANKS PRIOR TO 1983 FLOOD
GRAVEL PIT LOCATION
LANDFILL LOCATION



1.4 0.8 Cross bridge over Santa Cruz River. Continue through Indian cotton fields. Right turn at "T".

1.7 0.3 Road deadends into Mission. Turn left.

San Xavier Mission Del Bac

"We know that this mission, the third to serve the Piman village of Bac, was begun no earlier than 1776 and completed in 1797. We know that its sophisticated form and dazzlingly ornate baroque ornamentation was not executed mostly by Indians learning European art and architecture on the job; census documents counted 29 Spaniards at Bac in 1795, evidence that the Franciscans imported experienced artisans to build it.

We know why it was such an ambitious building. Capt. Jose de Zuniga, comander of the Tucson presidio, wrote this in 1804: "The reason for this ornate church at this last outpost of the frontier is not only to congregate the Pimas of the San Xavier village, but also to attract by its loveliness the unconverted Papagos and Gila Pimas beyond the frontier."

And we think that it did not have the intended effect on the natives. "The Indian concept of the House of God is nature, with all its vast spaces," says McCarty, "so I think they may not have seen this as a religious building in their own terms."

Nevertheless, they came to value it as a special place. In 1831, 10 years after Mexico won independence from Spain, the last of San Xavier's Spanish priests was recalled, and it was left in Indian hands. Its religious function evaporated.

It became an active church again in 1859 when put under the wing of the Diocese of Santa Fe, and through the next 100 years gradually became a more and more conventional Roman Catholic parish - although some Indian religious customs, such as the curing ceremony, coexisted with the same people's Christian faith" (Cheek, 1986).

2.0 0.3 Indian cemetary on right.

2.4 0.4 Mission Rd. Turn right.

3.2 0.8 Los Reales Rd. Turn left.

3.9 0.7 Cardinal Ave. Turn left.

4.5 0.6 STOP. Mission Hills Detention-Retention facility on right. Walk up wash to basin.

Flood Hazards

Definition

Flood hazards occur in three distinct settings within Pima County: 1) overbank inundation along sizable watercourses, created by rising water levels when flows exceed channel capacities; 2) shallow sheet flooding, which occurs in areas dominated by poorly defined braided channel systems; and 3) flooding within streets designed to carry local runoff and within roadway dip section crossings of watercourses.

Examples

Overbank inundation presents a very real hazard in this semiarid desert environment. For example, from September 28 to October 3, 1983, southern Arizona received approximately 6.71 inches (170 mm) of precipitation (Saarinen, et al., 1984), which resulted in extensive flooding along the Santa Cruz River, Tanque Verde Creek, and Rillito Creek. Minor flooding also occurred along Pantano Wash. To the south of Tucson, overbank flooding of the Santa Cruz River caused major damage to the Green Valley wastewater treatment plant. To the north, the Santa Cruz River changes from a deeply incised and narrow channel that exists through the City of Tucson to a channel of limited flow capacity that measures as much as 1300 feet (400 m) in width and only 3 to 10 feet (1 to 3 m) in depth. Flood damage in October, 1983 and during previous flood events in 1977 and 1979, was most severe to agricultural and business areas north of Tucson. In Marana and Rillito massive flooding of residences and business occurred to depths of 2 to 4 feet (0.6 to 1.2 m) (Pima County Department of Transportation and Flood Control District, 1985). This portion of Pima County was a major area of evacuation in 1983. Seventy-four residences were severely damaged from mud and flood waters in excess of four feet (1.2 m) within La Puerta Del Norte mobile home park, located adjacent to Silverbell Road on the west of the Santa Cruz River.

Tanque Verde Creek, which consists of a shallow stream system in its upper reaches, also overflowed during the October, 1983 event, primarily through residential areas. Numerous utility lines were also exposed. Overbank flooding also occurred along Rillito Creek in the Country Club Road-Prince Road area, cutting off access to single residences and apartment complexes. Along Pantano Wash, overbank flooding in the vicinity of Escalante Road resulted in the loss of numerous mobile homes. Emergency evacuation measures were in effect throughout much of Pima County during this flood event, primarily due to loss of access to outlying areas resulting from flooding.

A different situation exists along shallow, braided channel systems within such basins as Avra Valley, west of the Tucson basin, and in alluvial fan areas of Pima County. Drainage in such areas is dominated by very shallow interfingering channel systems. They are characterized by limited flow capacity; dense riparian vegetation, and potential for breakover of runoff from one channel system to another created by minimal differential topographic relief between adjacent watersheds. The hazard is further intensified by the tendency of such alluvial channels to abruptly switch course. As the Tucson metropolitan area expands outward from the center of the Tucson basin, areas subject to shallow sheet flooding, where depths of flow generally range from one to three feet (0.3 to 0.9 m), are being increasingly targeted for urban development. Design of subdivision drainage and all-weather access transportation routes in these areas presents a very real challenge to developers, engineers, and local regulatory agencies.

Damage to property within the Tucson metropolitan area has also resulted from runoff within subdivision streets. Historically, subdivisions in this area have been designed to drain into internal street systems, and eventually into local watercourses. Only in recent years have storm drains become more prevalent, primarily in newer subdivisions. Even now, however, storm drains are generally designed to convey only the 10-year and lesser flood events, with runoff up to the 100-year event designed to be contained within the curbs of the streets. As a result, numerous streets carry significant amounts of runoff, which often overtops curbs, limits access to and causes flood damage to property, and presents a severe traffic safety hazard. Regulations have recently been developed through the current Pima County Floodplain Management Ordinance (1985-FC1) and local channel and drainage design standards limiting the use of streets for conveyance of drainage.

A frequent drainage crossing design also employed in Pima County and numerous other areas throughout the Southwest is the roadway dip crossing of a watercourse. Since channels are dry for long periods of time, roadway dip crossings represent inexpensive and relatively safe channel crossings for much of the year. When the channels contain flow, however, roadway dip crossings present a severe flood hazard. Residents frequently attempt to drive through such crossings despite the presence of signs and barricades warning of significant depths and velocities of flow, often resulting in loss of life.

Mission West Detention Basin

This area offers a good example of drainage problems encountered upon development of floodprone lands and some of the floodplain management alternatives employed to resolve these drainage problems. The area is located south of Los Reales Road adjacent to Cardinal Avenue and drains to the West Branch of the Santa Cruz River. Less than 40 years ago, there was virtually no development within the watershed upstream or immediately downstream of this area. Less than 15 homes existed at that time within the 16.5 square mile drainage basin. The remainder of the watershed consisted of scattered desert brush vegetation, underlain by highly erodible soil groups. The topography of the watershed was composed of predominantly mild slopes, which graded to steep slopes in the headward reaches at the base of Black Mountain. Because of these basin characteristics, the drainage system is poorly defined. It consists of numerous shallow, braided channels typical of an area susceptible to sheet flooding.

Examination of the 1949 aerial photograph reveals the numerous washes that drain towards the Los Reales/Cardinal area. This photograph also provides a glimpse of the lateral migration potential of each of these washes. During any given storm, these washes could easily cut new channels or form new locations along their channels where runoff could breakout and continue downstream as sheetflow.

During the 1950s and 1960s very little additional development occured within the watershed. Only the area one (1) mile west of Cardinal Avenue within the upper watershed was developed, containing about 75 residential dwellings prior to 1970.

Development of the San Xavier Mobile Home Park began in 1970: the site was platted, the roads bladed, utilities were provided, and mobile homes were brought in and hooked up. Shortly afterwards, the first residents began to experience flooding. To mitigate the drainage problems, the developer had an earthen channel excavated and the surplus material piled around the perimeter of the park, forming a channel/levee system. It should be noted that the action used to resolve the mobile home park's drainage problem was common practice at the time. Pima County did not have a floodplain management ordinance prior to 1970. Unfortunately, little thought was given to the impact of the channel/levee system on surrounding properties. This levee, constructed to floodproof the San Xavier Mobile Home Park, created a pounding effect on the properties immediately west and south of the mobile home park, along with displacing the floodplain several hundred feet to the north. In addition, the channel/levee system concentrated former sheetflow, which used to spread over the entire area at shallow depths and low velocities.

Shortly after the construction of San Xavier Mobile Home Park, development began immediately east (downstream) of the Park. As development occurred downstream of the Park where the channel/levee system discharged runoff, the drainage problems increased. By the time Pima County adopted a floodplain management ordinance in 1974 and began its enforcement, this area was well known for its drainage problems. No further development occurred within this area between 1974 and 1978. Meanwhile, periodic flooding of the existing dwellings continued.

In 1977, the owners of a 320 acre parcel located north of the San Xavier Mobile Home Park, identified as Mission West, requested a change in the zoning classification of the property in order to construct a moderate density residential development. Arguments against the proposed rezoning mainly held that downstream flooding to existing dwellings would be compounded. The petitioner, however, claimed that:

1. the downstream dwellings were already located in a floodplain and that the Mission West project should not be financially constrained for prior mistakes committed by others.

2. the owner of the Mission West site was already burdened by having to accept a larger floodplain on his property than existed naturally, because of the ill-planned channel/levee diversion system constructed around the San Xavier Mobile Home Park.

3. a large portion of the land within the Mission West subdivision was not located within a floodplain.

After much discussion, the Pima County Board of Supervisors decided to approve the rezoning of the Mission West site provided that a runoff detention facility be constructed on the property. The purpose of this detention facility was to regulate the additional runoff created by development of the Mission West site. In 1980-81, the detention facility was designed and approved by the Pima County Department of Transportation and Flood Control District.

The detention basin covers a 9 acre area and has a storage volume of approximately 41.3 acre feet at a maximum depth of seven feet. It was designed to regulate the 100-year flow event generated by the Mission West subdivision by limiting the discharge at its outlet (a 5-cell 3' x 8' concrete box culvert) to 960 cubic feet per second (cfs). Runoff from this detention basin and from the San Xavier Mobile Home Park channel/levee system then flows into a 16 foot alley that extends easterly from Cardinal Avenue adjacent to another mobile home subdivision, and eventually into the West Branch of the Santa Cruz River. Property owners located downstream of this detention basin believed that it would resolve their drainage problems. Not long after the detention facility was completed several flaws in the design became evident. First, the design of the detention facility only considered the 100-year storm event and resulting runoff. Smaller flows whose frequencies were increased because of the greater amount of imprevious cover (roofs and pavement) within the urbanized watershed, flowed through the detention basin with only minor attentuation. The previous 25 year event now occurs at about a 10-year frequency. The second design flaw was that only the Mission West subdivision drained to the detention facility. The remaining 15.9 square mile drainage basin which affects the area remained uncontrolled.

In 1983, the Arizona Department of Water Resources investigated this area and concluded that to protect the dwellings located within primary floodways east of Cardinal Avenue, levees could be constructed to confine the floodwaters. Because of the expense of purchasing the necessary land and construction costs, and because potential ponding on the western side of the levee would flood other dwellings, Pima County decided that relocation of the residents located within the primary flow path of this watershed was the best option. In late 1983, Pima County began purchasing land east of Cardinal Avenue and relocating the residents. A grading plan for the area east of Cardinal was also prepared that would best convey runoff towards the West Branch of the Santa Cruz River. After the grading was completed, the area was seeded with desert type grasses. It is now designated for recreation and open space purposes.

At present, the Floodplain Management Ordinance has been strengthened to render development within flood-prone land more restrictive. Detention of various frequency storms (2-, 10-, and 100-year) is now required in the design of detention facilities. The Pima County Flood Control District still receives drainage complaints from this area but they are few and primarily from residents who were not relocated.

DETENTION/RETENTION SYSTEMS

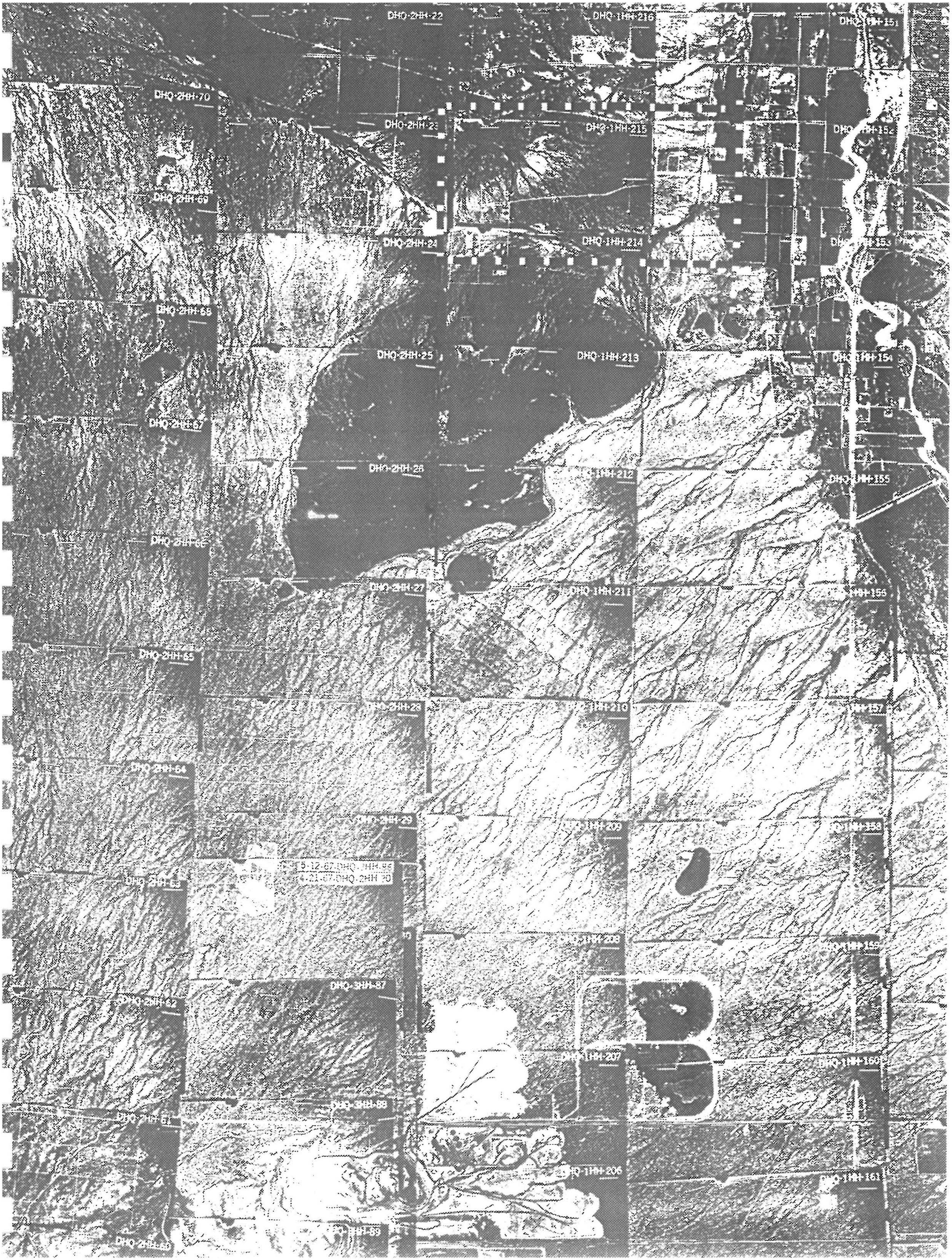
When deemed necessary by the County Engineer, in a balanced or critical basin, flood detention/retention systems shall be employed in lieu of or in combination with structural flood control measures to reduce flooding potential or restrict it to a level no greater than pre-platting and/or pre-development conditions or in accordance with Article XIII of this Ordinance.

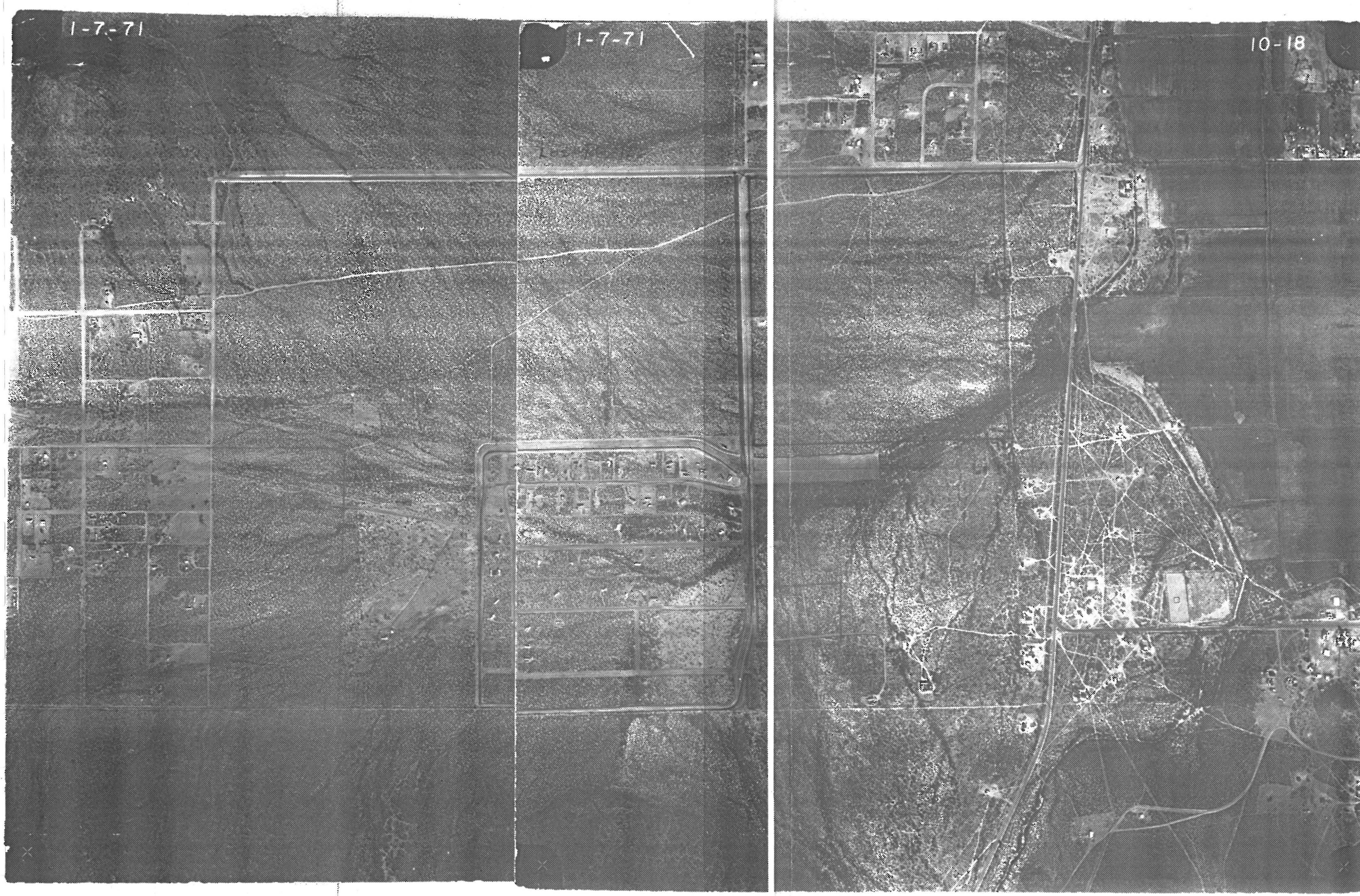
1. Balanced Basin

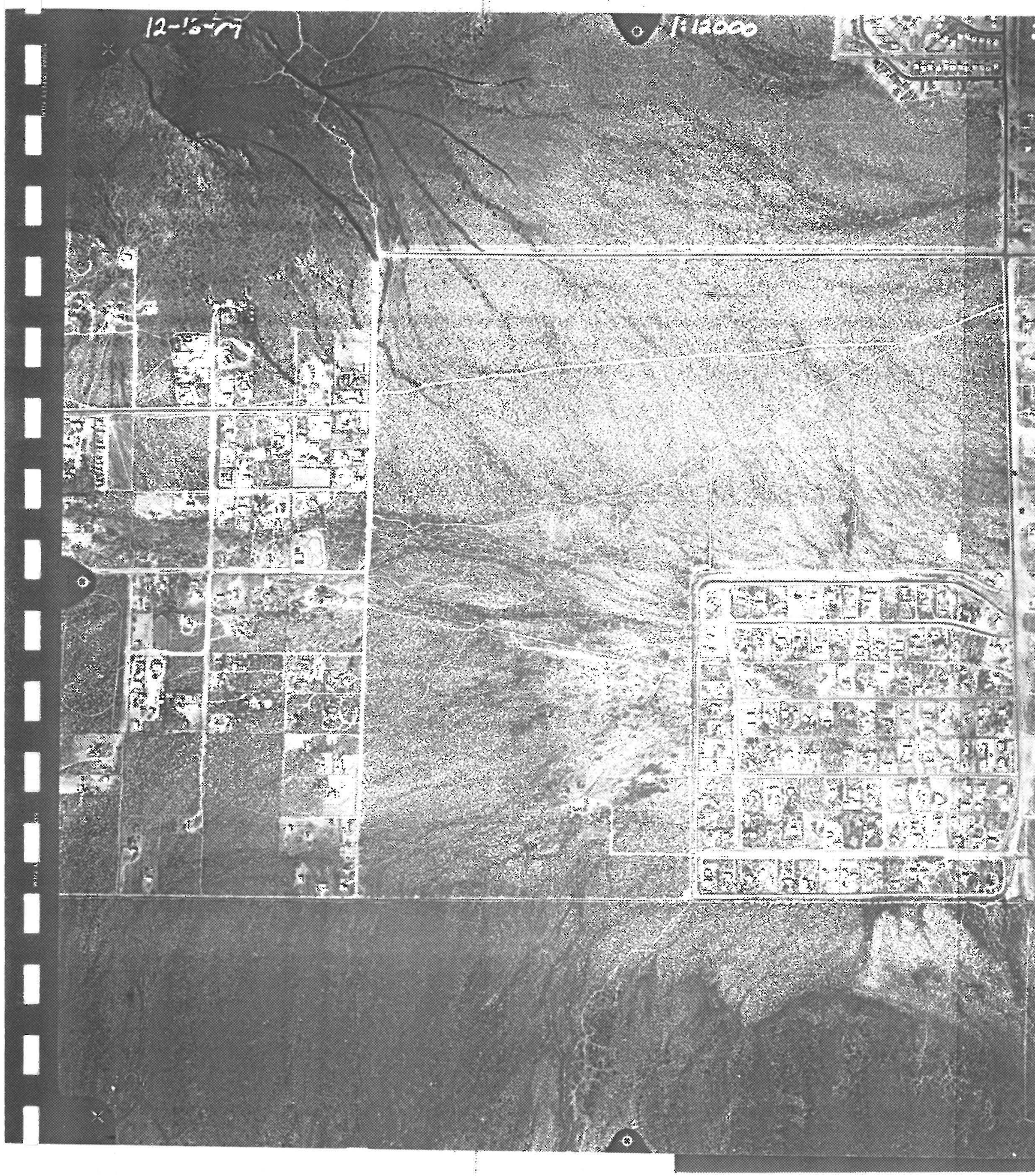
   If a drainage basin is determined to be a balanced basin, detention and/or retention systems shall be values no greater than pre-developed conditions. A balanced basin is one which the County Engineer has identified as having the potential for a severe increase in flood hazards as a result of increased development within the basin.

2. Critical Basin

   If a drainage basin is determined to be a critical basin, detention and/or retention systems shall be employed. The purpose of such systems in a critical basin shall be to reduce the potential flood hazard, at a minimum, from the 2- 10- and 100-year peak discharges through the detention and/or retention of storm runoff in fair and equi= tably apportioned increments. A critical basin is one which the County Engineer has identified as already containing severe flood problems related to existing runoff potential.


DHQ-2HH-22
DHQ-1HH-216
DHQ-2HH-70
DHQ-1HH-215
DHQ-2HH-24
DHQ-1HH-214
DHQ-2HH-68
DHQ-2HH-25
DHQ-1HH-213
DHQ-2HH-26
DHQ-2HH-27
DHQ-1HH-211
DHQ-2HH-65
DHQ-2HH-64
DHQ-1HH-207
DHQ-1HH-160
DHQ-1HH-206
DHQ-1HH-161


1-7-71
1-7-71
10-18


12-15-79
1:12000
20-27


1:12000
21-27

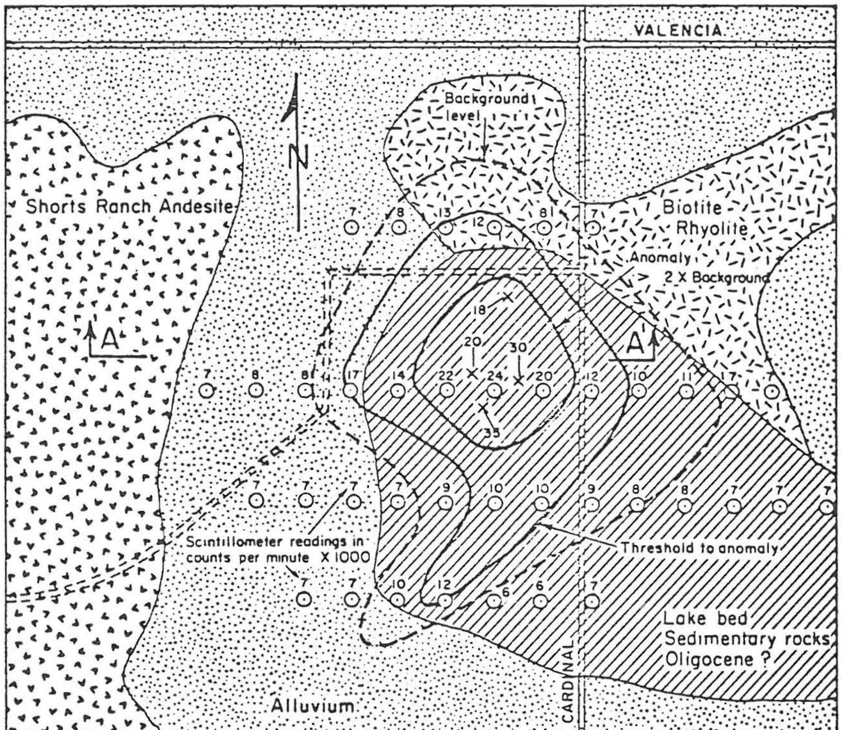
Del Bac Hills

The Del Bac Hills form a physiographic unit approximately 7 miles long and are part of a regional northeast structural trend. The definition of this trend is based on the interpretation of water table contour maps and on the structurally high occurrence of sediments of probable Pantano age in deep wells south of Tucson along the belt formed by the Del Bac Hills, Twin Hills, and Reddington Pass between the Santa Catalina and Rincon Mountains. Turkey Track porphyry is exposed both in the Del Bac and Twin Hills. Gravity and magnetic surveys have revealed that this trend marks a probable basement scarp extending from Avra Valley to Twin Hills. North of this trend alluvial deposits are approximately 3,000 feet thick and south of it the same deposits exceed 5,000 feet in thickness. Basin sediments encountered in wells of the central basin south of the trend are much finer than similar sediments north of the trend.

Volcanism in the Del Bac Hills area commenced approximately 27 million years ago as dikes of Turkey Track porphyry broke through the San Xavier conglomerate and spread both as relatively fluid and viscous flows. These flows were soon capped by a sequence of basaltic andesite flows in the area near the present channel of the Santa Cruz River. The Turkey Track porphyry in the west was topographically high and became deeply eroded. A thin conglomerate was deposited on top of the western portion of the porphyry, while a much greater thickness of the same deposit accumulated above the basaltic andesites in the east. Additional volcanism took place in the east during deposition of the conglomerate, culminating in a thick flow of sanidine-quartz-plagioclase basaltic andesite deposited in a stream channel of the conglomerate. This distincitive flow also extended to the extreme northern end of Black Mountain. No record of further volcanism remains in the eastern part of the area. Black Mountain volcanism ensued with the extrusion of cindery material soon after extrusion of the porphyritic basaltic andesite, incorporating fragments of it at the contact at the northeast end of Black Mountain. The composite thickness of basaltic andesites and intercalated sediments in the Del Bac Hills probably exceeds 1,000 feet (Percious, 1968).

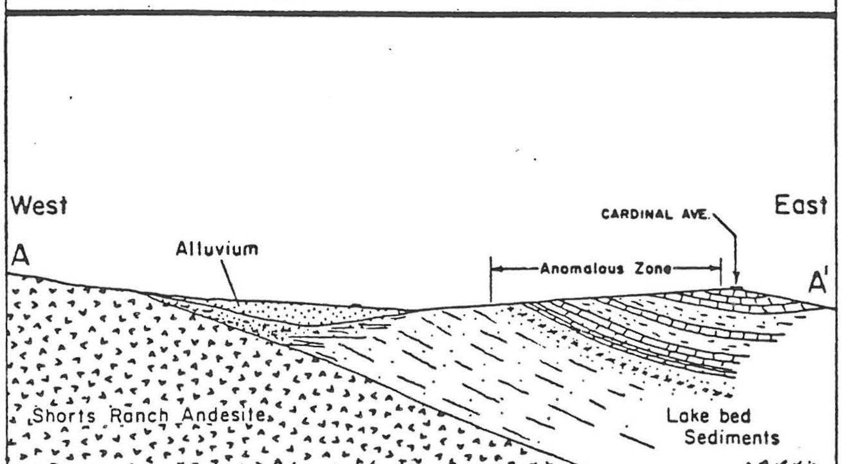
5.3 0.8 U-turn. Head North on Cardinal Ave. Cross Valencia Rd.

5.7 0.4 Crest in road - San Xavier Vista Estates. Anomalously high radiation concentration.



SURFACE GEOLOGIC MAP SKETCH; NOT TO SCALE.

⊙ GRID SAMPLE SITE   × SELECTED SPOT CHECK SITE



GEOLOGIC CROSS SECTION SKETCH; NOT TO SCALE.

Radiation

Definition

The presence of low level radiation or background radiation is a natural phenomenon produced by a variety of sources. A moderate dose of radiation to an individual may have carcenogenic or leukemomenic effects that may be delayed by a period of years or decades.

People's exposure to radiation emitted from the earth's surface comes from the naturally occurring radionuclides potassium 40, uranium 238, and thorium 232. The background radiation produced by radionuclides within the surface sediments (along with cosmic radiation) generates a lower limit of continuous exposure to rdiation that is "tolerated" by people. There is, however, a much higher level of exposure that is definitely known to be harmful to humans. Between the two extremes, there is a level of exposure considered to be safe for humans. It is important to determine the effect of natural, background radiation on humans because, presumably, this is the level of radiation exposure to which humans have established a biological tolerance.

The adsorption of radiation causes various types of changes. Cells may be killed when subjected to a high enough dose or by long exposure to low level radiation. The lethal dose varies enormously among cells, depending on organ, miotic activity, physiological state, and environmental factors, as well as dose rate, number of exposures, and interval between exposures.

Unfortunately, the "experts" disagree as to what constitutes a dangerous level of exposure. The state of Arizona sets a maximum level of 0.5 rem/year in an unrestricted area. The National Academy of Sciences sets a maximum exposure level of 0.17 rem/year. The Federal code governing occupational workers sets maximum exposures for various body parts.

Significance

The importance of identifying a source of potentially hazardous radiation is that radiation may affect the genetic code. The genetic alterations vary, but are on the whole, harmful (of those that are detectable). Damage may appear in the following generation but alteration of a recessive trait may not appear for many generations.

A moderate dose of radiation to an individual may have carcenogenic effects which may take many years to manifest themselves. Minimum and maximum values of tolerable radiation were developed to protect people. Background radiation is frequently used as a standard for comparison in considering human exposure to various man made sources of radiation. Unfortunately, very little is known about the long term effects of low level radiation on the human body, so this type of approach may be worthless. The total natural background radiation from all sources results in an average annual dose equivalent of 125 mrem/year (in the U.S.).

Several organizations on the local and national level are responsible for setting radiation standards: the National Council on Radiation Protection and Measures (NCRP), the Environmental Protection Agency (EPA), the Federal

Radiation Council (FRC), and the Arizona Atomic Energy Commission.

Examples

There is a radiation hot spot in Tucson. Oligocene (?) limestone beds are in unconformable contact with a 61 m. y. old biotite (biotitic) rhyolite volcanic flow. To the east of Cardinal Avenue, exist two synclinal features in the limestone beds: one plunging to the Southeast while the one nearer to the road plunges to the Northwest. The hot spot appears to be on or near the axis of the latter syncline but this cannot be verified in the field because of the housing development. The greatest gamma radiation values in the area were measured at 0.2238 rem/year by the EPA.

The uranium concentration in the limestone was calculated at 6.8 ppm which is well within the range for typical abundances. Does the radiation pose a hazard to people in the immediate area? The hot spot would only affect those people on the North side of Paseo de Los Aves, four houses in from the corner.

A second hot spot is located closer to home: there was a Uranium bearing rock in the mineral museum of the Geology building. The radiation level is about the same as that at Cardinal Ave. However, because of the radiation in a public building where an office worker may walk past the rock a dozen times a day (radiation exposure is cumulative), the rock was considered a potential danger and removed.

6.8 1.11 Roadrunner Rd. Turn right. Septic Tanks.

Septic Tanks

Definition

Septic tanks are a commonly used method of waste disposal in the Tucson Metropolitan area. The regulations governing septic tank systems do not fully address the geologic details of the subsurface in the region. Consequently, septic tank systems are used in geologically inappropriate areas.

Septic tanks may be used in areas with as little as 4 feet of soil over bedrock. When such areas are also on a slope and there are heavy rains, such as summer thunderstorms, the water table and septic tank effluent will rise to the surface. On the other hand, a septic tank system may be used with only 4 feet of soil above the ground water table. If a septic tank is to function as intended, the effluent should percolate downward. Four feet is not a lot of alluvium. The effluent from the septic tank will percolate down to the water table and pollute the ground water.

Significance

Tucson relies on ground water for all of its water supply. Septic tanks polluting the ground water supply pose a health hazard and an expensive clean-up problem. If left untreated, ground water contaminants can circulate out of the immediate area where they were introduced and pollute more of the ground water supply. In those areas where septic tanks overlie shallow impermeable material, the effluent may come to the surface where it poses a local though no less severe health hazard.

Examples

On the West side of Tucson along Cardinal Avenue, south of Drexel Road, septic tanks are used by the houses and mobile homes. Six to eight feet of alluvium overlies impermeable bedrock on a 5% slope. When an intense summer thunderstorm occurs directly over this area, the alluvium "fills up" with water and brings the effluent from the septic tank systems to the surface.

On the far east side of town, near Tanque Verde Creek, the water table is very high. In fact, there are springs which come to the surface. Houses in this area use septic tanks with much the same result as mentioned previously.

The Arizona state health code provides few specifics regarding the conditions under which septic tank systems may be used. Pima County's health code is much more detailed. A revised set of guidelines for septic tank systems is before the Pima County Board of Supervisors for adoption. The new guidelines would require that septic tanks be 50 feet above the ground water table instead of the present 4 foot minimum. Areas with natural springs would be excluded from septic tank use. At present there are no restrictions. Unsubdivided areas would need a minimum of 36,000 feet^2 to use a septic tank system. At present there is no minimum. At present a septic tank system may be used on slopes having a maximum gradient of 10%. The revised guidelines would increase the slope limit to 20%. The increase in the slope limit is the major geologic flaw in the revised guidelines.

7.0 0.2 Cactus Wren Ave. Turn left.

7.3 0.3 Drexel Rd. Turn right.

8.1 0.8 Cross Mission Rd.

8.3 0.2 STOP. Dip crossing. Channelized West branch of Santa Cruz River.

Midvale Park

According to the Final Environmental Impact Statement (December 1980), "The Estes Company has master planned 2.14 square miles of land for the development of housing, commercial and industrial project located adjacent to the southwestern boundary of the City of Tucson." Almost 9000 units will be built, housing a population of about 22,000 people.

This type of development represents "infilling"; diverting some of the region's growth from the outer fringes of the basin to more central, but undeveloped, locations. This area was previously used for agricultural practices only. Development did not occur earlier because this entire region was subject to flooding by the West Branch of the Santa Cruz River. Hence, the Estes Company was able to purchase the land at a very attractive price (1400 acres for 12 million dollars, or about $8500 an acre).

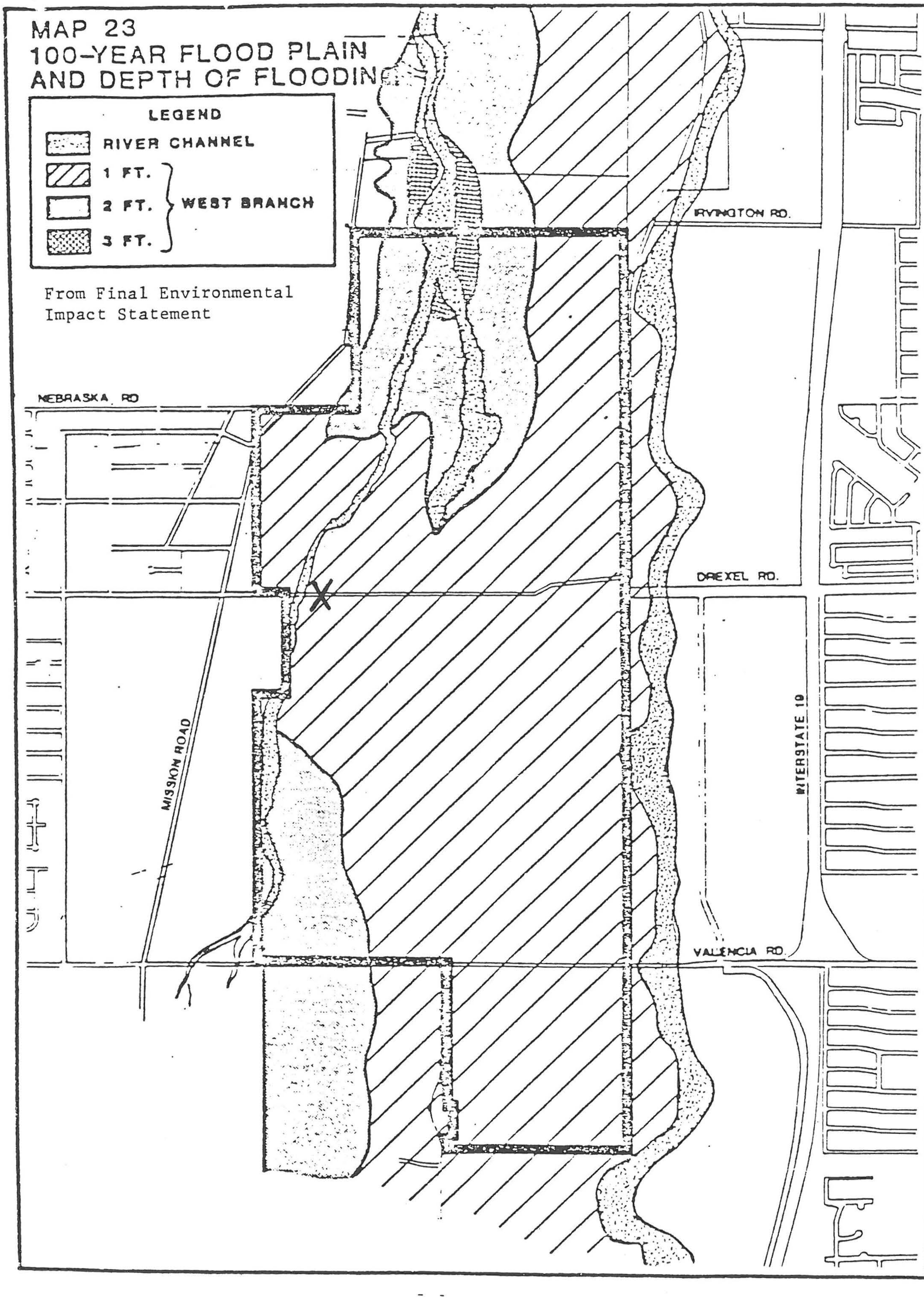
Before any development could take place, the site had to be removed from of the 100-year plain pursuant to the Pima County Floodplain Management Ordinance (Pima County Ordinance 1974-86). The Estes Company, with the aid of the

Dooley-Jones and Associates Engineering firm, decided that the best way to solve this problem would be to divert and channelize the West Branch of the Santa Cruz.

At this time there are several concerns about the earthen channel. One major problem that has been experienced is bank erosion associated with low flow conditions. During low flows the river naturally tends to meander from side to side along the bottom of the channel, undercutting the unprotected banks. The channel has not yet experienced large discharges. What erosive problems will occur then are unknown.

Another problem here is that of head-cutting erosion of the channel banks. Drainages from the development discharge relatively sediment-free water over the edge of the bank, causing severe erosion as the water entrains sediment from the bank.

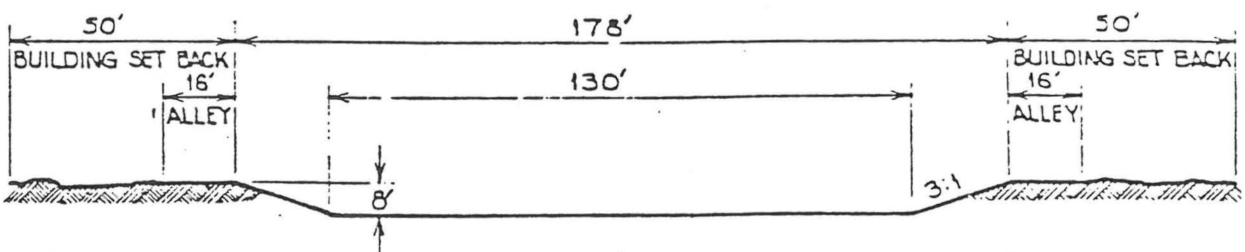
8.5	0.2	U-turn. Mission Road-turn left.
9.5	1.0	Valencia Rd. Turn left.
9.8	0.3	Old channel/new channel: West branch of Santa Cruz River.
10.6	0.8	Midvale Rd. Turn left.
11.6	1.0	Cross Drexel Rd.
12.8	1.4	Approaching bridge, left turn onto dirt road immediately before bridge.
13.0	0.2	<u>STOP</u>. Energy dissipator.


MAP 23
100-YEAR FLOOD PLAIN
AND DEPTH OF FLOODING
LEGEND
RIVER CHANNEL
1 FT.
2 FT.
3 FT.
WEST BRANCH
From Final Environmental
Impact Statement
IRVINGTON RD.
NEBRASKA RD
DREXEL RD.
MISSION ROAD
INTERSTATE 19
VALENCIA RD.

From Final Environmental Impact Statement

Prior to developing the Midvale property, the sheetflooding problem associated with the West Branch of the Santa Cruz River must be resolved. The preferred solution for removing this area from the 100-year flood plain is the channelization of the West Branch. This channel will be designed to carry the 100-year storm and deposit it safely in the Santa Cruz River. The location for the proposed channel is identified on Map 10, Proposed Channel Alignment - West Branch Santa Cruz. The channel will be earthen-lined and will contain bank protection only at road crossings and at the off-site drainage inlets. An energy dissipator structure will be provided at the confluence of the Santa Cruz River. Pima County will not issue building permits nor will HUD approve any tracts until this channel is constructed to specifications and FIA revises the flood insurance rate map showing that the property is removed from the 100-year flood plain. Figure 9 shows a typical cross section of the proposed channel.

FIGURE 9



TOP WIDTH	164.29 FT.	Q_{100}	9908 cfs
AREA	841.03 SQ. FT.	SLOPE	.0035 FT./FT.
VELOCITY	11.78 FT./SEC.	MANNINGS n	.022
VELOCITY HEAD	2.15 FT.	DEPTH	5.72 FT.

Construction of the proposed channel will be performed in phases. The first phase will consist of that portion of the channel from the Santa Cruz River upstream to Drexel Road. The second phase will complete the construction of the channel. The channel will remove this property from the 100-year flood plain. When constructed to specified standards, Pima County will accept dedication of the channel for operation and maintenance.


4800
S.C.
28

13.2 0.2 Reverse. Return to Irvington Road. Turn left.

13.8 0.6 Cross Santa Cruz River (Left lane). Left turn, North on I-19.

14.8 1.0 1'st exit, 'Ajo Way', left onto Ajo Way (at light).

15.4 0.6 Cross Santa Cruz River.

16.2 0.8 Cross Mission Rd.

16.9 0.7 Entering Tucson Mountains. Rock quarry on right.

Life Cycle Of The Saguaro

Maturity

Saguaros bloom once they reach a height of about 10 feet and an age of about 35 years. Their first branches emerge even later in life, at an age of more than 60 years. The giant cacti may live for 200 years. Winter climate controls the geographical limits and local distribution of saguaro populations. Death comes from freezing, lightening strikes, windthrow, and, possibly, old age. Although the impact of human activity on saguaros has not been quantified, vandalism, theft, and pollution remain serious threats to the survival of this marvelous cactus despite the protection afforded it by Saguaro National Monument and the State of Arizona.

Reproduction

Blooms appear on the tips of the stems in late spring. The flowers open in the evening, are pollinated by birds, bats, and insects, and close the following afternoon. Fruits ripen in July. A large saguaro may produce several hundred fruits, each housing about 2,000 seeds, which are relished by birds, ants, rodents, and coyotes. Less than 1 out of 1,000 seeds reach a suitable germination site.

Establishment

Tiny saguaro seedlings are sought by birds and rodents; half will be uprooted before the end of their first year. Freezing temperatures, sunburn, and drought kill many more young plants. Those that do survive those critical first months are protected in rock crevaces or under other plants. Saguaros grow very slowly, especially when very young. 5 years after germination, a plant may only be a minute 1 inch tall. Later growth is variable and depends on the availability of moisture.

17.6 0.7 Cat Mountain at 1:00.

18.9 1.3 Beginning of urban development (right side) and danger zone from rockfalls.

19.9 1.0 U-turn, pull off road to right.

Mass Wasting

Definition

Mass wasting is the preferred term denoting downslope or gravitational movements of weathered rock material. Although gravity is the most important factor, water plays a role in a variety of ways. In the Tucson area, debris flows, rock falls and slides dominate the mass wasting process. Debris flows are the result of the movement of saturated material, more coarse than sand, along valley floors. They result from short duration high intensity rainfalls at the heads of small washes where weathered material has collected. Rock falls take place when a mass of any size is detached from a steep bedrock slope and descends rapidly by bound-ing, rolling and freefall. Slides are a result of displacement along one or several surfaces. These surfaces may be joint, fault or bedding planes. In this area, they are always accompanied by abundant water resulting from snow melt or excessive rainfall.

Significance

Urban development in the Tucson area had not occurred adjacent to steep mountain slopes until recent years. As construction moved into the Tucson and Catalina Mountain foothills, the risks of mass wasting increased.

Examples

Debris flows have recently occurred in the Tucson and Catalina Mountains. In September 1962, 5-6 inches of rainfall took place over a short time period and numerous debris flows up to 1000 feet in length resulted on the west side of the Tucson Mountains.

Weathering of the volcanic rocks in the Tucson Mountains and the gneissic rocks in the Catalina Mountains along joint sets as well as contacts and foliation planes has resulted in the occurrence of loose rock masses situated near developing areas. The gradual loosening of these masses over time, as weathering proceeds creates a rock fall hazard zone at the base of these mountains. The occurrence of a major earthquake in adjacent areas of a magnitude of that of the 1887 earthquake in Sonora, Mexico could cause significant damage and loss of life.

Cat Mountain

As the growing Tucson population encroaches into the mountains surrounding the Tucson Basin, humans and structures are exposed to different kinds of hazards than the problems experienced in the flatter areas. One of these is rock fall, where large boulders tumbling down hillslopes can reach velocities of several tens of meters per second.

Cat Mountain, a 3852 foot high peak, lies to the southwest of Tucson in the Tucson Mountains. The top of the peak is approximately 1200 feet above the elevation of the Ajo Highway. The geologic units that comprise Cat Mountain are the Amole Arkose, a Cretaceous arkosic sandstone, the Tucson Mountain Chaos consisting of Cretaceous volcanics and sedimentary rocks, and topping the sequence, massive lava flows and ash flow tuffs of Tertiary age; the Cat Mountains Rhyolite.

It is the resistant Cat Mountain Rhyolite that produces the cliffs and steep slopes that are conducive to rock fall. This further evidenced by noting that the majority of the large boulders that are found scattered around the base of the mountain are of the rhyolitic unit.

One criteria that can be used in delineating the extent of the hazard is to map where boulders from rock falls of the past presently rest. This doesn't preclude the fact that future boulders may roll beyond this point, but will give the planner some idea of the extent of the hazardous area.

Presently, only three structures exist within the zone of past rock fall. However, the area to the immediate south of Cat Mountain has been bought by a California development company and subdivided in preparation for development of a higher density residential community. If this comes about, the hazard of rock fall in this area may become even more dangerous.

Cat Mountain Reservoir Site:

This topographic basin that drains to the east through San Juan Wash has been studied as a terminal reservoir site for the Central Arizona Project (CAP). Presently the site is in a fairly pristine condition where former mine workings have been closed and vehicular traffic has been prohibited.

There are several advantages to this site as opposed to other proposed terminal reservoir locations:

1) A natural topographic basin already exists. Other proposed sites, such as in the Avra Valley, would require excavation.

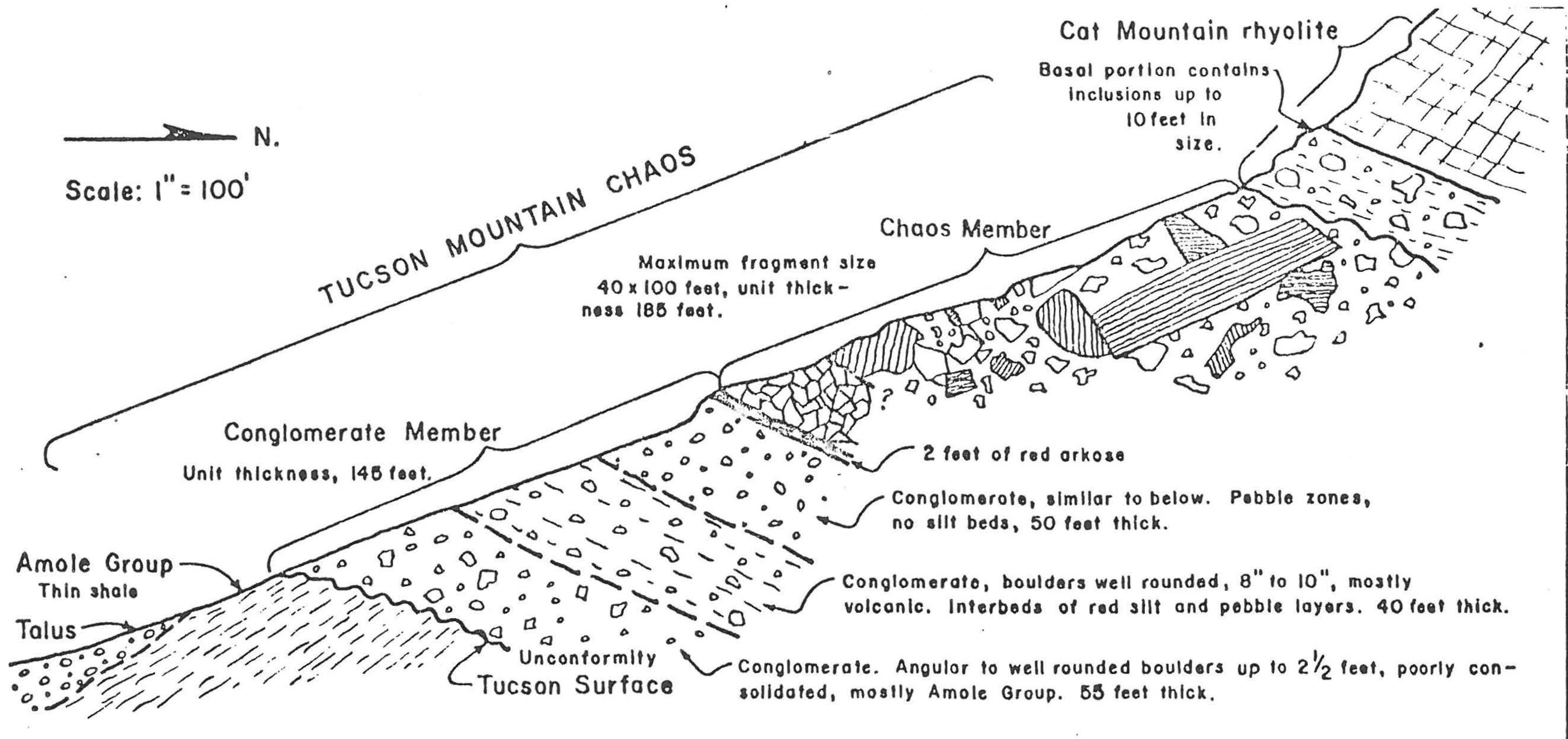
2) The site is elevated relative to Tucson. The City of Tucson would not have to pay for pumping in transporting the water from the reservoir to the city. The costs of pumping the water up to the reservoir would be externalized to the entire CAP region as part of the CAP project.

3) The surrounding area is scenically attractive. This is especially conducive to using the reservoir as a recreational area as well.

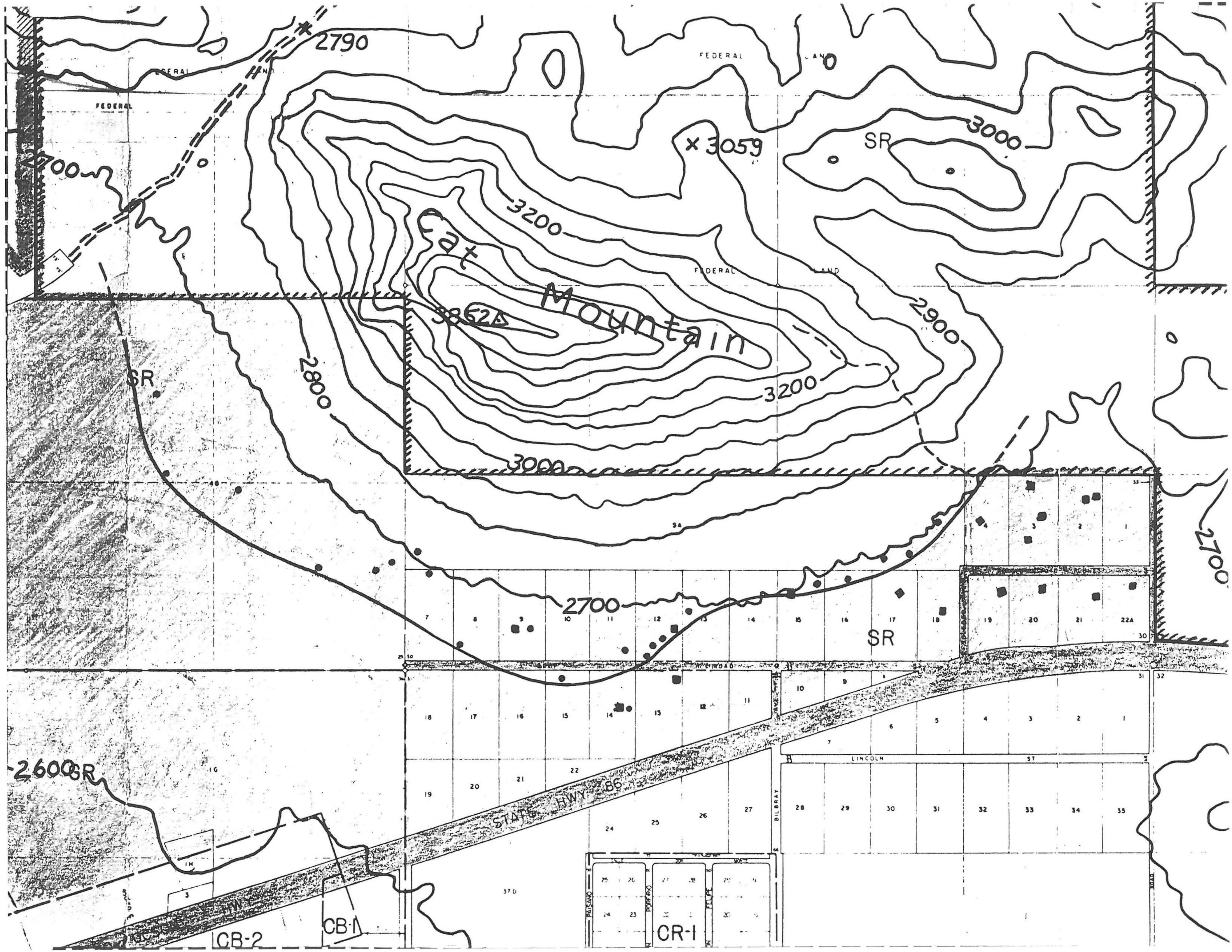
However, there are several issues that must be considered before a reservoir can be built here. There are several inferred faults in the area as well as pervasive jointing. The faults are generally considered presently inactive and probably won't be hazardous to the reservoir. However, both the joints and faults probably represent areas of high permeability, which could potentially cause large water losses from the reservoir. Pressure grouting may be necessary to seal the faults and joints.

Another issue is more of an environmental concern. Conservationist groups argue that a reservoir should not be built here because it would destroy some of what's left of a rapidly diminishing Sonoran desert environment. Other groups argue that there is a great need for water-based recreation in the Tucson area and that site would be ideal.

As of April 1983, the present City Government has decided not to use the Cat Mountain site as the terminal reservoir location for CAP. However, as the completion date nears, and governments change, the Cat Mountain area may be reconsidered.



Cross section of the Tucson Mountain chaos at Cat Mountain, Tucson Mountains, Arizona. Cross section is viewed looking west and is a composite



Cat Mountain
3862
3200
3000
2900
2800
2790
2700
2600
x 3059
SR
FEDERAL LAND
STATE HWY 286
LINCOLN ST
BILBRAY
CR-1
CB-1
CB-2

23.5 3.6 Cross Mission Rd. Quarry on left, Rincon Peak at 12:00, Mica Peak at 11:00.

Rincon Mountains

The Rincon Mountains of southeastern Arizona are a large, rugged domical range situated in the southern Basin and Range province. The bulk of the range consists of a metamorphic basement dominated by mylonitic quartzofeldspathic gneisses, although metamorphic tectonites derived from Paleozoic strata locally form a carapace over the crystalline basement. Allochthonous rocks of many ages and lithologies crop out from place to place along the perimeter of the range. The allochthonous terrane consists of unmetamorphosed (non-tectonite) Precambrian basement, Paleozoic strata, Mesozoic strata, and mid-Tertiary coarse clastics (Lingrey, 1982).

24.3 0.8 Cross Santa Cruz River (stay in right lane).

24.6 0.3 Turn right to enter I-19.

26.5 1.9 Enter I-10.

27.3 0.8 9:00: "A" visible on A-Mountain. 1:30: old church.

A-Mountain

Fourteen rock units are recognized in the Tumamoc Hill-Sentinel Peak (A-Mountain) sequence which comprises over 390m of interbedded volcanic and sedimentary rocks of Late Cretaceous through Early Miocene age. These units compose the most complete section of Tertiary rocks in the Tucson Mountains, and their recognition refines and elucidates the geologic history for that epoch in this area.

Two volcanic episodes (one in the Paleocene, and one in the Late Oligocene to Early Miocene) are separated by a hiatus of erosional and probable non-depositional nature which extends from Late Paleocene to Late Oligocene. Tilting occurred in Paleocene time inclining the sequence 30-45 degrees northeastward. High-angle faulting also took place during the Paleocene along N-S or N5W strikes, and after Early Miocene along E-W or N80W, and N15E strikes.

The northeastward dipping, homoclinal attitude of the Tucson Mountains was probably derived during Laramide (Paleocene) deformation. Intensities of igneous and tectonic activity during the Tertiary in the Tucson Mountains appear to have been directly proportional to one another (Phillips, 1976).

27.7 0.4 Quarry @ 9:00-base of A-Mountain.

28.3 0.6 Carnegie Desert Research Station @ 9:00.

28.7 0.4 9:00: Apartments built on site of old development that was condemned because it was built on shrink-swell soils.

Silvercroft Housing Development

The area bounded by Mission Road and the Santa Cruz River between St. Mary's Road and Sentinel Peak Park roughly comprises the site of the Silvercroft Housing Development. This development, located on the floodplain of the Santa Cruz River, consisted of approximately 120 homes built during the spring of 1961. By 1969, 52 of these homes had suffered damage to such an extent that they were abandoned and subsequently repossessed.

The damage consisted of cracks occurring in the footings, walls, and floor slabs resulting from differential expansion/contraction of the substrate below the houses. A drive around the neighborhood will reveal that this problem is an ongoing one, with many of the houses showing evidence of having experienced some degree of fracturing. The problem is especially prevalent in the homes constructed of the more brittle materials such as brick and adobe.

The root of the problems lies in the high clay (especially montmorillonite) content of the soils in this area. These clays were probably periodically deposited during times of overbank flooding of the Santa Cruz. All clays expand when wetted and contract when dried (mudcracks are an example). The volume change associated with a wetting and drying of a montmorillonite sample is about 10%.

This volume change would not pose a problem if it occurred uniformly; the homes would simply rise and fall. However, the presence of a house causes some areas to dry out faster than others (the soil near the perimeter will dry out faster than the soil directly beneath the house), resulting in differential volume changes. It is these differences in volume changes that set up the stresses that damage the structures.

Subsidence

Define

Subsidence, the gradual settling of the earth's surface, is occurring in a number of areas of Arizona. There are two causes of subsidence: shrink-swell soils and declining ground water levels. Shrink-swell soils contain clays which expand when wet and contract when dry. The phenomenon is local and produces only small cracks on the ground surface. However, the ramifications are significant when there is any sort of structure on top of the soils. The swelling pressures are much greater than the loads of single family detached houses and single story commercial buildings with light industry. In Tucson, the problem can be particularly acute due to the wide variation in soil moisture over a short period of time. If the soil is largely wet or dry, the problems are minimized. Tucson's arid climate and seasonal rainfall generate very dry soils which become wet in the rainy season and have a maximum potential for swelling.

The city of Tucson and much of the agricultural lands around Tucson derive their water supply from ground water. Recharge in the area is negligible and the water table has dropped up to 300 feet in the Tucson area. The lowering of the water table removes fluid support for the sediment materials and allows compaction to take place. The lowering also results in dewatering of clay layers which leads to surface subsidence. When dealing with confined water, the removal of water results in a lowering of fluid pressures and a corresponding subsidence at the surface.

Significance

Subsidence due to ground water pumping is a serious potential problem although the city of Tucson proper has exhibited only 0.4 feet of subsidence during the period 1951-1980 (near the Davis-Monthan Air Force Base and and I-10). However, to the North of Tucson, subsidence of up to 16 feet has been measured, resulting in long fissures in the ground surface which have been widened by surface water flow. Since Tucson draws all of its water supply from ground water, the problem of subsidence due to groundwater withdrawal seems inevitable, with no solution apparent. The effect of subsidence on buildings can be accomodated, to some degree, by engineering. However, subsidence is difficult to predict in magnitude and location. These uncertainties also do not offer much solace for existing structures not engineered to accomodate subsidence.

Subsidence due to shrink-swell soils is an immediate problem in Tucson although it is confined to local areas. The areas adjacent to the major rivers are covered with overbank deposits, rich in clays, deposited prior to the present downcutting of the rivers. This land is popular for building because it is flat and until recently, inexpensive. Unfortunately, after a few cycles of wetting and drying, the structures cannot tolerate the soil heaving beneath them and they crack.

Examples

Tucson is in the early stages of subsidence due to ground water withdrawal. It is anticipated that subsidence in the Tucson area will increase as ground water pumping continues and the water table continues to drop. As the Phoenix-Tucson corridor continues to develop, the need to pump ground water will increase, while simultaneously, the effects of same will cause increasing damage.

Shrink-swell soils occur beneath a number of neighborhoods in Tucson, causing major damage to houses. On the West side of the Santa Cruz River, adjacent to the riverbed, there are a number of examples of problems due to heaving soils: some of the houses have cracks in the outside walls wide enough to see through. The cracks are patched from time to time but short of rebuilding the foundation of the house, there is little that can be done. Repairs to the foundation would be cost prohibitive, given the worth of the houses.

A new housing development on Houghton Road at Pantano Wash is also experiencing problems due to shrink-swell soils. In some cases, one can see daylight through the outside walls. There are also a variety of lessor problems. Again the houses are being patched as it would be too expensive to rebuild the slab/foundation.

Subsidence and fissuring as a result of ground water withdrawal have affected several areas in Arizona, outside of Tucson, including the 120 square mile Picacho Basin near Casa Grande and Eloy. At some places in this area, subsidence of up to 12.5 feet has been recorded and a nine mile fissure pond has been formed.

More than 109 million acre feet of water has been pumped from the Picacho Basin since 1915 for agricultural purposes. This ground water extraction has been much greater than the natural recharge, resulting in a significant lowering (400 feet in some areas) of the water table. Coincident with the advent of heavy pumping in the 1940's was the observation of land surface subsidence.

Occurring in conjunction with the subsidence are fissures. The fissures generally start as small cracks that are quickly widened and deepened by erosion. These fissures are thought to be a result of stresses set up by dewatering sediments of varying depth. Supporting this hypothesis is the fact that the fissures commonly occur over areas of large gravity anomaly gradients, indicating the presence of subsurface bedrock topography.

The fissure zone here is part of the nine mile fissure zone. This fissure, readily observable from the air because of vegetation concentrations, is unique in that there is a vertical offset in addition to the horizontal offset. This vertical offset of up to three feet has posed problems to neighboring farmers as well as to the Interstate and the railway, mandating frequent releveling of the fields and repairs to the roadbed and railway.

30.1 1.4 Grant Road exit.

30.4 0.3 Left turn onto Grant Road.

30.6 0.2 Broadbent Interstate Center-turn left, quick right into parking lot, quick left. STOP. Note bridge, piers, narrowing of channel as approach bridge, lack of protection.

30.8 0.2 Continue over dirt section to next parking lot/building complex. Note channel bank on right: landfill/non landfill.

Solid Waste Disposal

The Tucson Basin is bounded by mountains comprised predominantly of metamorphic and plutonic igneous rocks with secondary amounts of volcanic and sedimentary rocks. The basin is filled with sediment derived from the surrounding mountains. Floodplain and stream channel deposits underlie the floodplains and channels of the major streams. Underlying this material are basin-fill deposits which are a heterogeneous mixture of weakly cemented to unconsolidated gravel, sand, salt and clay and form the principal alluvial aquifer sequence. This sequence is underlain by indurated sediments that are divided into sub-units based on major lithologic properties.

At least forty-one active and abandoned landfills have been identified in the Tucson Basin (Clark 1983). While most of the landfills are governmentally developed (Pima County and City of Tucson), some are wildcat sites. Most of the landfills are closed and are, depression landfills, i.e., located in natural or artificial gullies or pits and abandoned sand and gravel quarrys. Twenty-nine of the forty-one identified landfills are located in the floodplain of the Santa Cruz River, Rillito Creek or Pantano Wash.

The majority of the landfills were unregulated at the time they were developed. Although the landfill contents are not known they are probably representative of a typical city dump. In a 1972 study of California dumps, Davis found the following:

Paper products	45.5% (by weight)
Food	25.9
Glass	10.9
Metals	10.8
Leather & Rubber	1.0
Brick, rock, dirt	1.0
Plastics	1.7
Hardwaste	1.6
Cloth & synthetics	1.3
Wood	0.3

Several landfills located near industrial centers are suspected to contain hazardous chemical wastes.

The primary hazard of landfills is the pollution of ground water by leachate. The location of most Tucson Basin landfills in floodplains has significantly increased this hazard since leachate is generated when ground water or infiltrating surface water comes into contact with the buried wastes. Streams in this area are ephemeral, flowing in response to regional rainfall or to snowmelt/rainfall in the adjacent mountains. The streams may flow for several consecutive months a year depending on the rainfall patterns.

Over the last few years several significant flow events have occurred allowing water to move through the buried waste as recharge takes place. These sustained stream flows have caused ground water mounding which in turn results in the saturation of the landfills located in the floodplains. As the mound lowers over time leachate generated within the landfill drains into the water table.

Landfills have only been recently recognized as a potential problem. As a result, a limited number of studies have been un-dertaken. The Pima Association of Governments (PAG) has looked at the Ina Road Landfill. A network of monitor wells and existing supply wells was established at the Ina Road Landfill, and groundwater samples were obtained for six months. Surface water quality in the adjacent Santa Cruz River was also monitored during this period. The Santa Cruz River is an effluent dominated stream in the area of the landfill. Results of the monitoring program indicate an extensive plume of groundwater pollutants appear to originate in the older cells of the Ina Road Landfill. High concentrations of chloride, bicarbonate, sulfate and high values of electrical conductance (EC), chemical oxygen demand (COD) and high concentrations of Total Organic Carbon (TOC) characterize the leachate plume (Moordian, 1980a).

Less extensive studies of the TAA Landfill by the Arizona Department of Health Services found organic solvents in the soil underlying the landfill (ADHS, 1983) while PAG discovered no leachate plume associated with the El Camino del Cerro landfill.

Figure 1. Giant earth fissure near Chandler Heights, Arizona. Earth fissures begin as tiny cracks, but become enlarged by water erosion and collapse of adjacent soils. This fissure is related to subsidence due to ground-water withdrawal. Photo taken on October 21, 1983 by Larry D. Fellows.

Setback Requirements

O'Barr Autowrecking, located across the river, is an example of a business "caught" by the setback requirements of the county floodplain ordinance: businesses located along the riverbank here must be set back at least 500 feet from the edge of the channel bank. Because the business was here before the setback requirement was put into effect, the business is allowed to remain. However, O'Barr can sell his property only for use as an autowrecking yard. If the property were to be used for some other purpose, such as apartments, bank protection would have to be provided along this reach of the river. In most cases, the cost of the bank protection would be more than the worth of the business.

Hazards posed by frequent channel bank erosion are not treated adequately in the federal floodplain management regulations, which form the backbone of local floodplain management. The Flood Disaster Protection Act of 1973 expanded the meaning of the term "flood", as defined in the National Flood Insurance Act of 1968, to include abnormal erosion caused by unusually high levels of water, as during a flash flood (United States Code Congressional and Administrative News, 1977). However, in ephemeral alluvial stream systems of the Southwest, locally severe bank erosion as well as general channel widening and lateral channel migration have frequently been produced by flows of moderate magnitude that cannot be classified as unusual and unforeseeable events. Potential sites of significant bank erosion along a stream channel, such as land areas adjacent to the outer banks of channel bends that have not been artificially stabilized, are not always within the delineated 100 year floodplain. Unless a property owner at such a site happens to carry federal flood insurance, little compensation is available for property lost to bank erosion during a flow of less than unusual magnitude.

In recognition of this situation, minimum setback distances for buildings and other structures from unprotected channel banks of major and minor watercourses are required in the current Pima County and City of Tucson floodplain management ordinances. Much of the damage in Pima County caused by channel bank erosion has been to public and private facilities constructed prior to the establishment of building setback distances. Since 1974, when the first floodplain management ordinance was adopted by Pima County, building setback distances along the major water-courses have evolved from 100 feet (30 m) for commercial/industrial structures and residential structures for rent, and 300 feet (91 m) for owner-occupied residences, to 500 feet (152 m) for all structures. The latter distance was adopted following the October, 1983 flood, in response to the significant bank erosion and lateral channel migration seen during that event.

At this time, the minimum building setback distance of 500 feet (152 m) is required along major watercourses in Pima County where no unusual conditions exist. Where unusual conditions do exist, including historical meandering of the watercourse, presence of sand and gravel operations, poorly defined or unconsolidated channel banks, or local changes in directions, quantities or velocities of flow, building setback distances are to be established on a case-by-case basis by the County Engineer. Setback distances ranging from 50 to 250 feet (15 to 76 m) have also been established along smaller watercourses based on the magnitude of the estimated 100-year peak discharge.

The City of Tucson has also adopted similar setback requirements. It is also stated within the City of Tucson floodplain management ordinance (No. 6068) that floodway fringe development shall not significantly increase channel bank erosion or cause damage to public facilities resulting from erosion or flooding.

FLOOD PLAN CONSTRUCTION

Any dwelling unit built within a flood plain shall be constructed so as to place the minimum floor elevation of the dwelling unit at least one (1) foot higher than the regulatory flood elevation.

All natural streams, watercourses and/or constructed drainageways with a 100-year peak discharge which equals or exceeds 2,000 cfs must be dedicated to Pima County in fee simple.

BUILDING SETBACK REQUIREMENTS

A. Major Watercourses

For major watercourses, with 100-year peak discharges of 2,000 cfs or greater, the following building setbacks shall be required where bank protection is not provided.

a. Santa Cruz River, Rillito Creek, Pantano Wash, Tanque Verde Creek and the Canada del Oro Wash require a setback of five hundred (500) feet.

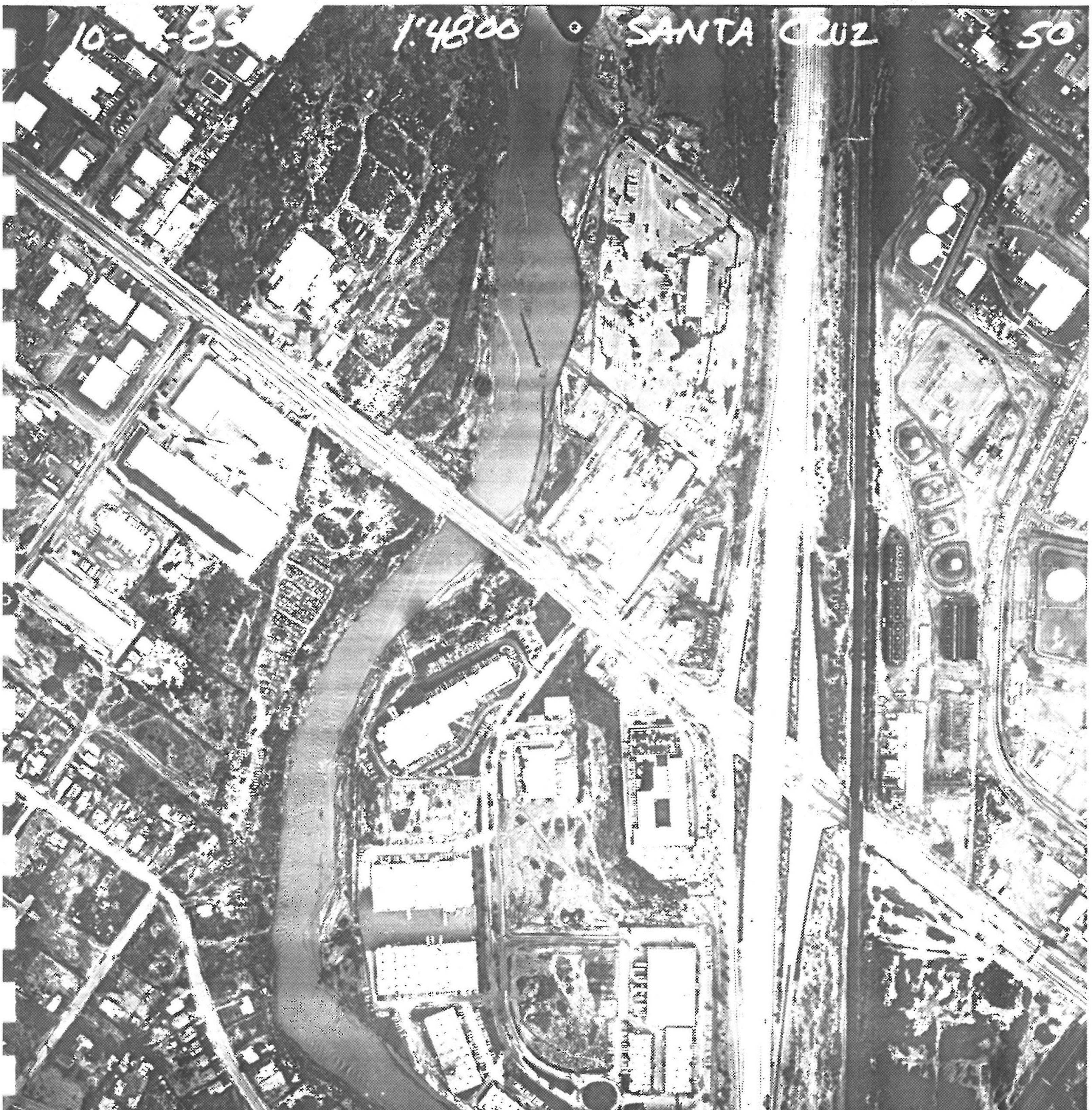
b. All other major watercourses with 100-year discharges greater than 10,000 cfs, such as Sabino Creek, Aqua Caliente Wash, etc., shall require a setback of two-hundred and fifty (250) feet.

c. Major washes with 100-year discharges of 10,000 cfs or less, but more than 2,000 cfs, will require a setback of one hundred (100) feet.

B. Minor Washes

For minor washes with a 100-year peak discharge of 2,000 cfs or less, the following building setbacks shall be required where bank protection is not provided.

1. Along minor washes where no unusual conditions exist, a minimum building setback of fifty (50) feet measured from the nearest primary channel bank shall be provided at the time of development.


10-
85
1:4800
SANTA CRUZ
50

Santa Cruz River at Grant Rd. looking downstream (south). O'Barr Auto is on outside of meander bend.

31.0 0.2 Left turn to parking lot.

31.2 0.2 Left turn onto access road.

31.4 0.2 Right turn onto Grant Road.

31.6 0.2 Left turn onto I-10 North.

34.3 2.7 Tortollita Mountains @ 1:00; Catalina Mountains @ 3:00; Graben structure between them; sewage treatment plant (in flood plain of Santa Cruz) @9:00.

Big John's, a.k.a. Ranch House bar @ 3:00-site of numerous shootouts.

Santa Catalina Mountains

Geologically, the mountain range can be divided into northern and southern portions by an imaginary east-west line that crosses through Mount Lemmon. The southern portion is gneissic. The southern edge of the mountain range is known as the Catalina forerange and is banded gneiss of Precambrian age. The rock between this banded gneiss and the Mount Lemmon area has been alternatively described as a granitic-gneiss and gneissic-granite. Much of the rock is of granitic composition and displays a metamorphic texture.

The eastern slope of the range consists of Precambrian and Paleozoic sedimentary rocks which are broken by faults and intruded by Cenozoic igneous rocks. The western portion is a large igneous complex of which the Catalina granite is the major unit. Because of the mixture of gneissic and igneous rocks and the structural relationships, the mountain range has been described as a large gneissic dome complex (Hoelle, 1976).

37.1 2.8 Cross Rillito River.

37.4 0.3 Exit-Orange Grove Road.

37.8 0.4 Right turn onto Orange Grove Road.

37.9 0.1 Right turn.

38.1 0.2 Left turn.

38.2 0.1 Right turn into parking lot.

38.4 0.2 STOP. Cross fence at right side of parking lot, walk down dirt road to Rillito River.

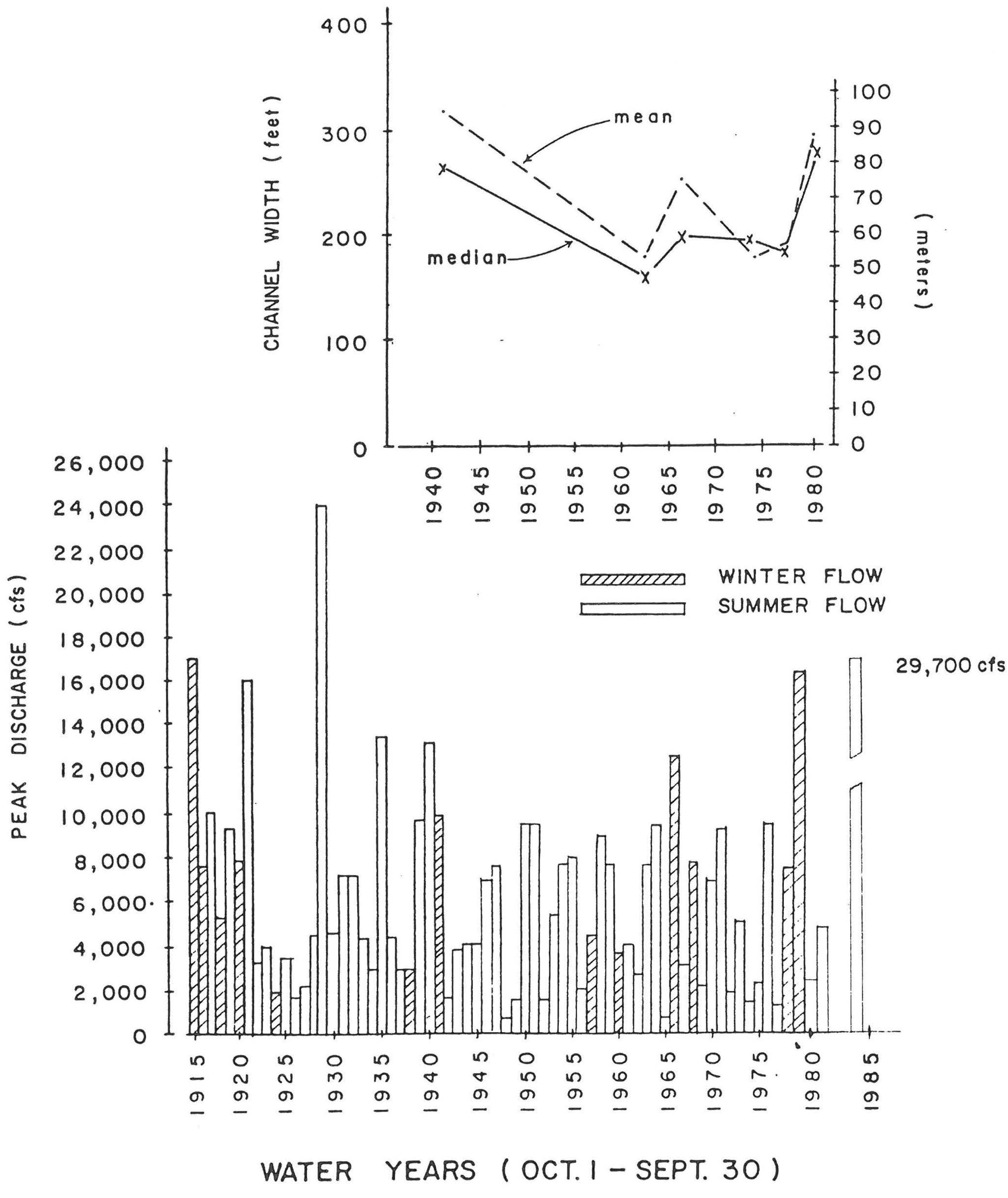
Rillito Creek

Rillito Creek is a major tributary of the Santa Cruz River. Its watershed encompasses a 934 square mile area that includes the Santa Catalina, Tanque Verde, Rincon, Santa Rita, and Whetstone Mountains. Tanque Verde Creek, which drains primarily a montane area northeast of Tucson, and Pantano Wash, whose watershed includes large basin areas southeast of Tucson, form the main tributaries of Rillito Creek.

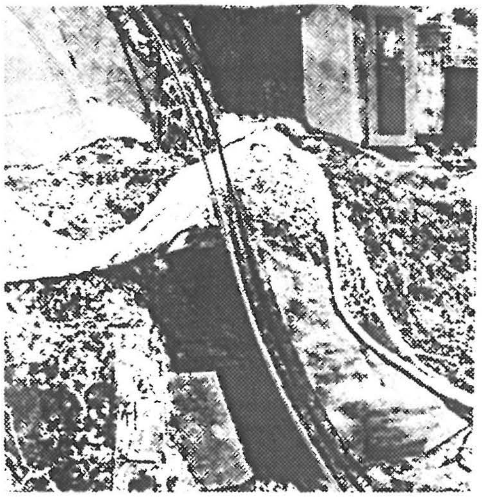
The Rillito Creek system has exhibited highly variable cross-sectional geometry, patterns, and positions over time (Pearthree, 1982). Stop 4 illustrates a 1978 change in channel width and alignment that currently endangers the Southern Pacific Railroad bed and the Interstate Highway 10 system, including the frontage road.

Two separate winter flow events, recorded in March and December of 1978, produced the channel change seen in the accompanying photographs. The annual peak discharge record of Rillito Creek at Tucson is shown on the accompanying diagram. Two such separate winter flow events had never been recorded previously in Rillito Creek within a 9-month period, nor in Tanque Verde Creek and its watershed where the flow events originated. The March flow reduced the amount of easily entrained sediment within the stream channels, which increased the tendency of the December flow to erode their banks (Thomas Maddock, Jr., University of Arizona, written communication, 1980). Undercutting of the banks of Rillito Creek caused large blocks of land to slump into the channel, where they were disaggregated and swept downstream.

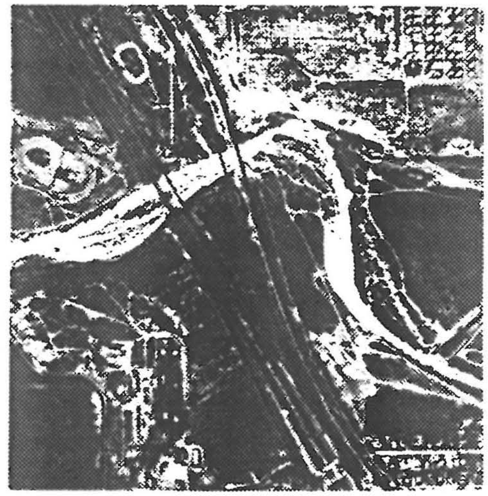
One result of this set of conditions was a shift in alignment of the Rillito Creek approach to the Southern Pacific Railroad Bridge east of Interstate 10. The bridge was constructed in 1925 perpendicular to the direction of flow in Rillito Creek. The channel remained in essentially the same position until the peak flow of December 18, 1978, when a large bend in the channel directly upstream of the bridge shifted to the west, removed approximately 50 acres of land, and damaged the northern abutment of the bridge (Laursen, 1979). As a result, the channel and bridge are no longer aligned. The river currently tends to flow northward parallel to and against the railroad embankment before attempting to turn approximately 90 degrees to the west and flow underneath the bridge. The bridge has since been reinforced. Stands of tires have been placed in the channel in an effort to redirect streamflow, and the banks have been rip-rapped in order to prevent further bank erosion. The approaches to several other bridges across Rillito Creek were damaged extensively by this flow event (Federal Emergency Management Agency, 1981).



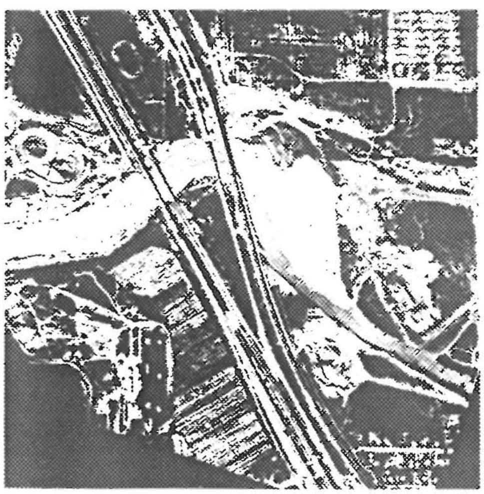
RILLITO CREEK



1941



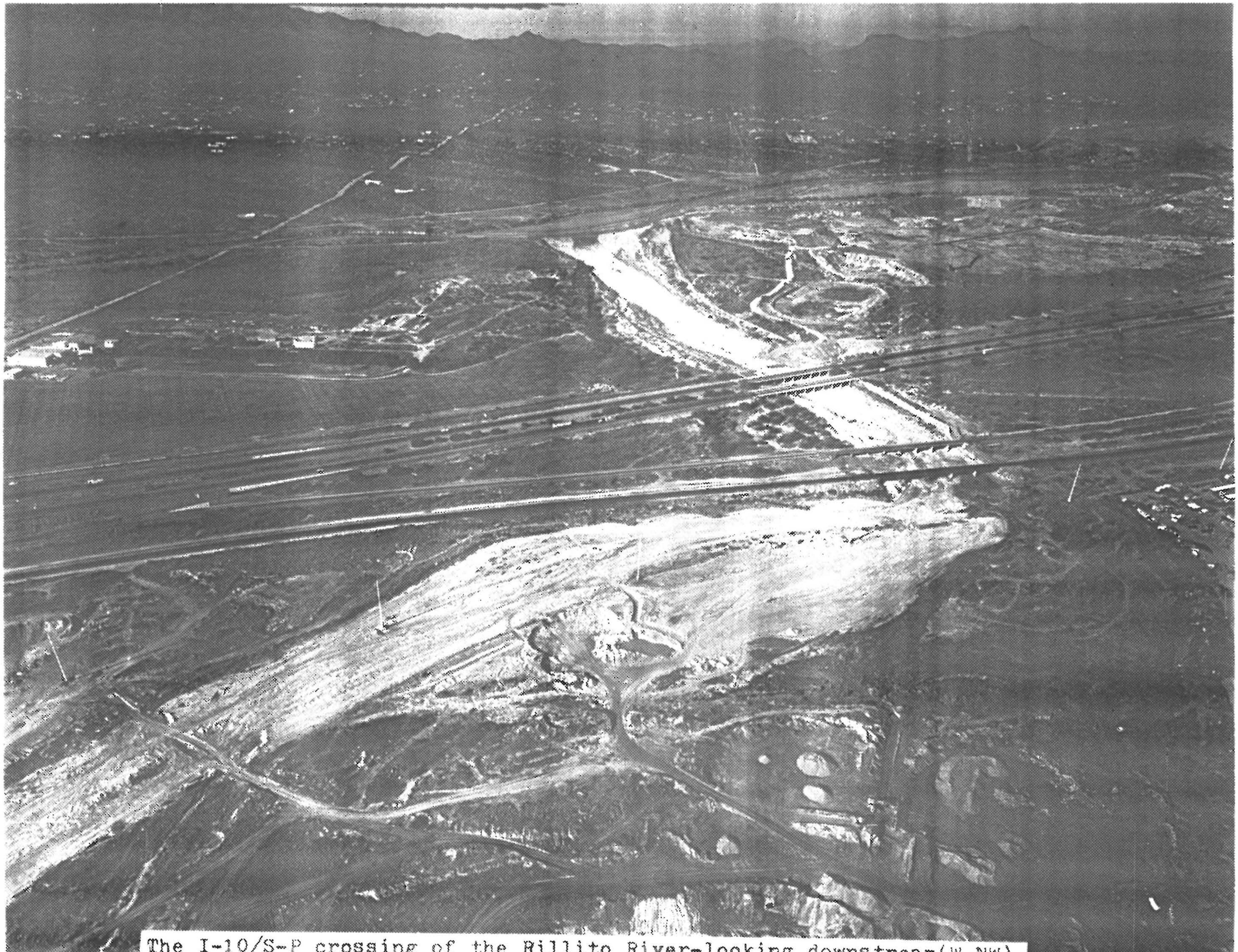
October 1978



January 1979

October 1983

The I-10/S-P crossing of the Rillito River



The I-10/S-P crossing of the Rillito River-looking downstream(W-NW).
Santa Cruz River in background. February 1986.

The I-10/S-P crossing of the Rillito River-looking upstream (east).
Santa Cruz River in foreground. February 1986.

Photo 13

13-15

38.6 0.2 Orange Grove Road. Turn right.

38.7 0.1 Thornydale intersection. Bear right.

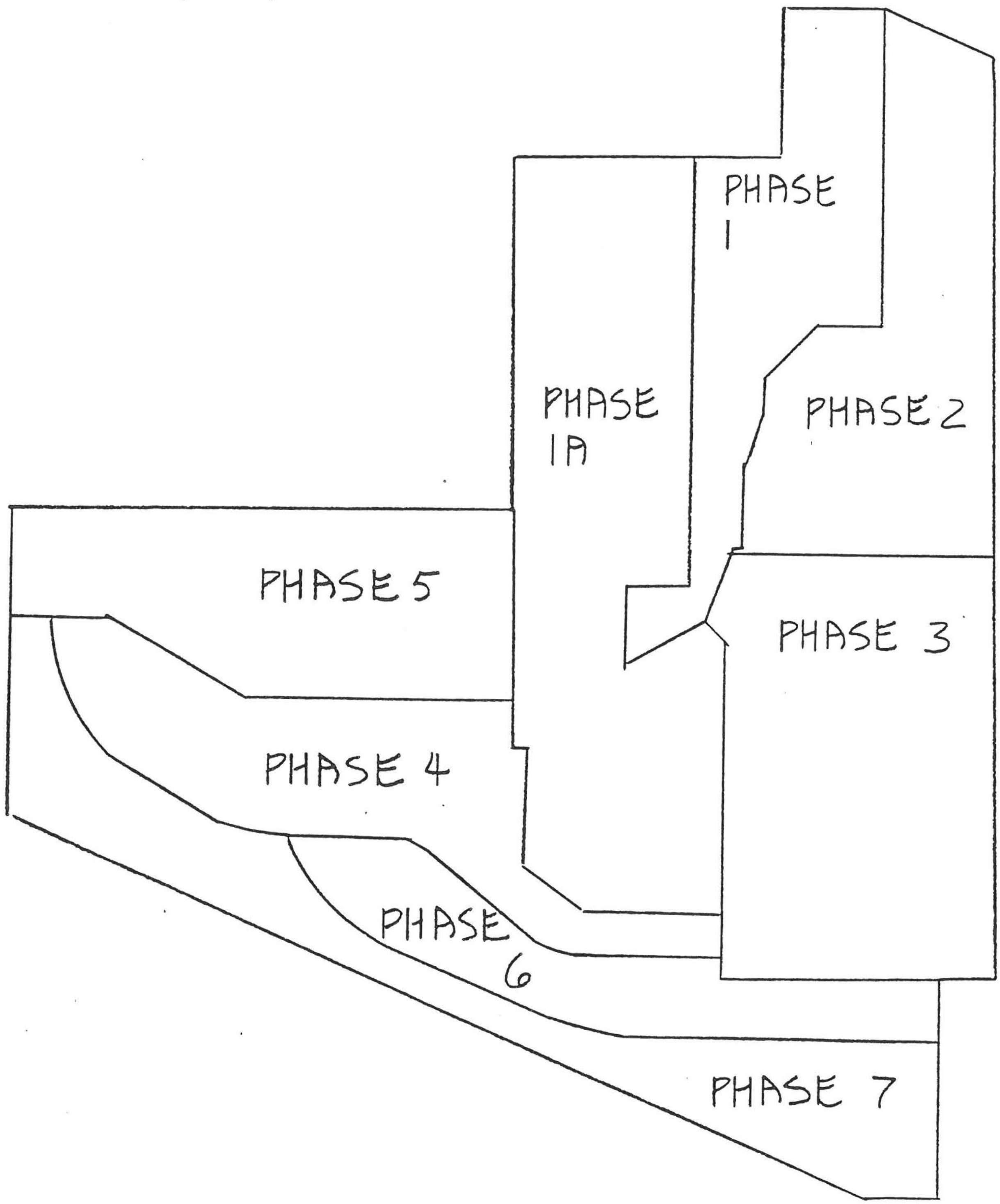
39.1 0.4 Cross Camino Del Terra. Mobile home park on right.

Pegler Wash Flood Problem

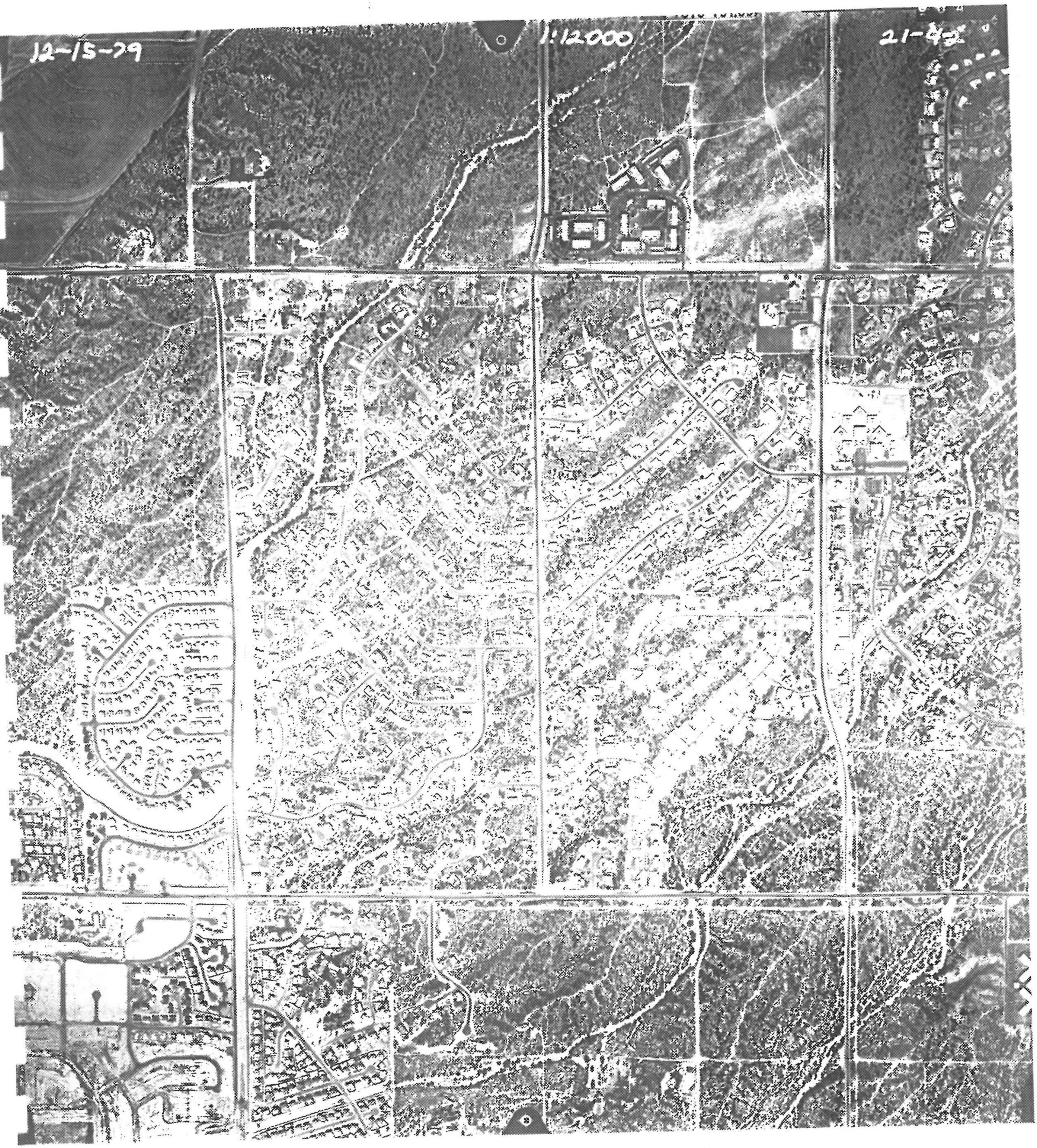
The Pegler Wash is a minor tributary of Rillito Creek that extends southwesterly from the Santa Catalina Mountains to Rillito Creek. The calculated 100-year peak discharge of this wash, generated by a 2342-acre watershed, is approximatlely 3230 cfs.

To the north of Oracle-Jaynes Station Road, the existing Pegler Wash channel can convey only about 1100 cfs, resulting in approximately 2130 cfs breaking out of the channel and overflowing in a southerly direction towards Rillito Creek over a large area. Within this area are several developments, including Shannon Business Park and Meadowbrook - a single-family residential subdivision currently under construction. At this time, only three phases of Meadowbrook, (see Figure) have received building permits, due to the Pegler Wash overflow problem. These three phases are protected by high ground north of Oracle-Jaynes Station road that directs the overflow runoff to the west. Development of the remaining phases of Meadowbrook is contingent upon containment and conveyance of the full 100-year discharge in Pegler Wash from the breakout location to Rillito Creek.

Construction plans have been drawn up by a consulting engineer showing a containment scheme for the overflow runoff. These plans propose the placement of an earthen levee along Pegler Wash from the flow breakout point, extending downstream to a cement channel that is capable of conveying the full 100-year flow. Once these plans are approved by the appropriate regulatory agencies and the levee is constructed, Meadowbrook and other areas subject to overflow from the Pegler Wash will be removed from this hazard and rendered more suitable for development.



MEADOWBROOK PHASE MAP



12-15-79
1:12000
21-4-2


1:12000
R
15-3

40.7 1.6 Cross La Cholla Blvd.

41.8 1.1 Cross La Canada Dr.

43.0 1.2 Cross Oracle Road

43.8 0.8 Cross 1'st Ave.

44.0 0.2 Cross Geronimo wash. Note house on left in wash.

"House in Wash"

6402 Calle de Estevan is the small brown house that is visible in the wash just north of Orange Grove Road. After purchasing the house from the builder, the owner experienced flooding problems every time the wash flowed. In an attempt to mitigate this problem, the owner has built a rock structure to divert the stream to the east.

While no formal action has been taken by the owner, this case exemplifies a common concern; should the builders and/or developers be liable for building the house in the wash, or should the old "caveat emptor" (buyer beware) philosophy take precedent? The Pima County Floodplain Management Ordinance currently requires a 50 foot setback from small washes unless a justified exception is approved by the Pima County Engineer. Obviously, in this case the home was built before this ordinance became effective (1974).

This case also illustrates a common perception problem in the southwestern United States. As more and more people vacate the humid northeast for sunnier lives in the southwest, the greater the potential for hazards associated with newcomers unfamiliar with the special climatic, fluvial and geologic characteristics of this area. A newcomer from a region, such as the northeast, where the streams are perennial, may not comprehend the danger presented by a wash that is dry 95% of the time. 6402 Calle de Estevan may just be a case of this type of perception problem.

45.2 1.2 Right on Skyline Dr. 12:00: looking up Finger Rock Wash drainage.

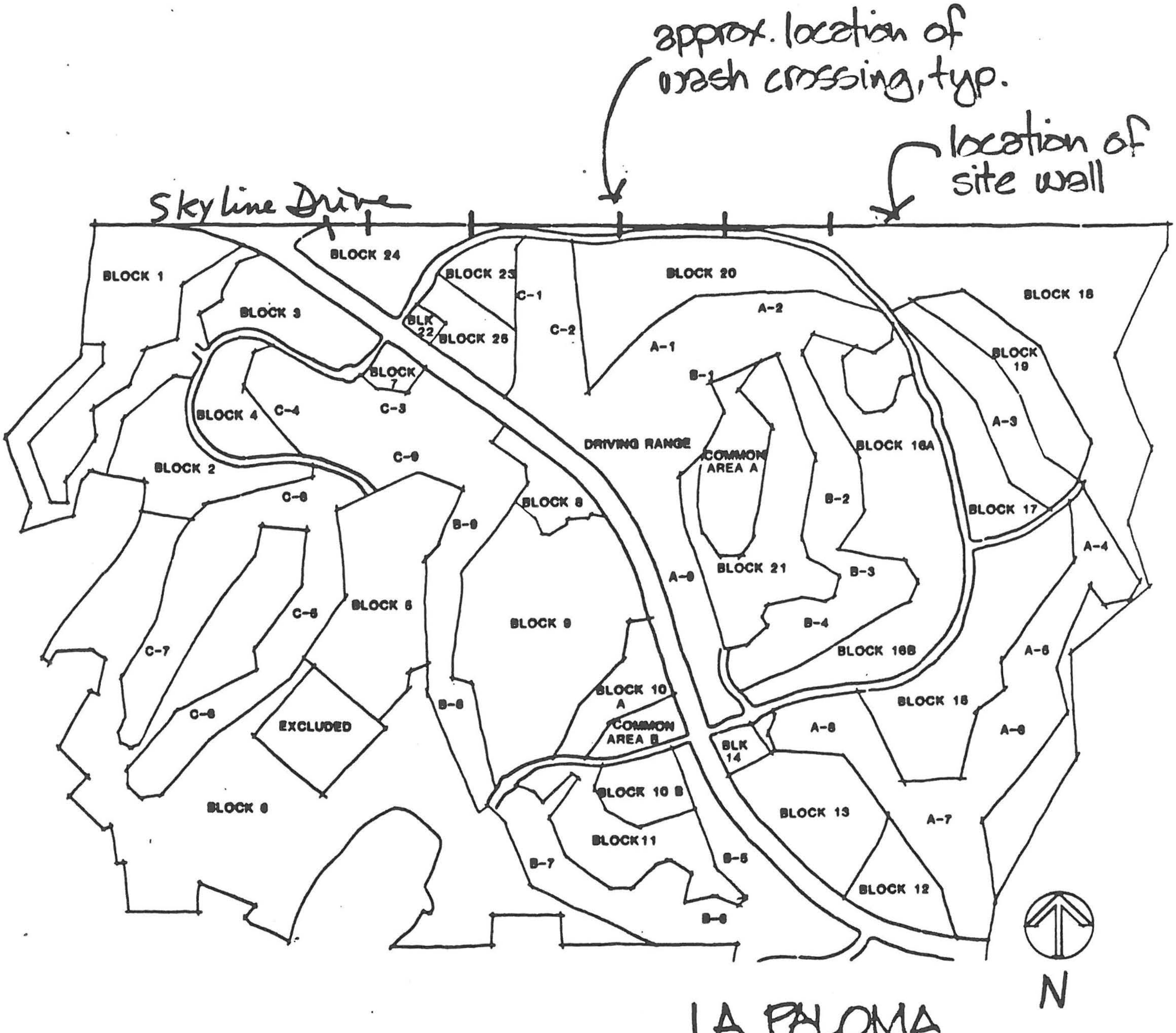
45.8 0.6 Cross Campbell Ave. Move to left lane.

46.3 0.5 Left turn onto Skyline Dr.

47.0 0.7 Right side: note openings at bottom of wall to pass water. Cross Alvernon Way.

La Paloma Masonry Screen Wall, Skyline Drive

One of the requirements attached to construction of the masonry wall that extends along the south side of Skyline Drive was issuance of a Flood Plain Use Permit by the Pima County Department of Transportation and Flood Control District. In its east-west alignment, this wall intercepts numerous washes that flow southward from the foothills of the Santa Catalina Mountains located to the north. Openings in the wall were required as part of the wall design. These openings were designed to pass the 100-year peak discharge of each wash,



LA PALOMA

SITE WALL PLOT PLAN

assuming 50 percent clogging of the openings by debris. Widths of the 100-year floodplains of these washes were matched by the wall opening widths.

Dam Failure

Definition

The failure of a dam above a densely populated river valley constitutes a catastrophic geologic hazard. Failure of earthen dams may be the result of 1) piping due to fluid pressures beneath the dam, 2) water infiltrating the core of the dam, 3) overtopping of the dam due to an inadequate spillway.

Significance in Tucson

The population of the Tucson basin is close to one-half million people and it is steadily increasing. Dams are constructed across the streams which issue from the mountains surrounding Tucson (annual mountain precipitation is 600-750 mm/yr compared with 275-300 mm/yr in the valley). The bulk of the population will be downstream from any reservoir impounded by a dam on a stream flowing into Tucson. Given that dam failures, in general, have been of a sudden nature which occur with little warning, there is the potential of significant loss of life.

Examples

Tucson has never experienced a major failure although there have been several examples of dams which have been intentionally breached because they appeared in danger of failing. Golder Dam is an earthen dam, constructed in 1964 across the Canada Del Oro Wash, north of Tucson. The reservoir at maximum storage capacity held 9500 acre feet of water with a surface area of 280 acres (113 Hectares). The dam was 130 ft. (40m) high, 2250 ft. (682m) long, and had a maximum base width of 700 ft. (212m). From the outset, there was considerable leakage through the dam itself as well as beneath the dam. The reservoir was ordered drained in 1967 by the state of Arizona as it was thought that the dam was in imminent danger of failing. What happened? Subsequent investigation showed that the developer and the subcontracted technical staff failed to evaluate the geology of the damsite in detail. The data indicated the subsurface to be marginal for an earthfill dam and required extensive remedial treatment. The coring program explored the subsurface to a maximum depth of only seventy-three feet (there is a brecciated fault zone running beneath the dam). The brecciated zone also extended beneath the grout curtain intended to minimize seepage beneath the dam. The dam was ordered breached after much controversy. Many people had bought property in the floodplain down-stream from the dam, assuming that the dam would provide flood control. After the dam was breached, the property was "back in the floodplain."

There are a number of "earthen dams" being constructed in Tucson which were never intended as such: many washes are being filled in as new roads, parallel to the mountain front, are being constructed in Tucson. Culverts are placed under the fill to accomodate the runoff but they are often filled with sediment. The water pools behind the road fill - most of the time the rainstorm is of short enough duration that the water eventually drains away. Occasionally, the water overtops the road and may even wash out the fill. The road fill is designed only to accomodate weight from above. No consideration is given to the fill being able to withstand lateral forces and infiltration, or to maintain its structural integrity once wetted.

Finger Rock Dam

Skyline Road has been changed from a dirt road that was impassable whenever Finger Rock Wash was running to an all-weather road that is about 15 feet above the channel of the wash. A 48" culvert allows the wash to flow beneath the built up road.

It is a combination of a small culvert and the built up road that poses a hazard here. The 48" culvert is too small to handle large flows in a wash the size of Finger Rock. During extremely large events the culvert, in addition to being too small to handle the flow, becomes clogged with debris. The built up road serves as a dam to the water not passed by the culvert. While this will protect homes downstream of Skyline Road, it constitutes a serious hazard to the homes immediately upstream.

A preliminary topographic analysis indicates that the ponded water could back up as much as 800 feet up the stream valley. About five or six residences would be partially inundated if maximum ponding occurred.

A less likely, but much more catastrophic possibility, is that an extremely large rainfall event centered over the Finger Rock Wash catchment produces a flow that completely fills and overtips the basin dammed by Skyline Road. Once the road has been breached, the dirt fill will erode quickly and completely. The rapid emptying of the unintentional reservoir will result in a wall of water traveling down Finger Rock Wash and into the Rillito River.

During the short history of Tucson, no extraordinary flows have occurred in Finger Rock Wash. However, it is just a matter of time until the culvert, and possibly the road, are tested.

47.5	0.5	Finger Rock "Dam."
48.0	0.5	Left turn onto Swan Road.
48.7	0.7	Left turn onto Coronado Dr.
49.0	0.3	Debris flows @ 3:00-note alignment of large rocks. Crossing trace of Catalina Fault. Scarp @ 2:00: alluvium to left, bedrock to right.

Debris Flows

Debris flows consist of boulders, vegetation, pieces of structures, mud and water in varying degrees of importance. They are often triggered by small landslides or soilslips which incorporate water and additional debris as they move downstream. In arid regions, they commonly come to rest on the gentler slopes of the alluvial fans outboard from the mountain front. As a debris flow moves downstream (at velocities ranging from 1-10 meters per second), the bigger boulders and debris migrate upward and outward with respect to the flow, becoming deposited as levees at the outer limits. With time, the fines and smaller debris of the debris flow deposit are washed away, leaving only a set of boulder trains.

There are two sets of boulder trains coming out of Finger Rock Wash. Several houses in the area are on top of, or within, these debris flow deposits. At first thought, this might be considered an extremely hazardous condition and that mitigating measures should be taken. However, the age of these debris flows are not known. They may be a relict of a climate that was different and more conducive to debris flows. It is possible that debris flows are not an active geologic process in this portion of the Santa Catalinas under the current climatic/environmental conditions. The presence of mature Saguaros within the deposits indicates a minimum age of 200-300 years. Archeological evidence above similar debris flow deposits in Pima Canyon indicate a minimum age of 6,000 years for those debris flows. So indeed, the debris flows that came out of the Santa Catalinas may be Pleistocene.

Of course, the alternative is also possible; debris flows may be an active process and do constitute a hazard to foothills residents. A lengthy recurrence interval, or just plain luck, may explain the lack of historic debris flows. Sites elsewhere in the Santa Catalina Mountains and the Tucson Basin have experienced debris flows (e.g. Golden Gate Mountain in 1980; just to the east of this site in October, 1983). Fortunately, they have occurred in uninhabited areas.

49.3	0.3	Left on Columbus Blvd.
49.4	0.1	Left on Havasu Rd. Wash on right is Finger Rock Wash. Note houses downstream in the channel.
49.6	0.2	4330 Havasu Rd.: look down driveway-note rock wall to divert flow of stream away from house.

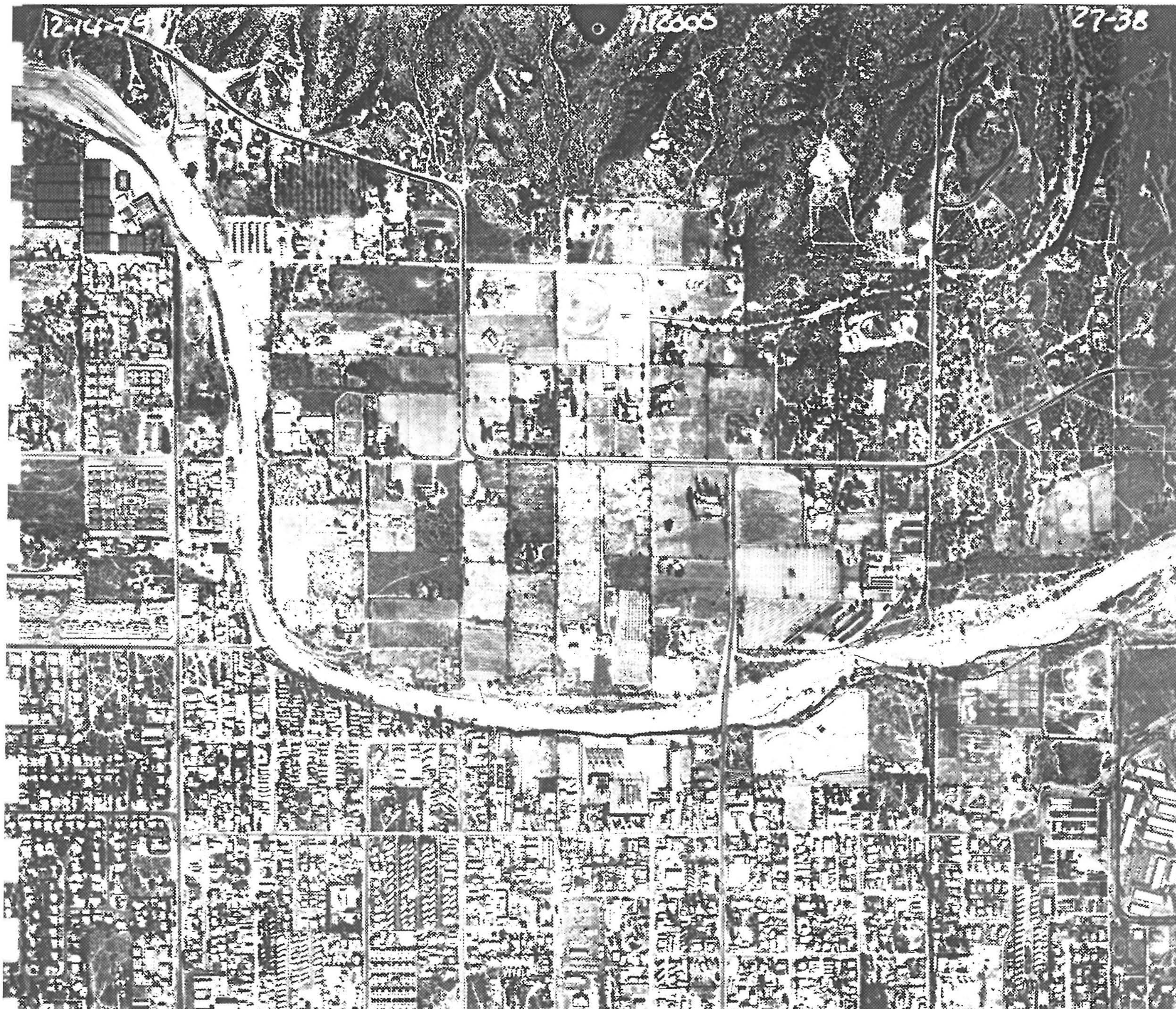
<u>Finger Rock Wash</u>

At first glance, the catchment of finger Rock Wash does not appear to be very large. However, at 3.34 square miles, it is comparable to other catchments in the area (eg. Pima Wash and Ventura Canyon). Thus, if a thunderstorm became centered over the catchment, a sizeable flow could result. Depending on the timing and amount of warning, substantial property damage and, perhaps, loss of life could occur.

Two homes that would be likely to sustain damage in such an event are 4260 and 4330 Havasu road. During low flows, the driveway of 4260 is inundated and a retaining wall protects 4330. During a higher flow, such as one associated with a thuderstorm centered over the drainage basin, these two homes, along with many others that are built perilously close to the wash in this area, are likely to sustain substantial damage.

49.9	0.3	Catalina Ave. Turn right.
50.4	0.5	Turn right onto Pontatoc Ave.
50.5	0.1	Turn left onto Skyline Dr.
50.7	0.2	Turn right onto Swan Rd.

50.8	0.1	Left side: De Grazia's Gallery.
51.7	0.9	Cross Sunrise.
53.7	2.0	Turn right onto River Road.
54.5	0.8	Dip Crossing: left side-note headcut migrating upstream, caused by sand and gravel excavation.
55.2	0.7	Pass by Dodge Blvd.
55.3	0.1	Right turn onto Sutton Lane (dirt road).
55.5	0.2	Cross Finger Rock Wash. The entire VisionQuest property is an active alluvial fan produced by a distributary of Finger Rock Wash.



12-14-79
1:12000
27-38

55.6 0.1 Left turn onto Roger Road.

55.8 0.2 Right turn onto River Road.

56.3 0.5 Note wash with headcut: left side (Valley View Wash).

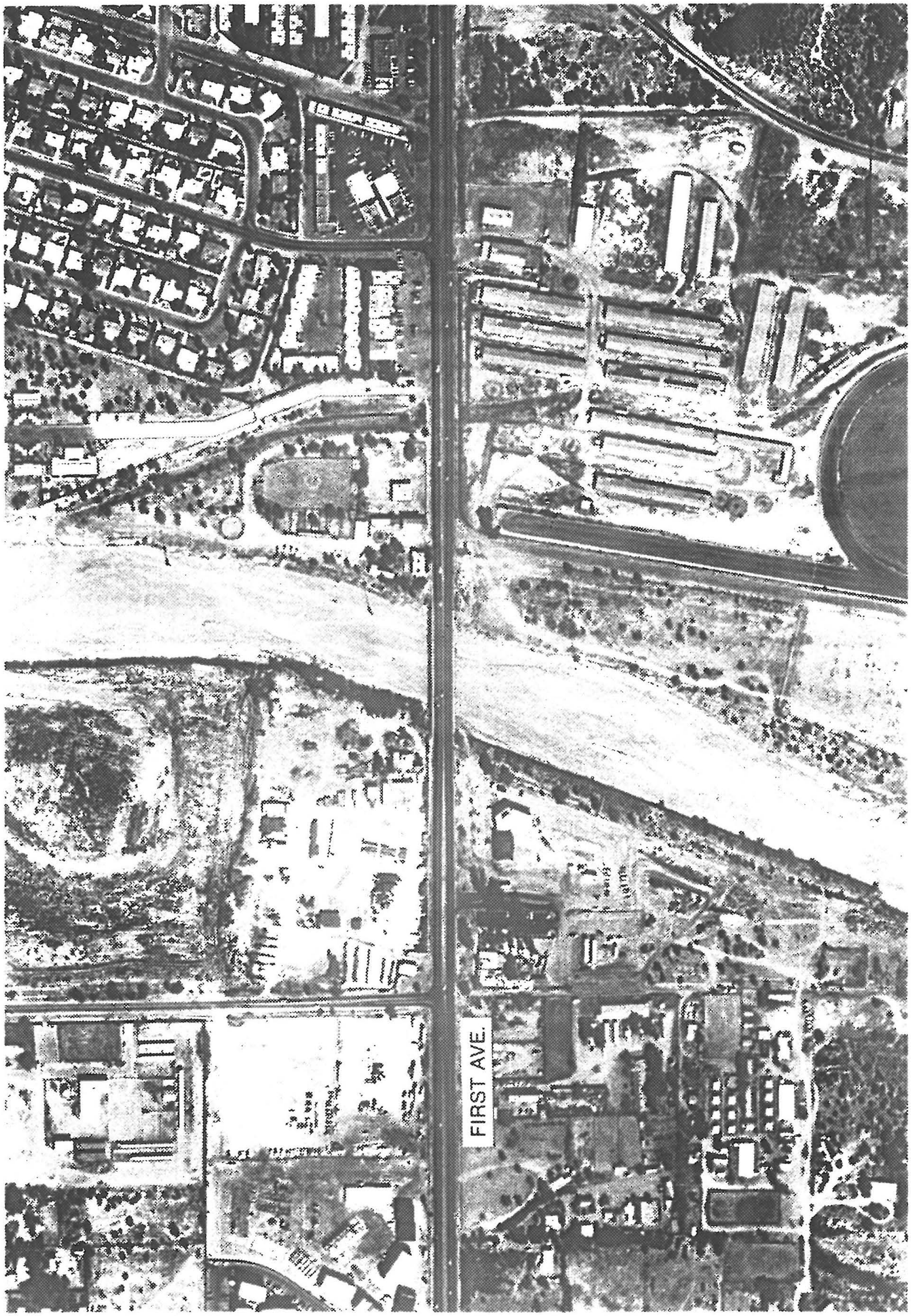
57.4 1.1 Cross Campbell Ave. Note extensive development along upcoming section of road, made possible with bank protection.

58.6 1.2 Left turn onto 1'st Ave.

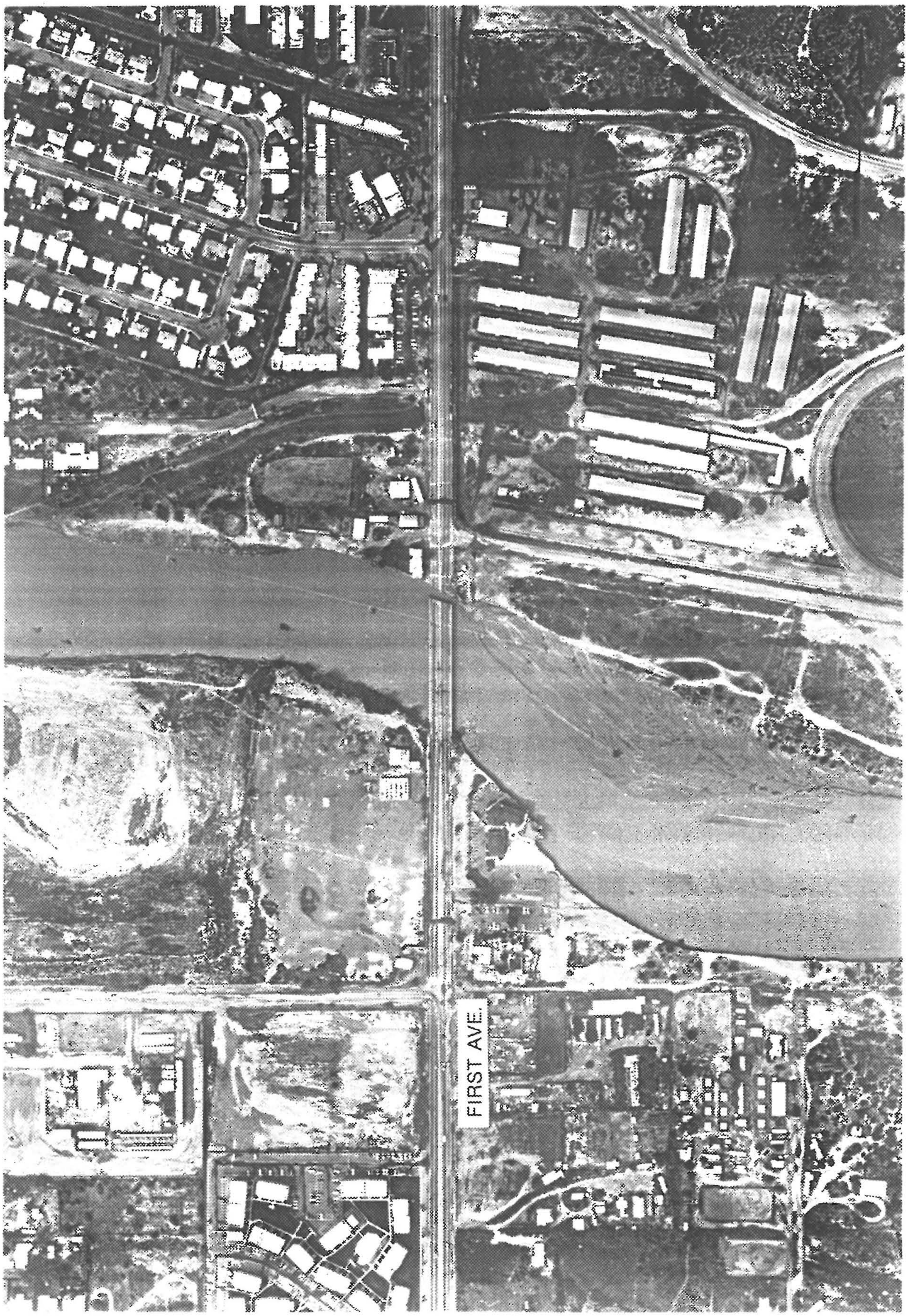
59.1 0.5 STOP. Cross bridge over Rillito River. Left turn into first paved road of small building complex (before traffic light). Continue straight on access road to river bank.

Rillito Creek at First Avenue

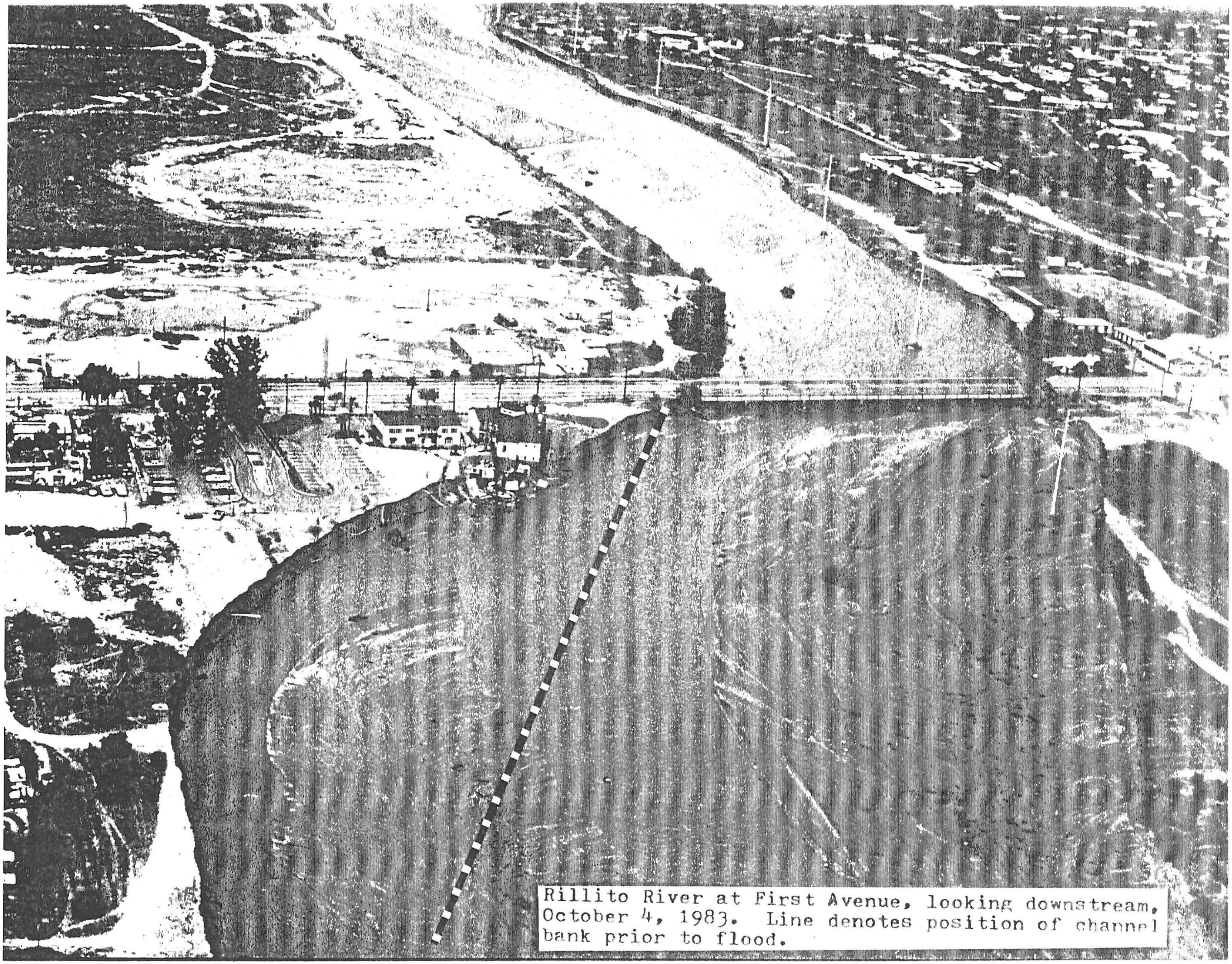
This portion of Rillito Creek has frequently experienced severe channel bank erosion during flow events of widely varying magnitude. Because of the existing alignment of the river at this location, flow impinges on the southern bank of the channel where it is deflected to the northern bank. At least twice in recent history, in December, 1965 and October, 1983, this erosional pattern occured, resulting in the loss of and emergency repair of the northern abutment of the First Avenue bridge. In October, 1983, severe erosion of the bridge resulted in complete undermining and destruction of a newly constructed office building. The banks of this reach of Rillito Creek have since been stabilized with soil cement.



Rillito River at First Avenue-downstream to left.
Pre-1983 flood.



Rillito River at First Avenue-downstream to left.
post 1983 flood.



Rillito River at First Avenue, looking downstream, October 4, 1983. Line denotes position of channel bank prior to flood.

Rillito River at First Avenue, looking upstream, February, 1986. Channel banks have been lined with soil cement.

References

Aldridge, B.A., 1970, Floods of November 1965 to January 1966 in the Gila River Basin, Arizona and New Mexico, and Adjacent Basins in Arizona: U.S. Geological Survey Water-Supply Paper; 1850-C, 176 p.

Arizona Department of Health Services, 1983, Possible Sources of Groundwater Contamination in the Tucson International Airport Area, Draft Report.

Baker, V.R., 1984, Questions raised by the Tucson Flood of 1983, in Proceedings, American Water Resources Association and the Hydrology Section, Tucson, April, 1984: Arizona-Nevada Academy of Sciences, v. 14, p. 211-219.

Betancourt, F. and R.M. Turner, in press, Historic arroyo-cutting and subsequent channel changes at Congress Street crossing, Santa Cruz River, Tucson, Arizona; U.S. Geological Survey Water Supply Paper.

Cheek, L.W., 1984, San Xavier Del Bac, Dove of the Desert: Tucson Citizen magazine, p. 1, Saturday, January 18, 1986.

Clark, S., 1983, Determination of the Potential Impact of Land Disposal of Solid Waste Upon the Groundwater Resources of the Tucson Basin, Pima County, Arizona, Term Paper, University of Arizona.

Cooke, R.U., and R.W. Reeves, 1976, Arroyos and Environmental Change in the American Southwest, Oxford, Clarendon Press.

Gordon, J.P., 1983, Channel Changes on the lower Canada Del Oro, 1936-1980, and policies of Flood Plain Management; unpublished M.S. manuscript, University of Arizona.

Hays, M., 1984, Analysis of Historic Channel Change as a Method for Evaluating Flood Hazard in the Semiarid Southwest: prepublication manuscript, University of Arizona.

Hoelle, J.L., 1976, Structural and geochemical analysis of the Catalina Granite, Santa Catalina Mountains, Arizona, unpublished M.S. manuscript, University of Arizona.

Lingrey, S.H., 1982, Structural geology and tectonic evolution of the northeastern Rincon Mountains, Cochise and Pima counties, Arizona, unpublished Ph.D. dissertation, University of Arizona.

Moordian, M.M., 1980a, Landfill leachate and groundwater quality analysis: Ina Road Landfill, Volume I, Pima Association of Governments 208 Project.

Moordian, M.M., 1980b, Landfill leachate and groundwater quality analysis: El Camino del Cerro Landfill, Pima Association of Governments 208 Project.

Pearthree, M.S., 1982, Channel Change in the Rillito Creek System, Southeastern Arizona; Tucson: prepublication manuscript, University of Arizona.

Percious, J.K., 1968, Geochemical investigation of the Del Bac Hills volcanics, Pima County, Arizona, unpubished M.S. manuscript, University of Arizona.

Phillips, M.P., 1976, Geology of Tumamoc Hill, Sentinel Peak and vicinity, Pima County, Arizona, unpublished M.S. manuscript, University of Arizona.

Pima County Department of Transportation and Flood Control District, 1985, Final Documentation, October, 1983, Flood Damage Report.

Pima County Department of Transportation and Flood Control District, in preparation, Santa Cruz River Management Plan Study, Technical Report by Simons Li and Associates, Inc.

Saarinen, T., V.R. Baker, R. Durrenberger and T. Maddock, 1984, The Tucson, Arizona, Flood of October 1983. Report of the Committee on National Disasters, National Research Council, National Academy Press, Washington, D. C.

Wilson, L.G., S.J. Keith and H.R. Fitch, 1982, Cortaro Area pollution source assessments, Pima Association of Governments 208 Project.

FIELD NOTES AND SKETCHES

[Original contains four sheets]

FIELD TRIP
HANDOUTS

DISCHARGE	SETBACK DISTANCE
MAJOR WATERCOURSES	
RILLITO CREEK SYSTEM	500
SANTA CRUZ RIVER	
CANADA DEL ORO WASH	
$Q_{100} > 10{,}000$ CFS	250
$Q_{100} \leq 10{,}000$ CFS	100
MINOR WATERCOURSES	
$Q_{100} \leq 3{,}000$ CFS	50

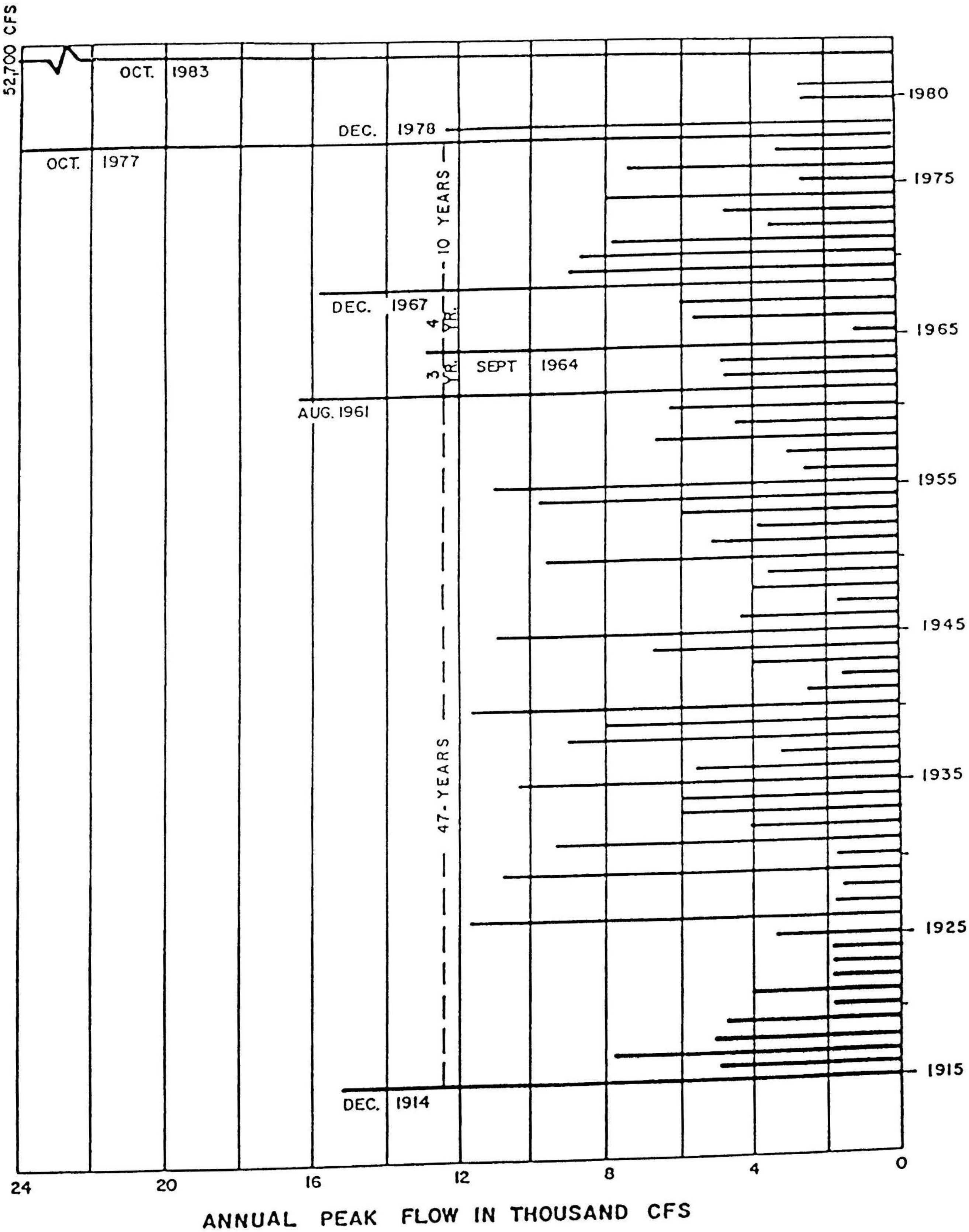


Figure 3.1 - Santa Cruz River annual peak flows at Congress Street Gaging Station.

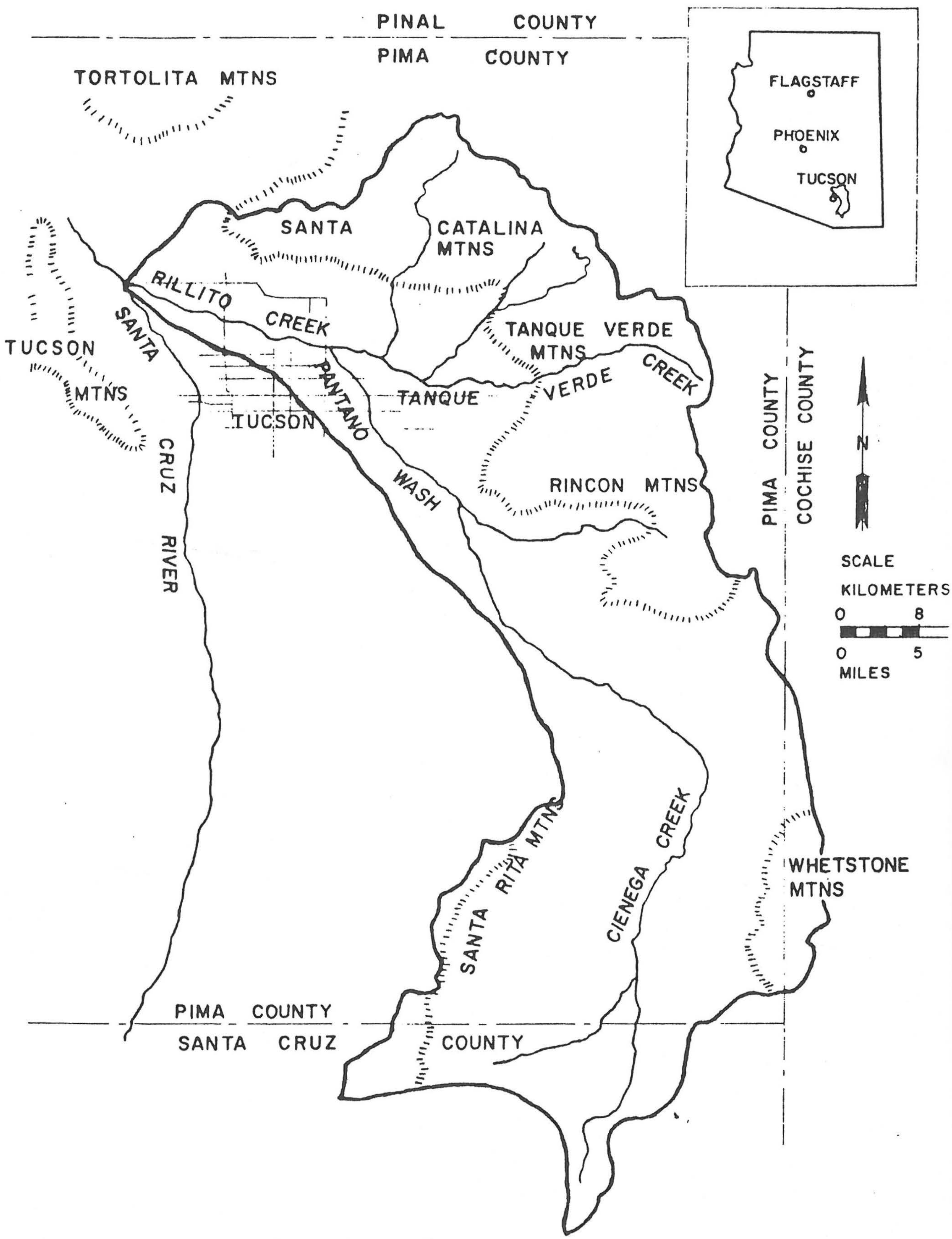
Santa Cruz River at Martinez Hill

Channel bank erosion and lateral channel migration of alluvial ephemeral streams constitute very real hazards to the southwestern United States. In addition to the loss of millions of dollars in property damage, frequent changes in cross-sectional geometry and position of such stream channels create uncertainties for floodplain management in this region. Federal floodplain management regulations, formulated by Congress in response to past and potential loss of life resulting from flooding, form the basis for floodplain management. These regulations address flooding on a national basis, and do not consider regional differences in stream channel behavior such as bank erosion and lateral channel migration.

The first stop of this field trip illustrates the erosional problems associated with alluvial stream channels. Historical photos of the Santa Cruz River from 1941 to October 1983 at this location, north of Martinez Hill. illustrate typical changes in channel width, pattern, and position over time of this stream channel, and numerous other alluvial channels of the southwest. In response to the past erosional problems at this site documented in the photographs along with concern for the continued integrity of the Interstate highway (I-19), located adjacent to the east bank of the river, the Arizona Department of Transportation (ADOT) has provided several levels of channel protection consisting of wire rock with rails along the current low-flow channel bank, and posts and tetrahedrons within the channel. These measures were implemented between 1965 and 1972 to protect the San Xavier Loop bridge and the later I-19 bridges.

The U.S. Geological Survey has operated a continuous recording gage at the Congess St. crossing of the Santa Cruz River from 1915 to 1981, and one at the Cortaro Road crossing further downstream since 1940. A summary of the annual peak flows measured at Congress St. are shown on an accompanying graph. The largest flows of recent years occured in October 1977 and October 1983 as a result of tropical storms from the Pacific Ocean. The flood of October 1983 caused widespread damage to public works, utilities, and private property along the river. The majority of the damage was caused, not by overbank flooding, but by the processes of local bank erosion, streambed scour, general channel widening and lateral channel migration, and formation of new channels by a process termed avulsion (Pima County Department of Transportation and Flood Control District, 1986). Total failure of the San Xavier Loop bridge and the northbound portion of the I-19 bridge occured at Martinez Hill as a result of channel bank scour and migration of the southern/western bank of the river to the southwest. Note the extensive width of the channel (750 to 1250 feet) through this reach of the Santa Cruz. Further downstream at Grant Road, the channel narrows to as little as 300 feet.

As a result of the October 1983 flood, the bridges have been rebuilt and their abutments have been stabilized with soil cement. Soil cement bank stabilization, constructed at various locations along the Santa Cruz River and its tributaries, proved to be a highly effective form of erosion control during the October 1983 event (Pima County Department of Transportation and Flood Control District, 1986).



Major drainage basins of the Tucson area.

FIGURE 6.1
EROSION HAZARD BOUNDARY MAP

PLATE 5