ALLUVIAL FAN DATA COLLECTION AND MONITORING STUDY

FOR THE

FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

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MARCH 1992

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Final Report

For the

Flood Control District of Maricopa County

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March 1992

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Acknowledgments

CH2M HILL would like to thank several individuals without whom successful completion of this project would not have been possible. Steve Waters, of the Flood Control District of Maricopa County, served as project manager and provided excellent guidance and support throughout the project. Insightful review comments were provided by Phil Pearthree of the Arizona Geological Survey, Win Hjalmarson of the U.S. Geological Survey, Jim Morris of the Arizona Department of Water Resources, Kyle House of the University of Arizona, Terri Miller of the Association of State Floodplain Managers Arid West Committee, Chuck Williams of the Arizona Floodplain Management Association Technical Review Committee, William Locke of the Federal Emergency Management Agency, Collis Lovely of the City of Scottsdale, and George Sabol of George V. Sabol Consulting Engineers, as well as many others who have informally contributed to this project. Subconsultants for the project were Richard H. French, Hydraulic/Hydrologic Consulting Engineer, Kinney Aerial Survey, Inc., and Brady-Aulerich Survey, Inc. Jay Livesay, of A-TEK, Inc. provided information and cost opinions for electronic gauging equipment. Most importantly, CH2M HILL would like to thank the Flood Control District of Maricopa County for the opportunity to participate in the Alluvial Fan Data Collection and Monitoring Study.

Executive Summary

The Alluvial Fan Data Collection and Monitoring Study was proposed by the Flood Control District of Maricopa County (FCDMC) in response to concerns expressed by the scientific and technical communities regarding the lack of measured data from actual flood events on alluvial fans. The Alluvial Fan Study consisted of two parts. For Part I of the Study, the existing alluvial fan data base was surveyed for pertinent information, the types of alluvial fans found in Maricopa County were defined and classified, four representative alluvial fan sites were selected, and hydrologic and geomorphic data were collected for each site. For Part II, data collection plans were developed for each alluvial fan site designed to quantify the types of flood processes described in Part I.

Three types of alluvial fans were found in Maricopa County: active alluvial fans, distributary flow systems, and inactive alluvial fans (fan terraces). An active alluvial fan is, in geologic time, a recently formed aggrading (depositional) landform, characterized by channel migration and deposition of sediment on the fan surface. In engineering time, an active alluvial fan may experience localized or concurrent erosion and deposition. Active alluvial fan processes are probably most like those assumed by the alluvial fan model currently approved by FEMA. Inactive alluvial fans are degrading (erosional) landforms characterized by dendritic drainage patterns and channel erosion. Distributary flow systems are landforms characterized by radiating drainage patterns similar to those found on active alluvial fans. Key characteristics of each type of alluvial fan are listed in a fan identification matrix.

An alluvial fan identification matrix was developed and used to classify over 40 potential data collection and monitoring sites in Maricopa County. Individual sites were evaluated and rated using a scoring matrix and subjective factors. Four alluvial fan sites were selected for further analysis and instrumentation. The four sites and categories are: (1) South Mountain Park, a natural distributary flow system; (2) White Tank Mountains, a natural distributary flow system and inactive alluvial fan with potential for urbanization in the future; (3) Tiger Wash, a natural distributary flow system and natural active alluvial fan; and (4) Sierra Estrella, a natural active alluvial fan. Urbanized and rapidly urbanizing alluvial fans were not selected because of the likelihood that structural improvements would probably prevent fan processes from occurring, and because any flooding on urbanized fans can be adequately monitored by residents.

Detailed descriptions of each of the four alluvial fan data collection sites selected were prepared. These descriptions included land use and jurisdictional information, soils and vegetation details, geologic and geomorphic data, and hydrologic data, including a flood history. These data were gathered from existing sources as well as from field investigations at each site. Maps detailing this information were also prepared.

Data collected at the four alluvial fan instrumentation sites revealed regional trends in the geomorphology of alluvial fans in Maricopa County. These regional trends indicate that vegetation, soil and sediment, and certain measurable geomorphic indices may be used to identify types of alluvial fans, but that field investigation by trained geomorphologists is also required in some cases. The evidence collected for the four instrumentation sites suggests that the FEMA alluvial fan model may not accurately portray flood risk on active alluvial fans or distributary flow systems in Maricopa County. Collection of actual flood data will be required to verify this hypothesis.

Instrumentation and monitoring plans were developed for each site which reflect the site specific hydrologic and geomorphic characteristics, design guidelines for the project, and the ultimate intended use for collected data. Site characteristics to be monitored include regional weather, rainfall, runoff, sediment transport, transmission loss, channel migration, scour and bank erosion, and fan aggradation. Gauging and monitoring techniques recommended include real-time telemetry, automatic and manual techniques, remote sensing, and digital topographic modeling using GIS software. Specific gauge types recommended include ALERT weather stations, precipitation gauges, pressure transducers, float, and crest stage gauge streamflow stations, turbidimeters and automatic suspended/bedload samplers for sediment, scour chains and surveys for scour, and NOWrad imaging for weather monitoring.

Planning-level opinions of probable cost for acquisition, installation, and maintenance of the recommended gauging and monitoring system were developed. The total order-of-magnitude cost to begin the alluvial fan monitoring program was estimated at about $180,000, not including an estimated 450 mandays of labor. Annual order-of-magnitude costs (1992 dollars, no adjustment for inflation) were estimated at about $30,000, not including 530 mandays of labor.

The FCDMC Alluvial Fan Data Collection and Monitoring Study represents the state-of-the-art in proactive floodplain management. Data collected in the instrumentation phase of the project will be used to develop new alluvial fan floodplain models, determine safe development standards for several types of alluvial fans, and may ultimately relieve landowners of unsafe or unfair floodplain restrictions imposed by use of the FEMA alluvial fan model, or other inappropriate modeling techniques.

The information collected in this study indicates that a practical and cost-effective instrumentation system can be designed which will advance the state-of-the art in floodplain management. The data collected will yield information which promote public safety and sound floodplain management. Responses and review comments from public and private agencies contacted in Part I confirms that systematic documentation of alluvial fan flooding is critically needed. Instrumentation of the four alluvial fans will facilitate this documentation. Therefore, it is recommended that the FCDMC proceed with the data collection and instrumentation of the Alluvial Fan Data Collection and Monitoring Study according to the design guidelines outlined in this report.

Introduction

The Alluvial Fan Data Collection and Monitoring Study was proposed by the Flood Control District of Maricopa County (FCDMC) in response to concerns expressed by the scientific and engineering communities regarding the lack of measured data from actual flood events on alluvial fans. Measured field data are needed to increase the fundamental understanding of hydrologic and geomorphic processes which occur on different types of alluvial fans. Data from this study will be used to improve the accuracy of hydrologic models of arid region alluvial fan flooding. These data will also be used to develop a design manual for alluvial fan management, fan identification, and design of structures. In addition, this study will provide data regarding sediment transport, sediment yield, flood attenuation including transmission losses, rainfall distribution, and channel migration and erosion in an arid environment.

Project Goals

The goal of this study is to design a systematic data collection network for four alluvial fans in Maricopa County. When implemented, long-term monitoring of the gauging networks designed in this study will provide the data required to develop and calibrate new models of alluvial fan flooding, and will document the types and frequencies of flood hazards experienced on alluvial fans.

The specific goals of the study are:

Part I

1. Select four sites for instrumentation.
2. Develop detailed site analyses for each site.
3. Identify geomorphic, hydrologic, and hydraulic processes typical of each alluvial fan site.

Part II

4. Select equipment and procedures capable of quantifying processes characteristic of each alluvial fan site.
5. Prepare instrumentation plans for each of the sites.
6. Develop a guide for implementation of the data collection system, monitoring, data archiving, and data analysis for use by FCDMC personnel.

Project Limits

The study limits are the boundaries of Maricopa County, the jurisdictional area of the Flood Control District of Maricopa County. Potential data collection sites included any of the mountain piedmonts and alluvial plains within the County. Figure 1 illustrates some of the key features in the study area.

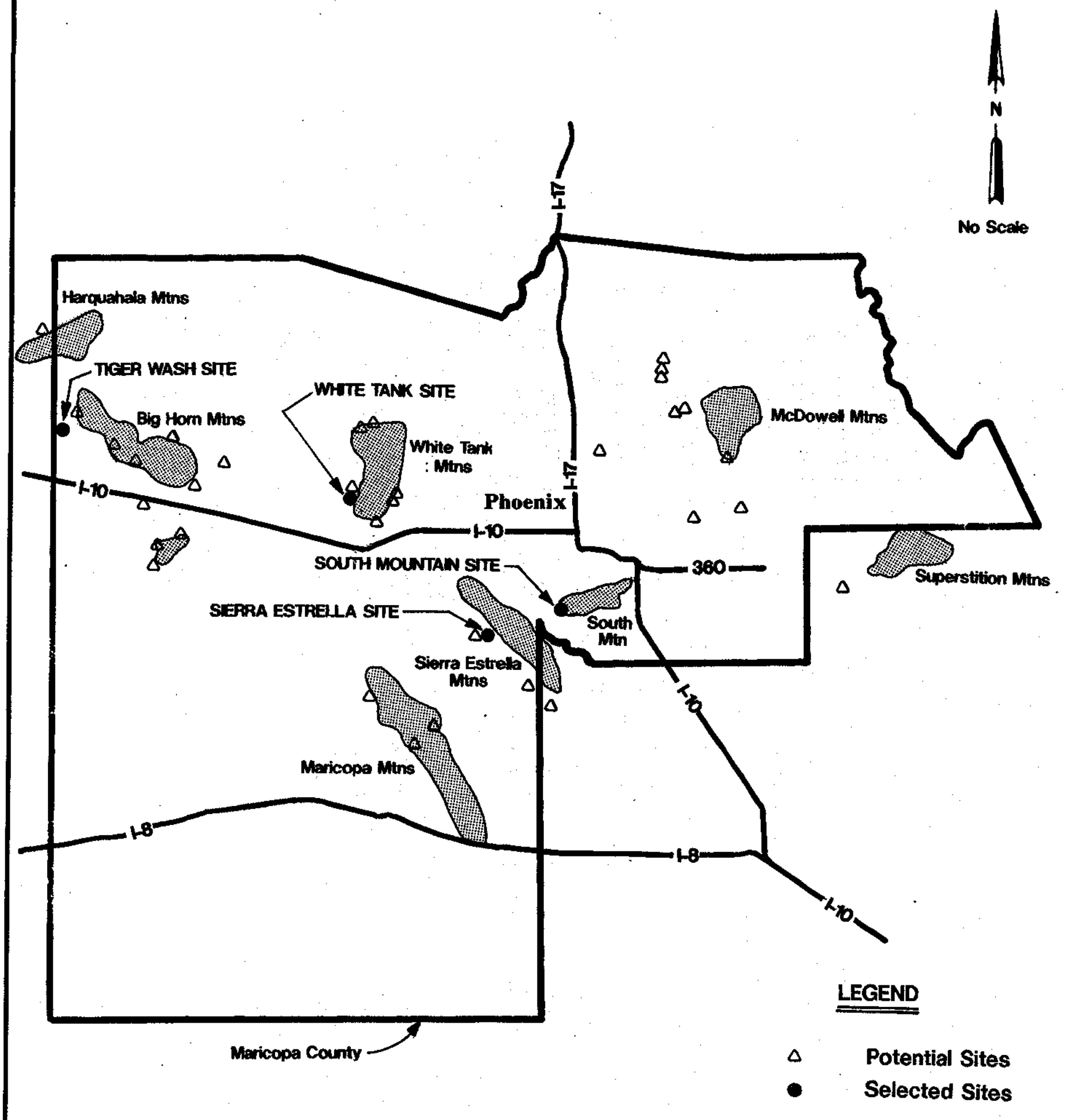

Figure 1

STUDY LIMITS AND SITE LOCATIONS

CH2M HILL

Authorization

This study was performed for the Flood Control District of Maricopa County under contract number FCD 90-22. The work for Part I was performed from November 1990 to July 1991. Part II of the study was completed between August 1991 and March 1992. This study was conducted by CH2M HILL in association with Richard H. French, Ph.D, P.E.

Part 1
Project Background

Alluvial Fan Controversy

Over the past five years, hydraulic modeling of alluvial fan flooding has become a source of controversy in Arizona and the southwest. Most of the controversy stems from the use of the alluvial fan model adopted by the Federal Emergency Management Agency (FEMA). The FEMA alluvial fan model is used to map flood hazards and set design criteria on alluvial fans throughout the United States. The consensus of Arizona engineers and floodplain managers is that the FEMA model is not applicable to most fans in Arizona (Fuller, 1990). However, lack of measured data from actual alluvial fan flooding has prevented development and calibration of new models (Ward, 1989). Because up to 30 percent of the developable land area in the southwest lies on alluvial fans of all types (Johnston, 1989; Anstey, 1965) and because the focus of floodplain management is shifting to non-riverine sources of flooding, accurate alluvial fan modeling is becoming increasingly important.

Definitions

Recent research concluded that a wide variety of alluvial fan types are found in the western United States. To accurately and consistently classify the unique types of alluvial fans found in Maricopa County, definitions for arid region alluvial fans and associated features were proposed. Because many of the descriptive terms used in this report may be unfamiliar to some readers, a glossary of key terms is provided at the end of this report.

Definitions for alluvial fans in the literature can be generalized into two types: definitions which describe a landform, and definitions which refer to processes (for example: Ward, 1989; French, 1987). The landform definitions tend to be more general, and recognize that fans are found in all climates, with highly variable watershed characteristics and geomorphic processes. The landform definitions describe only one geologic process: deposition of alluvium in a fan-shaped pattern. Therefore, landform definitions include many types of alluvial fans.

Process-oriented definitions of alluvial fans describe specific hydraulic and geomorphic processes which occur on some types of fans and are of interest to special interest groups, such as floodplain managers. These specific hydraulic and geomorphic processes occur on individual alluvial fans as a result of basic geologic, climatic, or anthropological characteristics unique to each type of fan. Thus, it is appropriate to classify alluvial fans by the types of processes which are likely to occur, while recognizing that each type of fan still fits into the broader category of landforms called alluvial fans.

For the Alluvial Fan Data Collection and Monitoring Study, the term "alluvial fan" will refer to a broad class of depositional landforms which are usually fan-shaped in plan view (Figure 2). In this study, use of the term "alluvial fan" does not imply the existence of any specific processes, such as those implied by FEMA's current definition of alluvial fans, which is given below. A landform-type definition of the term "alluvial fan" is appropriate because it does not limit consideration of features that look like (but do not act like), or act like (but do not look like) fans. This broader usage of the term "alluvial fan" in this study conforms with its use in the geologic literature.

This study, however, is chiefly concerned with monitoring specific processes ascribed to alluvial fans. Therefore, process-type definitions are proposed to describe specific types of arid region alluvial fans which exhibit specific processes. Because alluvial fan processes have yet to be gauged and quantified in Maricopa County, occurrence of specific processes are inferred from the geomorphic record and from field experience.

For this study, three types of arid region alluvial fans are defined: 1) active alluvial fans, 2) inactive alluvial fans (a.k.a. "fan terraces"), and 3) unconfined distributary flow systems (a.k.a. distributary flow areas--"DFAs"). These definitions represent points on a continuum of fan types. Active and inactive fans are end members of the continuum. DFAs are intermediate members. Each of these fan types may be urbanized or may remain natural, as defined below.

Definitions of key terms used in this study are as follows:

- **Natural.** A natural fan is one where the drainage pattern of the fan surface and upstream watershed have not been directly modified by agriculture, grading, or construction of homes, businesses, or roads; is zoned to remain in its existing condition; is not irrigated; and experiences runoff only in response to rainfall or groundwater return flow.

- **Urbanized.** An urbanized fan is one which has been modified by agriculture, grading, or building construction, or is traversed by improved roads which alter pre-construction flow paths.[1]

- **Engineering Time Scale.** For this study, an engineering time scale is a period less than 1,000 years. For certain applications such as hazardous or radioactive waste storage, engineering time concerns may approach geologic time limits.[2] An "engineering time scale" is largely a political or

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[1] The intent of selecting an urbanized alluvial fan is to monitor the changes which are caused by altering the watershed and the alluvial fan surface. Therefore, for this study, the optimum site will continue to become more urbanized, but the natural drainage pattern will remain evident.

[2] Inherent in the assumption of the definition of an engineering time scale is the assumption of stationary time series of causative processes such as precipitation.

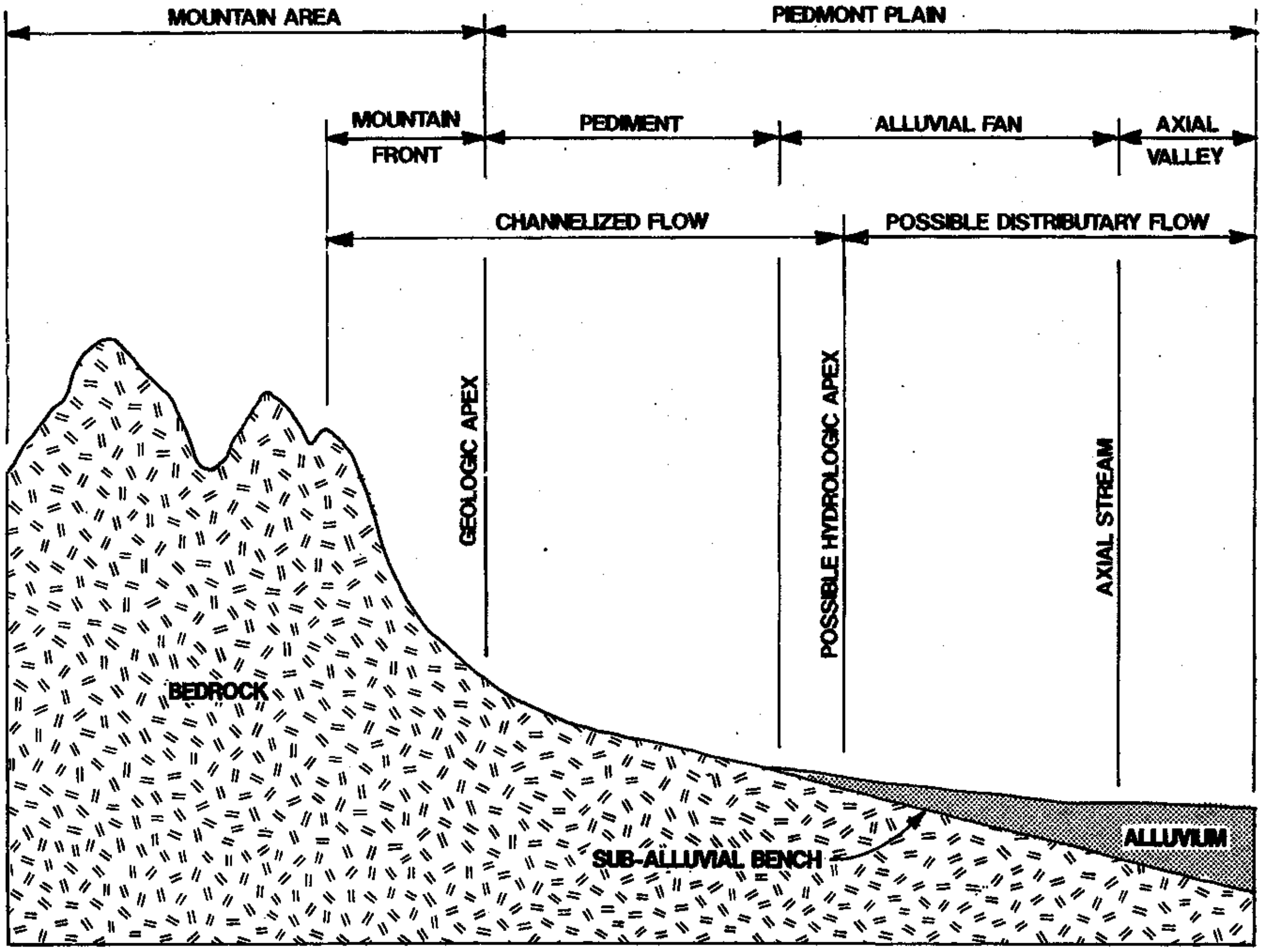

Figure 2

CROSS SECTION OF IDEALIZED PIEDMONT

regulatory issue. Most floodplain management applications are concerned with periods of 100 years or less.

- **Geologic Time Scale.** For this study, a geologic time scale is a period greater than 10,000 years. Greater age resolution, up to 1,000 years, may be possible for some Holocene-aged (Table 8) geologic features.

- **Geologic Apex.** The intersection of the mountain front and the piedmont. Alluvial fans may not be located adjacent to a mountain front. Therefore, all alluvial fans do not have geologic apexes.

- **FEMA Apex.** "'Apex' means a point on an alluvial fan or similar landform below which the flow path of the major stream that formed the fan becomes unpredictable and alluvial fan flooding can occur." (FEMA, 1990)

- **Hydrologic Apex.** The point where the primary alluvial fan channel splits into two or more channels. The primary alluvial fan channel is the single channel which exits the mountain front or source watershed.

- **FEMA Alluvial Fan Flooding.** "Alluvial fan flooding means flooding occurring on the surface of an alluvial fan or similar landform which originates at the apex and is characterized by high-velocity flows; active processes of erosion, sediment transport, and deposition; and unpredictable flow paths." (FEMA, 1990)

- **Active Alluvial Fan.** An active alluvial fan is an aggrading (depositional) landform. Overall fan aggradation occurs on both an engineering and geologic time scale. Active alluvial fans are formed where sediment supply exceeds sediment removal. Factors which can cause alluvial fan aggradation are climatic change, tectonic activity, or significant watershed changes. Of the types of fans found in Maricopa County, active alluvial fans are most like FEMA alluvial fans.

- **Inactive Alluvial Fan (Fan Terrace).** An inactive alluvial fan is a degrading (erosional) landform. Degradation occurs in geologic time. In engineering time, local aggradation may occur, though erosion occurs more frequently. Inactive alluvial fans are found where overall sediment removal exceeds sediment supply. Factors associated with fan degradation include tectonic and climatic quiescence, limited upstream sediment supply (resistant bedrock, slow soil formation, reservoir or debris basin construction), and base level fall.

- **Unconfined Distributary Flow System (DFA).** Unconfined distributary flow systems are relatively stable[3] stream networks within engineering time. They are characterized by balanced sediment transport, but with strong local aggradation-degradation components. Within geologic time, DFAs experience more degradation than aggradation. DFAs are typically found in distal parts of piedmonts adjacent to tectonically inert mountain ranges, often near zones of secondary entrenchment. DFAs are landforms which may be unique to the desert southwest. Refinement of DFA process descriptions requires more data, including real time monitoring.

Fan Identification

The types of alluvial fans found in Maricopa County are defined by their hydrologic and geomorphic processes. Physical evidence of these processes found on the fans can be used to help identify alluvial fan types in the field. Some of these processes are described below. A matrix summarizing key identifying characteristics is provided in Table 1.

Active Alluvial Fans

Processes associated with aggradation on active alluvial fans include channel migration within engineering time, debris flows, hyper-concentrated sediment transport, channel bank erosion, local bed scour, and flash flooding. Active alluvial fan processes may be identified[4] by geomorphic evidence such as:

- Bifurcating channel patterns which radiate outward (i.e., the number of flow paths increase in the downstream direction).
- Low channel capacity relative to significant flood events (e.g., two-year to ten-year flood not contained within channel banks).
- Channel capacity decreases in the downstream direction.
- Abandoned, discontinuous, or in-filled channels.

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[3]While the channel pattern on distributary flow systems is generally stable, predicting exact flood depths and velocities in portions of the distributary flow systems may not yet be possible. For instance, the numerous bifurcations in a distributary flow channel or in a sheet flooding zone make it difficult to accurately predict how flow will be distributed between channels on the fan. However, geomorphic and historical evidence can show that flooding will occur in existing channels or as sheet flooding rather than cut new channels through stable surfaces. Improvement in two-dimensional and sediment transport modeling techniques may improve prediction capabilities.

[4] Not all of these indicators need to be present for the landform to be classified as an active alluvial fan. These processes may not occur on active alluvial fans in humid or alpine environments.

Table 1
Characteristics of Arizona Alluvial Fans

FEMA ALLUVIAL FAN	ACTIVE ALLUVIAL FAN	INACTIVE ALLUVIAL FAN	DISTRIBUTARY FLOW SYSTEM
Radiating Channel Pattern	Radiating Changes to Sheet Flow	Tributary Drainage Pattern	Radiating Changes to Tributary
Abandoned/Discontinuous Channels	Abandoned/discontinuous Channels	Continuous Channels	Discontinuous Channels
Unpredictable Channel Location	Frequent Channel Movement	Stable Channels	Rare Channel Movement
Channel Movement by Avulsions	Stream Capture or Avulsions?	No Channel Movement	Channel Movement by Stream Capture
Channelized Flow (No overbank or sheet)	Channel Flow Changes to Sheet Flow	Channelized Flow (overbank possible)	Channel Flow and Sheet Flow
Regular Channel Geometry	Variable Channel Geometry	Regular Channel Geometry	Variable Channel Geometry
Channel Capacity = Q	Low Channel Capacity	High Channel Capacity	Variable Capacity
Cumulative Capacity Constant Downfan	Capacity Decrease Downfan	Capacity Increase Downfan	No Definite Trend
Uniform Vegetation in Floodplain	Uniform Vegetation in Floodplain	Diverse Vegetative Community	Diverse Vegetation
Uniform Topography (Low crenulation)	Uniform Topography (Low crenulation)	Topographic Relief (High crenulation)	Medium to Low Topographic Relief
Debris Flows Important	Debris Flows Possible	No Debris Flows	Minor (or no) Debris Flows
Weak Soil Development	Weak Soil Development	Strong Soil Development	Variable Soil Development
No (or buried) Desert Varnish	No (or buried) Desert Varnish	Varnished Surfaces Possible	Varnished Surfaces Possible
No Caliche	No Caliche	Caliche Horizons	Caliche Horizons Possible
No Surface Reddening	No Surface Reddening	Surface Reddening	Minor Reddening
Overall Deposition	Overall Deposition	Overall Erosion	Local Erosion and Deposition
Slope Not a Factor	Slope Decrease Downfan	Slope Variable	Slope Increase @ Apex

- Uniform deposition of fine sediment across the fan surface.

- Debris flow levees of deposits below the geologic apex.

- Recent or ongoing deposition on geomorphically older surfaces.

- Lack of soil development, including caliche or clay soil horizons.

- Lack of near-surface reddening of soils; soils away from channels have the same color as channel bottoms or low-flow terraces.

- Minimal or no desert pavement development.

- Lack of desert varnish on exposed rock litter on interfluves or apparent terraces.

- Immature vegetative communities and bottomland-type plant species.

- Limited topographic relief along a transverse cross-section on the fan surface (smooth topographic contours/low crenulation index on 10-foot contour interval or greater mapping), lack of dissection of the fan surface by a dense dendritic tributary drainage systems.

- Lack of bedrock exposure on the fan surface or in channels (no inselbergs, not a pediment).

Inactive Alluvial Fans

Processes which occur on inactive alluvial fans include local sheet flooding, channel bank erosion, local deposition and scour, flash flooding, and hyper-concentrated sediment transport. Channel patterns on inactive alluvial fans are stable within an engineering time scale. Inactive alluvial fans typically are located adjacent to geologically stable mountain areas. Inactive alluvial fans may be identified[5] by geomorphic evidence such as:

- Development of a tributary drainage network (i.e., fewer number of channels in the downstream direction).

- Channel or overbank capacity for significant flood events.

- Continuous channels which increase capacity in the downstream direction.

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[5] Not all of these characteristics may be present on every inactive alluvial fan.

- Lack of recent deposition of sediments on the fan surface.
- No debris flows below the geologic apex, or debris flow activity confined to mountain slopes.
- Soil profile development, including Stage I through IV caliche, and subsurface clay horizon development.
- Surface reddening of soils.
- Desert varnish on exposed rock litter.
- Development of desert pavement surfaces.
- Development of mature vegetative communities.
- Significant topographic relief along a transverse cross-section (crenulated topographic contours/high crenulation index) with topographically isolated geomorphic surfaces.
- Bedrock outcrops in or between channels (inselbergs or pediment present); dissection of the fan surface by development of tributary drainages.

Distributary Flow Areas

Processes occurring on distributary flow areas include local scour and fill, divergent flow, stream capture, flash flooding, hyperconcentrated sediment transport, and shifting of runoff between existing channels due to vegetative or sediment debris dams. Distributary flow systems may be identified by geomorphic characteristics such as:

- Bifurcating or anastomosing channel patterns which may radiate outward in the downstream direction (may consist of a single channel bifurcation).
- Lack of channel capacity for significant flood events on individual flow paths.
- Channels which may be discontinuous in the downstream direction.
- Sheet flooding.
- No debris flow activity below the geologic apex.
- A broad floodplain with no discernable stream terraces, or terraces which do not correlate between channels.

- Variable soil development, except between more widely separated flow paths with some topographic relief.

- Minimal surface reddening of soils, except between more widely separated flow paths with some topographic relief.

- Lack of desert varnish or desert pavement development, except between more widely separated flow paths with some topographic relief.

- Vegetation transitional between mature communities, including riparian plants, and immature bottomland-type species.

- Low to variable topographic relief.

- Poorly defined channel banks.

- Stable, though not necessarily completely predictable, flow paths (compare channel pattern to historical aerial photographs).

- Bedrock inselbergs or a pediment surface may be present.

DFAs are difficult to distinguish from active alluvial fans. The key differences are the general lack of channel shifting, debris flow activity, and the age of geomorphic surfaces between channels as expressed by isolated soil, desert varnish, and desert pavement development.

Site Selection

The project definitions and identification matrix were used to classify potential data collection and monitoring sites. Individual sites were evaluated and rated quantitatively and qualitatively in order to select the optimum sites for alluvial fan gauging and monitoring.

Selection Process

The site selection process included several steps. First, potential sites were identified using Soil Conservation Service 7.5-minute orthophotographs and USGS 7.5- and 15-minute topographic maps of the entire county. Of the numerous sites identified, more than 40 potential sites were selected (Figure 1). Second, sites with no ground access or potential gauge sites were eliminated, reducing the number of potential sites to 23. Third, field visits to each fan accessible by a 4-wheel drive vehicle were made to assess the geomorphology of each site. Each fan was then assigned to one of six categories: natural active alluvial fan, urban active alluvial fan, natural inactive alluvial fan, urban inactive alluvial fan, natural distributary flow system, urban distributary flow system. Fourth, 21 sites which best fit categories of alluvial fans outlined in the scope of work were chosen for more detailed evaluation. Final selection of the four instrumentation sites was based on an objective scoring matrix as well as subjective factors.

Selection Criteria

Objective evaluation of the 21 potential gauging sites used a spreadsheet-based selection matrix. Each potential site was rated according to 33 criteria. Each of these criteria were weighted according to importance. Both the criteria and the weighting factors were chosen by FCDMC and CH2M HILL personnel. These criteria included gauging factors, the existing data base, hydrologic data, and geologic features. The products of the criterion weight values and a site's score for each criterion was summed to determine a site's overall rank within each of six categories of fan types. The completed matrix showing the six categories, evaluation criteria, weighting, and site point totals is shown in Table 2. The specific criteria and the rating values are fully described in a document entitled "Alluvial Fan Data Collection and Monitoring Study: Selection Matrix Criteria," submitted with Part I, Preliminary Report.

The site selection matrix was used to eliminate all but 10 sites from further consideration. The remaining 10 sites were evaluated independently by the project team and the FCDMC. This final evaluation was based on field experience and other factors, such as likelihood of completion of the City of Scottsdale's proposed "brown belt" channelization project.

As a result of this subjective analysis, the inactive alluvial fan (fan terrace) and urbanized alluvial fan categories were eliminated. Inactive alluvial fans behave like

Table 2. Site Selection Matrix

CRITERIA	WEIGHT (1-5)	CATEGORY: Natural Active Alluvial Fan				Urban Active Alluvial Fan			Natural Fan Terrace		
		HQ4-10-32	SE3-1-24	SE2-1-11	SE2-1-12	BH2-8-7	BH2-8-14	MD2-6-16	SB1-8-15	SB1-2-28	0-0-0
GAUGING FACTORS											
Access											
All-weather:	4	1	0	1	1	4	3	4	0	0	0
Roads:	3	2	0	2	2	3	3	3	2	2	0
Percent:	2	2	0	1	1	3	3	4	2	1	0
Land Ownership	4	4	4	3	3	3	2	0	3	3	0
Repeater Sight	2	4	0	0	0	4	4	4	0	0	0
Existing Gauges	2	0	0	0	0	0	0	0	0	0	0
Control Reaches											
Bedrock:	3	0	0	0	0	4	4	0	0	0	0
Location:	3	2	2	2	2	0	0	2	2	2	0
Attenuation:	3	4	0	0	4	4	4	0	4	0	0
Flood Structures											
Sediment:	4	0	0	0	0	0	0	4	0	0	0
Discharge:	4	0	0	0	0	4	4	4	0	0	0
Hinder/Assist:	4	0	0	0	0	-4	4	4	4	0	0
Fan Area	3	4	4	4	4	2	0	4	4	4	0
Distance to Site	3	2	0	2	2	4	4	2	2	2	0
Urbanization	2	4	4	4	4	2	4	2	4	4	0
Coalescing Fan	3	4	4	4	4	4	4	4	4	4	0
Vandalism	3	4	4	4	4	2	0	2	4	4	0
EXISTING DATA BASE											
Topographic Maps											
Contour/Scale:	4	0	2	2	2	2	2	2	4	0	0
Recent:	4	0	0	0	0	0	0	0	0	0	0
Percent:	4	0	0	0	0	2	2	0	1	0	0
Geologic Maps	2	4	0	0	0	0	4	4	0	0	0
Geomorphic Maps	4	0	0	0	0	0	0	0	0	0	0
Soils Maps	4	2	2	2	2	2	2	2	2	2	0
Bedrock Depth	2	0	0	0	0	4	4	0	0	0	0
Historic Aerials											
Oldest Photo:	4	0	0	0	0	0	0	0	0	0	0
Frequency:	4	0	0	2	2	2	2	2	0	0	0
Flood History											
Gage:	3	0	0	0	0	0	0	0	0	0	0
Paleoflood:	3	4	4	0	4	0	0	0	4	4	0
Anecdotal:	3	4	0	0	0	0	0	4	0	0	0
Vegetation Study	2	0	4	4	4	0	0	4	0	0	0
Hydrology	2	0	0	0	0	4	4	4	4	4	0
Archeology	2	0	0	0	0	4	0	4	0	0	0
OTHER FACTORS											
Cost Sharing opportunity	3	0	0	0	0	0	0	4	0	0	0
TOTAL SCORES		138	94	104	128	163	179	207	146	96	0

Table 2. Site Selection Matrix.

Urban Fan Terrace			Distributary Flow System – Natural						Distributary Flow System – Urban			
CATEGORY												
CC5-4-14*	CC5-4-23	0-0-0	WT2-4-12	WT2-4-13	HQ4-10-4	SB1-8-21	MC3-3-30	SM1-2-26	WT2-3-34	MD2-5-22	MD4-5-8	SP1-8-12
4	4	0	0	0	4	0	0	4	0	4	0	4
3	3	0	2	2	3	2	2	3	2	3	3	3
3	3	0	2	3	4	1	3	4	3	4	4	2
0	0	0	3	3	4	1	4	3	1	0	0	2
4	4	0	4	4	0	0	4	4	4	4	4	0
0	0	0	2	2	0	0	0	3	2	4	2	1
0	0	0	0	4	4	0	0	4	4	4	4	4
4	4	0	2	2	4	2	4	2	2	4	2	2
4	4	0	4	4	4	4	4	4	4	4	4	4
0	0	0	0	0	4	0	0	4	4	4	0	0
0	0	0	0	0	0	0	0	4	0	4	4	0
0	0	0	0	0	4	4	0	4	4	4	4	0
4	4	0	4	4	2	4	2	4	4	4	2	4
2	2	0	2	2	2	2	2	4	2	2	2	2
4	4	0	4	4	4	4	4	4	4	4	4	4
0	0	0	4	4	4	4	4	0	4	4	4	4
2	2	0	4	4	4	4	4	0	2	0	2	2
4	4	0	2	2	2	4	2	2	2	4	4	2
4	4	0	0	0	0	0	0	0	0	4	4	0
4	4	0	0	0	0	1	0	0	0	4	3	4
0	0	0	0	0	4	0	0	4	0	4	4	0
0	0	0	4	4	0	0	0	4	0	4	4	0
0	0	0	4	4	2	2	0	2	0	4	4	0
4	4	0	0	0	4	0	4	4	4	4	4	0
0	0	0	0	0	0	0	0	0	0	0	0	0
4	4	0	0	0	0	0	0	4	2	4	4	2
0	0	0	0	0	0	0	0	0	0	4	0	0
0	0	0	4	4	4	4	0	0	4	4	0	4
0	0	0	0	0	4	4	0	4	4	4	4	4
0	0	0	0	0	0	0	0	4	0	4	4	0
4	4	0	0	0	4	4	0	4	0	4	4	4
0	0	0	4	4	0	0	0	4	0	4	4	4
4	4	0	0	0	0	0	0	4	0	4	4	4
187	187	0	146	160	217	156	120	273	142	274	216	197

* Site Numbering refers to Township, Range, and Section.

typical arid west tributary drainage systems already gauged by the FCDMC. Therefore, the project team decided that little new information would be gained through additional instrumentation of these systems. Specific monitoring of inactive alluvial fans could be accomplished through periodic aerial photography or existing gauge systems. Heavily urbanized alluvial fans also may not behave like natural alluvial fans due to structural control of runoff and sedimentation. Because the goal of the study is to understand natural alluvial fan processes, monitoring urban sites would yield little new information. Because alluvial fan flooding on an urbanized fan would not pass unnoticed, adequate data collection from field and anecdotal evidence eliminates the need for sophisticated instrumentation. Potential sites near the McDowell and Phoenix Mountains were eliminated for these reasons.

The final subjective analysis was also based on the following criteria:

- Sites which combined two or more categories of fans were preferable to sites which had only one category of fan.

- Sites should be representative of the types of fans which are likely to be found in Maricopa County. Based on the preliminary analysis completed as part of this study, distributary flow systems and inactive alluvial fans probably make up about 90 percent of the alluvial fans found in Maricopa County.

- A key project goal is to understand the processes that occur on fans so that development and flood control structures can be designed accordingly. Therefore, natural sites are preferable to developed sites because processes occurring on developed fans may only occur on those fans with identical types of development.

Sites Selected

Four alluvial fan sites were selected for further analysis and instrumentation, and were assigned to the following categories. Site category assignments are tentative subject to review upon further study, data collection, and results of instrumentation. Site locations are shown in Figure 1. The four sites and categories are:

- **South Mountain Park.** Natural Distributary Flow System. SM1-2-26 in site selection matrix (Table 2).

- **White Tank Mountains.** Natural Distributary Flow System and Inactive Alluvial Fan. WT2-4-13 in site selection matrix (Table 2).

- **Tiger Wash.** Natural Distributary Flow System and Natural Active Alluvial Fan. HQ4-10-32 in site selection matrix (Table 2).

- **Sierra Estrella**. Natural Active Alluvial Fan. SE2-1-12 in site selection matrix (Table 2).

The following sites were recommended as alternatives:

- **Lost Dog Wash**. Urban Distributary Flow System. MD2-5-22 in site selection matrix (Table 2).

- **Granite Reef Site.** Urban Active Alluvial Fan. MD2-6-16 in site selection matrix (Table 2).

Site Descriptions

General Information

Detailed descriptions of each alluvial fan data collection site selected were prepared. These descriptions included land use and jurisdictional information, soils and vegetation details, geologic and geomorphic data, and hydrologic data, including a flood history. These data were gathered from existing sources as well as from field studies of each site as summarized in Table 3. Maps detailing this information were also prepared. Descriptions of the types of information utilized, data sources, and information common to all of the data collection sites are outlined below.

Land Use and Jurisdiction

All of the proposed alluvial fan sites are located within unincorporated portions of Maricopa County, except portions of the South Mountain site. Most of the South Mountain site is located within the City of Phoenix South Mountain Park. Land management within site watersheds includes the U.S. Bureau of Land Management (BLM), United States Department of Defense, Gila River Indian Tribe, State of Arizona, Maricopa County, City of Phoenix, and private. Ownership data are based on mapping published by the BLM (1979) and Maricopa County Assessor's records.

Soils and Vegetation

Soils and vegetation data were summarized from existing information and were field checked. Soils information was obtained from maps published by the USDA Soil Conservation Service (SCS, 1974; 1977; 1986). Geomorphic soils data for the White Tank Mountains were supplied by the Arizona Geological Survey (Pearthree, 1991). Geomorphic soil features mapped for individual sites are described in other sections of this report.

Six major soil associations are found within the study area. These types include the Ebon-Pinamt-Tremant (South Mountain), the Gunsight-Rillito-Chuckawalla (White Tank), the Gilman and the Momoli-Carrizo-Denure (Tiger), and the Torrifluvents and the Antho-Valencia (Sierra Estrella) Associations. These general soil groups are composed of clean sands, sandy loams, gravelly loams, cobbly loams, gravelly clay loams and rock outcroppings. Most soil units are calcic, and many areas have well-developed caliche (carbonate) layers at shallow depths. Surface soil features include desert pavement and desert varnish.

The SCS distinguishes at least two geomorphic landforms, including "recent alluvial fans" and "fan terraces." The SCS defines fan terraces as "relict alluvial fans, no longer a site of active deposition, incised by younger and lower alluvial surfaces" (SCS, 1986). SCS fan terraces are identified in the field by surface reddening, pavement development, at minimum a stage I carbonate horizon, uplands vegetation species, and

TABLE 3. LIST OF MAPS AND PHOTOS FCDMC ALLUVIAL FAN STUDY

	South Mountain	White Tanks	Tiger Wash	Sierra Estrella
Aerial Photo (source/date)	Rupp/1989	Corps of Engrs/1942	Landiscor/1951	Landiscor/1978
	SCS/1970	SCS/1970	SCS/1970	Rupp/1989
	Natl Archives/1936	BLM/1979	Landiscor/1979	SCS/1970
		Landiscor/1979	Rupp/1986	Natl Archives/1936
		Landiscor/1981		
		Rupp/1986		
		Rupp/1989		
Topo Maps (scale/source) (name/date)	24000/USGS Laveen/1973 Lone Butte/1973	24000/USGS Buckeye NW/1982 Wagner Wash Well/1988 White Tanks Mtns SE/1971 Valencia/1982	24000/USGS Weldon Hill(p)/1990	24000/USGS Avondale SE/1971
	4800/FCDMC Laveen Area Drainage Master Study/1990		62500/USGS Gladden/1961 Aguila/1962	
Soils Maps	100,000/AGS *Geologic Map of...* Alluvium...Phoenix South.. /1989	100,000/AGS *Geologic Map of...* Alluvium...Phoenix North.. /1988		100,000/AGS *Geologic Map of...* Alluvium...Phoenix Sout /1989
	380,160/USDA(SCS) Soil Survey of Maricopa Co, AZ Central Part/1977	380,160/USDA(SCS) Soil Survey of Aguila-Carefree... Maricopa and Pinal Counties, AZ/1986	380,160/USDA(SCS) Soil Survey of Maricopa Co, AZ Central Part/1977	380,160/USDA(SCS) Soil Survey of Maricopa Co, AZ Central Part/1977
	250,000/USGS Thickness of Alluvial Deposits/1969	250,000/USGS Thickness of Alluvial Deposits/1969	24,000/USDA(SCS) Aguila-Carefree... Maricopa and Pinal Counties, AZ/1978	250,000/USGS Thickness of Alluvial Deposits/1969
	Soil Associations Map (Date unknown)	Soil Associations Map (Date unknown)	Soil Associations Map (Date unknown)	Soil Associations Map (Date unknown)

TABLE 3. LIST OF MAPS AND PHOTOS FCDMC ALLUVIAL FAN STUDY

	South Mountain	White Tanks	Tiger Wash	Sierra Estrella
Vegetation Maps (scale/source)	250,000/USGS Map Showing Vegetation In The Phoenix Area Phoenix, Az.	250,000/USGS Map Showing Vegetation In The Phoenix Area Phoenix, Az.	250,000/USGS Map Showing Vegetation In The Phoenix Area Phoenix, Az.	250,000/USGS Map Showing Vegetatio In The Phoenix Area Phoenix, Az.
Land Use Maps (Source) (Book/Map/Sheet)	Maricopa County Assessor's Office 300,6,1 300,5, 300,7,1 300,7,2 300,4,1 300,4,2	Maricopa County Assessors Office 504,6,- 504,5,- 504,73,- Maricopa County Dept Plan/Devel Sheet C27/1987 100,000/BLM Surface Mgmt Status Phoenix North/1979	Maricopa County Assessors Office 506,14,- 100,000/BLM Surface Mgmt Status Salome/1978	Area Not Assessed
Geology (source/date)	Az Bur of Mines/1962 Geologic Cross Sections Az Bur of Geology and Mineral Technology/1985	Az Bur of Mines/1962 Geologic Cross Sections Az Bur of Geology and Mineral Technology/1985	Az Bur of Mines/1962 Geologic Cross Sections Az Bur of Geology and Mineral Technology/1985 USGS/1955 Map of Harquahala Plains Area, AZ	Az Bur of Mines/1962 Geologic Cross Sections Az Bur of Geology and Mineral Technology/198

stable channel pattern (Johnson, 1990). [Recent] alluvial fans are defined as "fanlike deposits of streams where they issue from a gorge upon on a plain..." (SCS, 1986). Recent alluvial fans are identified in the field by lack of soil development, recent stratified surface deposition, bottom land type vegetation, and by their position within the landscape (Johnson, 1990). Although SCS mapping of recent fans and fan terraces is generally not diagnostic, it often approximates geomorphic boundaries. The vast majority of near mountain piedmont surfaces in Maricopa County are mapped by the SCS as fan terraces.

Vegetative data were obtained from a general vegetation map for Maricopa County (USGS, 1974), and from published reports (Sundell, 1974; Estabrook, 1981). All four alluvial fan sites are located within a vegetative transition zone between the Lower Colorado Valley and Arizona Upland divisions (Estabrook 1981) of the Upper Sonoran desert climatic region. Sundell (1974) recognizes five discrete vegetative communities within the region: the Upper Sonoran Desert Scrub, Mountain Canyon and Desert Wash, Alluvial Plain, Gila River, and Disturbed Ground. Alluvial fans are typically found in the Upper Sonoran Desert Scrub/Desert Wash communities. Estabrook (1981) recognizes two principal biotic communities in the region: the Cercidium-Cereus (Palo Verde-Saguaro) of the more moist Arizona Upland, and the Larrea-Ambrosia (Creosote-Bursage) of the drier lower Colorado valley region. The latter occurs on less rocky slopes and flatter bajadas, and consists almost exclusively of creosote and bursage, except where small leaved trees occur along washes. The former is present on steep slopes, rocky hills, and coarse soiled slopes, and consists of a more diverse range of species, including numerous shrubs and cacti types.

There is some diversity of plant species between the different fan sites. These differences have less to do with differing alluvial fan processes than with climatic differences such as aspect, elevation, annual and/or recent precipitation, and soil conditions. Plant species observed at the alluvial fan sites are summarized in Table 4. Use of vegetation to delineate fan surfaces is described in the Discussion section of this report.

Table 4 Dominant Vegetative Species at Fan Sites			
South Mountain Park	**White Tank Mountain**	**Tiger Wash**	**Sierra Estrella**
STREAMBANKS			
Mesquite	Mesquite	Mesquite	Mesquite
Ironwood	Ironwood	Ironwood	Ironwood
Palo Verde	Palo Verde	Palo Verde	Palo Verde
Creosote	Creosote	Creosote	Creosote
		Catclaw	
		Salt Cedar	
FLOODPLAINS			
Creosote	Creosote	Creosote	Creosote
Bursage	Bursage	Bursage	Bursage
Grasses	Grasses	Grasses	Grasses
Cacti	Ocotillo	Palo Verde	Palo Verde
	Cacti		
	Palo Verde		
TERRACES			
Saguaro	Saguaro	Saguaro	Saguaro
Barrel Mutant	Barrel	Pencil Cholla	Jumping Cholla
Hedgehog	Jumping Cholla	Creosote	Cane Cholla
Pincushion	Creosote	Palo Verde	Barrel
Creosote	Palo Verde		Creosote
Palo Verde			Palo Verde

Climate and Hydrology

Climatic data are summarized from the SCS publications (SCS, 1986) and other sources. Hydrologic records consisted of precipitation gauge records and streamflow gauge records. These data were supplied by the FCDMC and the USGS. Field data included reconnaissance level mapping of recent flood debris, and paleoflood surveys for White Tanks Wash and Tiger Wash. Anecdotal accounts of flooding were collected from road maintenance crews, park supervisors and rangers, and County personnel.

The project sites lie within a semi-arid climatic zone. Summers in the project area are long and hot, with maximum daily temperatures averaging more than 90 °F. Winters are mild, with daily maximum temperatures generally ranging between 65 and 70 °F. Relative humidity averages 20 percent at mid-afternoon. The sun shines 90 percent of the time in summer and 80 percent of the time in winter.

Average annual precipitation varies between 7 and 11 inches, primarily as a function of elevation. Precipitation occurs during two major wet seasons. The first occurs during the winter months and is invoked by Pacific storms producing gentle, widespread showers and occasional snowfall at higher elevations. The second type occurs during the late summer to early fall and is characterized by violent, localized thunderstorms produced by orographic and convective affects on moist air originating in the Gulf of Mexico. Typically, 19 to 25 rainstorms greater than 0.1 inch occur each year.

Climate influences alluvial fan morphology through control of bedrock weathering rates, soil formation rates, and vegetative cover type and density, as well as control of the volume and frequency of rainfall and runoff. The semi-arid climate of Maricopa County favors weathering of granitic and gneissic bedrock to sand- and gravel-sized particles, rather than weathering of the rock types which form clays and silts. Consequently, washes and mountain slopes typically lack significant clay material. Sand on mountain slopes is usually more easily eroded than clay. Fan and mountain erosion rates generally exceed weathering and soil development rates in the study area. The lack of soil material on mountain slopes suppresses vegetative growth, and limits debris flow potential.

Maricopa County rainfall patterns also contribute to alluvial fan formation. Intense localized rainstorms cause flash floods and rapidly remove loose weathered material from mountain slopes and wash bottoms. Because runoff is uncommon and flashy, channels do not have sufficient time to adjust their geometry to a specific dominant flow rate (Burkham. 1972), resulting in overbank flow. The presence of overbank flow creates a favorable environment for sediment deposition, new channel formation, and stream capture.

Climatic changes over the past 2 million years has strongly influenced morphology of alluvial fans in Arizona. The tectonic forces which uplifted the mountains and provided energy for their erosion and subsequent deposition of the eroded material as alluvial fans have been dormant for several million years. Therefore, recent fan deposition which created active alluvial fans and distributary flow systems in Arizona was caused by climatic change.

At the end of the Pleistocene (about 10,000 years before present), the climate was wetter and/or cooler than today. Weathering and soil formation rates were higher, and erosion rates were lower. As the climate became dryer, abundant vegetation on mountain soils died. Without the vegetation to stabilize the soils, debris flows and other erosive processes caused a pulse of sediment to be eroded from the mountain slopes and deposited on the piedmont creating alluvial fans on what had been fan terraces and piedmonts. This pulse of sedimentation ceased by about 7,000 years ago. Active deposition today has mostly ceased, except where old fans are being eroded and their material is transported toward the axial valley (Bull, in press; Demsey, 1988; 1989). However, some investigators feel that active deposition is still an important process for isolated alluvial fan areas in central Arizona (Pearthree, 1992).

A flood history for each site was prepared using existing data, field data, and anecdotal accounts of flooding. Existing hydrologic data sources included FCDMC and USGS streamflow and precipitation gauges. The USGS maintained several recording precipitation gauges near each of the fan sites between 1960 and 1980. However, the raw data on the recording tapes from these stations have never been reduced. Therefore, only the site names and length of record is reported here. The USGS reportedly is negotiating with FCDMC to fund a project to reduce these data. At that time these data would be used to supplement rainfall records. Significant rainfall events recorded at FCDMC gauges are shown in Table 5.

Peak flow rates for specific recurrence intervals and key concentration points were determined from HEC-1 rainfall-runoff modeling provided by the FCDMC. Figure 3 illustrates the location of existing and historic streamflow and precipitation gauging sites. Tables 6 and 7 summarize hydrologic data collection sites and the period of record for each alluvial fan site.

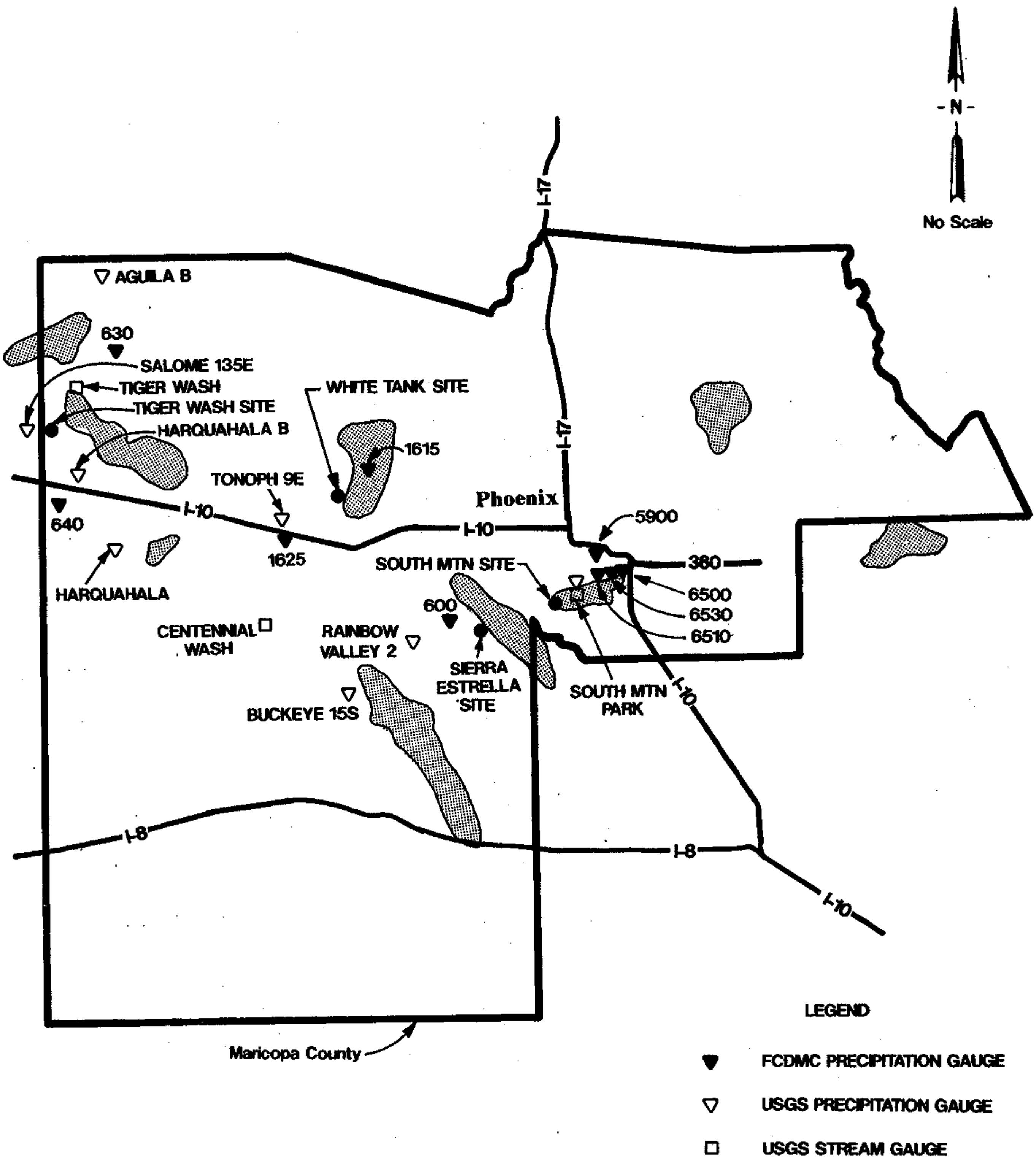

Figure 3

EXISTING AND HISTORIC GAUGE LOCATIONS

TABLE 5. PRECIPITATION MEASUREMENTS (greater than 1.0 inches/48 hrs)

Flood Control District of Maricopa County Gauges

SENSOR	640			630			600			1615			1625			6510		
YEAR / FAN	TIGER			TIGER			ESTRELLA			WH.TANK			WH.TANK			S.MTN		
	date	depth	durat.	date	depth	durat.	date	depth	durat.	date	depth	durat.	date	depth	durat.	date	depth	durat.
1991																		
	3/27	0.39	24										3/27	0.39	24			
	3/26	0.63	24										3/26	0.67	24			
	3/1	1.38	24										3/1	0.39	24			
	2/28	0.59	24										2/28	0.63	24			
1990																		
	8/15	0.43	24	8/15	0.24	24				8/15	0.87	24	8/15	0.94	24	8/15	2.05	24
	8/14	0.12	24	8/14	0.91	24				8/14	0.55	24	8/14	2.2	24	8/14	1.28	24
	8/13	0.63	24	8/13	0.39	24												
	7/15	0.83	24	7/15	1.54	24	7/15	0.98	24									
	7/14	0.31	24															
	7/8	0.31	24															
	7/7	0.79	24	7/7	0.63	24												
				7/6	0.35	24												
													1/18	0.24	24			
													1/17	1.06	24			
1989																		
																3/26	1.02	24
				1/26	0.98	24												
										8/21	3.11	24	8/21	2.52	24			
1988																		
	4/22	0.43	24										4/22	0.79	24			
	4/21	0.63	24										4/21	0.39	24			
				1/28	2.09	24												
				1/27	1.5	24												
				1/26	0.71	24												
				1/18	0.47	24												
				1/17	0.51	24												
	12/17	1.02	24															
1987																		
	12/17	1.02	24													12/17	1.22	24
							8/4	1.14	24									
				12/25	0.55	24	12/25	0.31	24							12/25	0.79	24
				12/24	1.06	24	12/24	1.26	24							12/24	1.46	24

TABLE 5. PRECIPITATION MEASUREMENTS (greater than 1.0 inches/48 hrs)

Flood Control District of Maricopa County Gauges

SENSOR / FAN	640 TIGER			630 TIGER			600 ESTRELLA			1615 WH.TANK			1625 WH.TANK			6510 S.MTN		
YEAR	date	depth	durat.	date	depth	durat.	date	depth	durat.	date	depth	durat.	date	depth	durat.	date	depth	durat.
1986				11/18	1.1	24												
	7/21	1.34	24				7/21	1.1	24							7/21	0.91	24
1985													12/11	1.02	24			
	11/25	1.57	24	11/25	2.32	24	11/25	0.94	24	11/25	2.64	24	11/25	0.83	24	11/25	0.94	24
										2/7	1	24						
1984							12/28	0.39	24				12/28	0.55	24	12/28	0.28	24
							12/27	0.63	24				12/27	0.56	24	12/27	1.28	24
				9/10	1.42	24												
	9/2	0.75	24															
	9/1	0.28	24							9/1	1.26	24	9/1	1.54	24			
																7/28	1.26	24
																7/27	1.46	24
																7/21	1.22	24
1983													9/30	1.34	24	9/30	1.57	24
										9/29	1.38	24						
				8/17	1.54	24				8/17	1.96	24				8/17	0.12	24
				8/16	1.06	24				8/16	0.18	24				8/16	0.94	24
				3/4	0.12	24	3/4	0.75	24	3/4	0.13	24				3/4	0.24	24
				3/3	0.47	24	3/3	1.46	24	3/3	1.23	24				3/3	2.24	24
				3/2	0.47	24	3/2	0.98	24	3/2	0.15	24				3/2	0.24	24
							2/7	2.17	24									

TABLE 5. PRECIPITATION MEASUREMENTS (greater than 1.0 inches/48 hrs)

Flood Control District of Maricopa County Gauges

SENSOR	640			630			600			1615			1625			6510		
YEAR FAN	TIGER			TIGER			ESTRELLA			WH.TANK			WH.TANK			S.MTN		
	date	depth	durat.	date	depth	durat.	date	depth	durat.	date	depth	durat.	date	depth	durat.	date	depth	durat.
1982																		
				12/10	0.31	24				12/10	0.34	24				12/10	0.47	24
				12/9	0.75	24				12/9	1.09	24				12/9	1.02	24
				12/8	0.31	24				12/8	0.43	24				12/8	0.35	24
										11/10	0.4	24						
										11/9	0.24	24						
										11/8	1.23	24						
				8/12	1.14	24												
1981										11/28	1.42	24						

Table 6 Existing and Historic Precipitation Gauge Sites			
Tiger Wash	**Sierra Estrella**	**South Mountain**	**White Tank**
FLOOD CONTROL DISTRICT SITES			
Tiger Wash #630 (since 9/12/80)	Waterman Wash #600 (since 5/12/83)	South Mountain #6510 (since 9/28/82)	White Tanks Peak #1615 (since 5/15/80)
Centennial Levee #640 (since 3/7/84)		Guadalupe FRS #6500 (since 6/29/89)	Buckeye FRS #1625 (since 1/26/83)
		Pima Wash #6530 (since 5/21/89	
		Salt River @ 24th St. #5900 (since 1/24/90)	
USGS SITES			
Salome 13 SE (5/62 to 3/80)	Buckeye 15 S (6/61 to 7/67)	So. Mountain Park (10/61 to 3/80)	Tonopah 9 E (5/62 to 3/80)
Aguila B (12/70 to 3/80)	Rainbow Valley #2 (7/68 to 3/80)		
Aguila SW (6/61 to 12/70)			
Harquahala Valley (6/61 to 12/65)			
Harquahala (2/67 to 7/70)			

Table 7 Existing and Historic Stream Gauge Sites.			
Tiger Wash	Sierra Estrella	South Mountain	White Tank
Tiger Wash[1] USGS 1963 to 1979, 1991 to present	No Gauges	Gila R. Trib. at So. Mtn. Park USGS 1961 to 1991 (adj. watershed)	No Gauges
Centennial Wash USGS 1961 to 1979 (adj. watershed)			
[1]The USGS re-activated the Tiger Wash gauge in early 1991.			

Paleoflood data were collected at the White Tank Mountain, Tiger Wash, and Sierra Estrella sites. Paleoflood data consist of any flood stage or discharge information which predates or supplements historical flood records. Deposits of flood sediment in low energy slackwater zones are used to estimate a minimum flood peak stage. These minimum stage estimates are connected within a control reach and correlated to a HEC-2 water surface profile (HEC, 1982). The HEC-2 water surface profile of a given discharge which best matches these highwater marks reveals the estimated peak flow rate of the flood which emplaced the flood deposits. Highwater marks, flood deposits, and HEC-2 cross-section information were collected in the field. HEC-2 water surface profiles were provided by the FCDMC for the Tiger Wash and White Tank Mountain sites.

Regional Geology and Geomorphology

Alluvial fans are composed of eroded bedrock material. The type of bedrock, how the bedrock was formed, and how the bedrock became exposed to erosion determine both the type of alluvial fan formed and the range of processes experienced on the fan. Therefore, an understanding of the regional and watershed geology is critical to understanding the behavior of alluvial fans. A brief synopsis of the regional geology of Maricopa County summarized from several key sources (Nations and Stump, 1981; Reynolds, 1982; Demsey, 1989) is outlined below.

Physiography. All of the alluvial fan sites are located within the Basin and Range Physiographic Province, a region characterized by northeast to northwest trending mountain ranges and intervening valleys. Mountain ranges in the Sonoran Desert region of the Basin and Range Province are extensively eroded and worn down, but are characterized by extremely steep mountain fronts with deep embayments and rock pediments. Mountain peak elevations in Maricopa County range from 3,000 to 6,000 feet. Valley elevations are from 1,200 to 1,600 feet. Valleys are typically underlain by thick accumulations of late Cenozoic alluvium and volcanic rock. Mountain ranges are generally composed of Precambrian metamorphic and granitic rock. The Precambrian basement rock is occasionally overlain by Cenozoic volcanic and sedimentary rocks, with no intervening Paleozoic or Mesozoic supracrustal rocks. Therefore, the Precambrian and Cenozoic geologic history of the region can be known directly, but the Paleozoic and Mesozoic history must be extrapolated from elsewhere in Arizona.

Geologic History. The earliest known rock types of the region were near-coastal sedimentary graywackes and shales formed during the Archeozoic Era in Precambrian time (Table 8). During the Mazatzal Orogeny, 1.7 to 1.8 billion years (b.y.) before present (b.p.), these sedimentary rocks were extensively metamorphosed, primarily to gneiss. This metamorphism was characterized by compressional folding and upward thrusting toward the northwest, followed by a period of normal and strike-slip faulting. The orogeny concluded with post-tectonic plutonic up-wellings of molton rock deep within the earth's crust. These precambrian gneiss and granites form the majority of the bedrock exposed in the mountains of Maricopa County.

During the Cambrian Period, the Arizona landscape was submerged as far south as the Harquahala Mountains, although Cambrian stratigraphy is poorly understood. During the remainder of the Paleozoic Era, most of central Arizona was probably overlain by a cratonic sequence of clastic and carbonate rocks (Pierce, 1976). However, sedimentary unit outcrops from the Cambrian to Permian periods are lacking in the region due to erosion down to the Precambrian basement (Harshbarger et al, 1957) during the Mesozoic and early Cenozoic Periods. Regional uplift and erosion during the mid-Paleozoic to late Mesozoic is seen in the geologic record as deposition of fanglomerate units which contain boulders assigned to the early Paleozoic age.

Evidence of mid-Mesozoic volcanism, sedimentation, plutonism, and deformation is preserved in other parts of Arizona (Reynolds, 1980). It is unclear how this Mesozoic tectonic activity affected central Arizona, but it is probable that central Arizona was part of an uplifted area, called the Mogollon Highlands, that shed detritus northward during part of the Mesozoic (Harshbarger et al, 1957; Cooley and Davidson, 1963).

During the late Cretaceous/early Tertiary-aged Laramide Orogeny, the Maricopa County area was the site of widespread magmatism, sedimentation, and compressional deformation (Davis, 1979). Late Cretaceous orogenic events included emplacement of granites associated with porphyry-copper mineralization, and deposition of waterlain volcanic tuffs. Early Tertiary orogenetic activity included emplacement of muscovite-bearing, peraluminous granites (Reynolds and Keith, 1983). Isolated fanglomerate deposits indicate rapid uplift and erosion due to up-warping during the Laramide Orogeny.

The Tertiary history of the region, following the final stage of the Laramide Orogeny, is divided into four episodes. The first stage was characterized by tectonic and magmatic quiescence during the Eocene and early Oligocene (60 to 32 million years (m.y.), as expressed by development of a widespread low-relief erosion surface. The second stage

Table 8
Geologic Time Scale

Era	Period	Epoch	Millions of Years Ago	Significant Geologic Events in Arizona
PHANEROZOIC				
Cenozoic	Quaternary	Holocene	0.01	Change to hotter drier climate.
		Pleistocene	1.8	
	Tertiary	Pliocene	5	
		Miocene	25	Basin and Range Crustal Extension and Volcanism Mid-Tertiary Orogeny.
		Oligocene	37	
		Eocene	55	
		Paleocene	65	Laramide Orogeny and Regression.
Mesozoic	Cretaceous		135	
	Jurassic		180	Plutonism and Volcanism in Southern Arizona.
	Triassic		230	
Paleozoic	Permian		275	
	Pennsylvanian		330	
	Mississippian		355	
	Devonian		410	
	Silurian		430	Regional Uplift and Erosion.
	Ordovician		500	
	Cambrian		600	Grand Canyon Disturbance.
PRECAMBRIAN				
Proterozoic			1000	
			1500	Mazatzal Orogeny and Plutonism.
			2000	
Archeozoic			3000	
			4500	

consisted of major calcalkaline volcanism, plutonism, and associated sedimentation during the mid-Oligocene/early Miocene (32 to 20 m.y.). The sedimentary and volcanic rocks formed during this stage rest unconformably on older rocks, indicating widespread erosion characteristic of the first stage of Tertiary geology. In the third stage, mid-Miocene (20 to 12 m.y.) minor post-orogenic volcanism, complicated tectonism, and important sedimentation took place. The latter two stages are referred to by some investigators as the (unnamed) mid-Tertiary Orogeny.

Mid-Tertiary orogenic metamorphism, mylonitization and uplift locally accompanied plutonism in metamorphic core complexes of southern and western Arizona (Crittendon et al, 1980). A metamorphic core complex is a geologic feature originally identified in Arizona. It consists of three parts: a basement composed of metamorphic, plutonic, and mylonitic rock; an unmetamorphosed cover zone; and a marginal zone of brittle deformation and detachment faulting separating the two rock units. The metamorphic basements are usually emplaced by up-welling of high temperature and pressure rock material during compressional orogenic events. As a result of this up-welling, mountain ranges formed from core complexes have a bulbous, flat-topped topographic profile in direct contrast to the sharp-crested, linear physiography of extensional Basin and Range mountains. The northeast-southwest trend of the Arizonan core complexes, such as South Mountain and the White Tanks, is also in direct contrast to the north to northwest trend of the mountains formed during the Basin and Range disturbance.

The Basin and Range disturbance was the fourth phase of Tertiary geologic history. The late-Miocene (12 m.y.) Basin and Range disturbance marked a transition to a different style of tectonism. This transition was characterized by cessation of listric compressional faulting and andesitic volcanism, and the onset of high-angle normal extensional block faulting and basaltic volcanism. Also, the orientation of active faults changed to mostly north-south. Horsts and grabens were produced with a wide range of displacements and lateral dimensions. The result is that the principal basin-margin fault zones commonly have a zig-zag pattern, with some segments trending northeast or northwest, in contrast to the general north to north-northwest trend.

Basin and Range deformation produced the larger elements of the present topography in Maricopa County. High angle normal faulting caused the valleys to drop up to 10,000 feet, with total vertical relief of up to 19,000 feet. These intermontane structural basins contain late Miocene syntectonic sediments, including some evaporites, deposited in formerly closed basins near Phoenix (Pierce, 1976b) that grade upward into relatively undeformed Pliocene deposits. Basin and Range mountains in Maricopa County include the Sierra Estrella, Phoenix, Big Horn, and McDowell Mountains.

The Basin and Range disturbance was the final major formational episode in central Arizona's geologic history. Basin and Range extensional normal faulting ended 10.5 to 6 m.y. b.p., and significant faulting ceased completely by the early Pleistocene, though localized diminishing faulting continued to occur (Shafiqualla et al, 1980; Morrison, 1985). Cessation of faulting was followed by gradual fill of closed basin valleys by alluvium, mountain front retreat, and burial of range bounding fault zones, as evidenced by the presence of inselbergs on the piedmonts. Concurrently, the formerly closed basins of the Phoenix area were opened as the Salt and Gila River systems became integrated (Eberly and Stanley, 1978) and assisted the final sculpting of the regional landscape.

Geomorphic History. During the Quaternary Period, as a result of cessation of faulting, alluvial deposition on piedmonts was no longer dominantly caused by uplift and erosion of mountain areas, but now was primarily caused by climatic fluctuations (Demsey, 1989). Climatic fluctuations and vegetative changes result in variations in weathering rates, sediment transport, and deposition. Extensive piedmont deposits of similar (mid-Pleistocene to Holocene) age likely represent discrete pulses of aggradation triggered by climatic change. Climatically controlled bedrock weathering rates are also important. Piedmonts flanking mountains of resistant lithologies, such as the volcanics of the Palo Verde Hills or basalts of the Gila Bend Mountains, are composed of coarse deposits. Piedmonts near less resistant lithologies, such as the granite-dominated Sierra Estrellas, South Mountains, White Tank Mountains, or Maricopa Mountains are composed of fine grained younger materials.

The Holocene Epoch is characterized by gradual erosion of mountain and upland areas, and deposition in the valleys. Two types of deposition dominate. Younger deposits near mountain fronts which occur as thin veneers of fine material over older surfaces protrude in isolated topographic rises. These early Holocene fine sands and silts were formed on mountain slopes during the late Pleistocene pluvial, a period of wetter and/or cooler climate and enhanced soil formation. The soils were rapidly shed from the slopes as the climate turned drier and warmer at the onset of the Holocene, resulting in a pulse of sedimentation onto some older piedmont surfaces (Bull, in press). The most recent Holocene depositional zones located on distal reaches of piedmonts (Demsey, 1988; 1989) represent less a renewed period of deposition than erosion of the finer grained material from older Pleistocene alluvial fans near the mountain front.

A final control on fan formation during the Holocene is slight changes in base level along axial streams. This is most clearly demonstrated by the Sierra Estrella range. The north and east side of the Estrellas do not contain any geologically recent fans due to progressive base level fall in the Gila River which impinges on the piedmont slope. This causes enhanced entrenchment of piedmont watercourses and removal of sediment from the toe of the fans, limiting deposition. The west and south end of the Estrellas is not as closely related to the Gila River system and hence sediment deposition is enhanced and dissection of the piedmont is limited (Demsey, 1989).

Individual Site Descriptions

South Mountain Park

Location. The South Mountain Park distributary flow system is located at the west end of the South Mountains, also known as the Salt River Mountains (Figure 1). Most of the site is located within the South Mountain Park, operated by the City of Phoenix. The remainder of the site is privately owned or is on the Gila River Indian Reservation (Figure 4). The watershed includes the interior basin between the South Mountain main ridge and the front range, west of the main road. The lower portion of the fan drains through the Gila River Indian Reservation, which begins at the western park boundary, to the Gila River located approximately 2 miles to the southwest. The lower portion of the fan will eventually be traversed by the South Mountain Outer Loop Freeway.

Access. Access to the fan apex follows paved park roads. From Central Avenue, go south to the South Mountain Park main entrance. Continue west and south on the main road, through a four-way stop. Turn right on the San Juan Vista Road 1.2 miles after the stop sign. San Juan Vista Road parallels the primary fan wash, crossing its main tributaries several times. Continue west on San Juan Vista Road to a broad turn north just past milepost 4.0. The fan apex is approximately 1,000 feet southeast of this bend.

Selection Criteria. Key advantages of the South Mountain Park site are easy, all-weather access, an extensive existing data base, including detailed photo-topography and historical photography, and permanent public ownership. Construction of the South Mountain Freeway Loop at the base of the fan will provide opportunities for sediment gauging and flow volume measurements. Inclusion within park boundaries ensures that development will not directly alter the geomorphology, and will provide some protection against vandalism.

Vegetation. Vegetative communities found at the South Mountain Park site (Figure 5) are typical of the region. Dense, leaf-bearing riparian vegetation lines channel banks. Sparse cacti and creosote/bursage dominate older surfaces and terraces. Well developed desert pavement presumably limits plant growth on the older surfaces. Limited grass and annual lowland species may be found within the more frequently wetted distributary and sheet flow area. Specific plant types were summarized in Table 4.

Soils. Soils at the South Mountain Park site (Figure 5) belong to the Ebon-Pinamt-Tremant General Association (SCS, 1977). The Ebon-Pinamt-Tremant Association is described as a nearly level to gently sloping gravelly loam/very cobbly loam, and gravelly clay loam on fan terraces at the base of mountains. Four soil units within this association are found at the South Mountain site. The Carrizo-Ebon gravelly sandy loam and gravelly loam forms on the sides of alluvial channels at slopes of 3 to 12

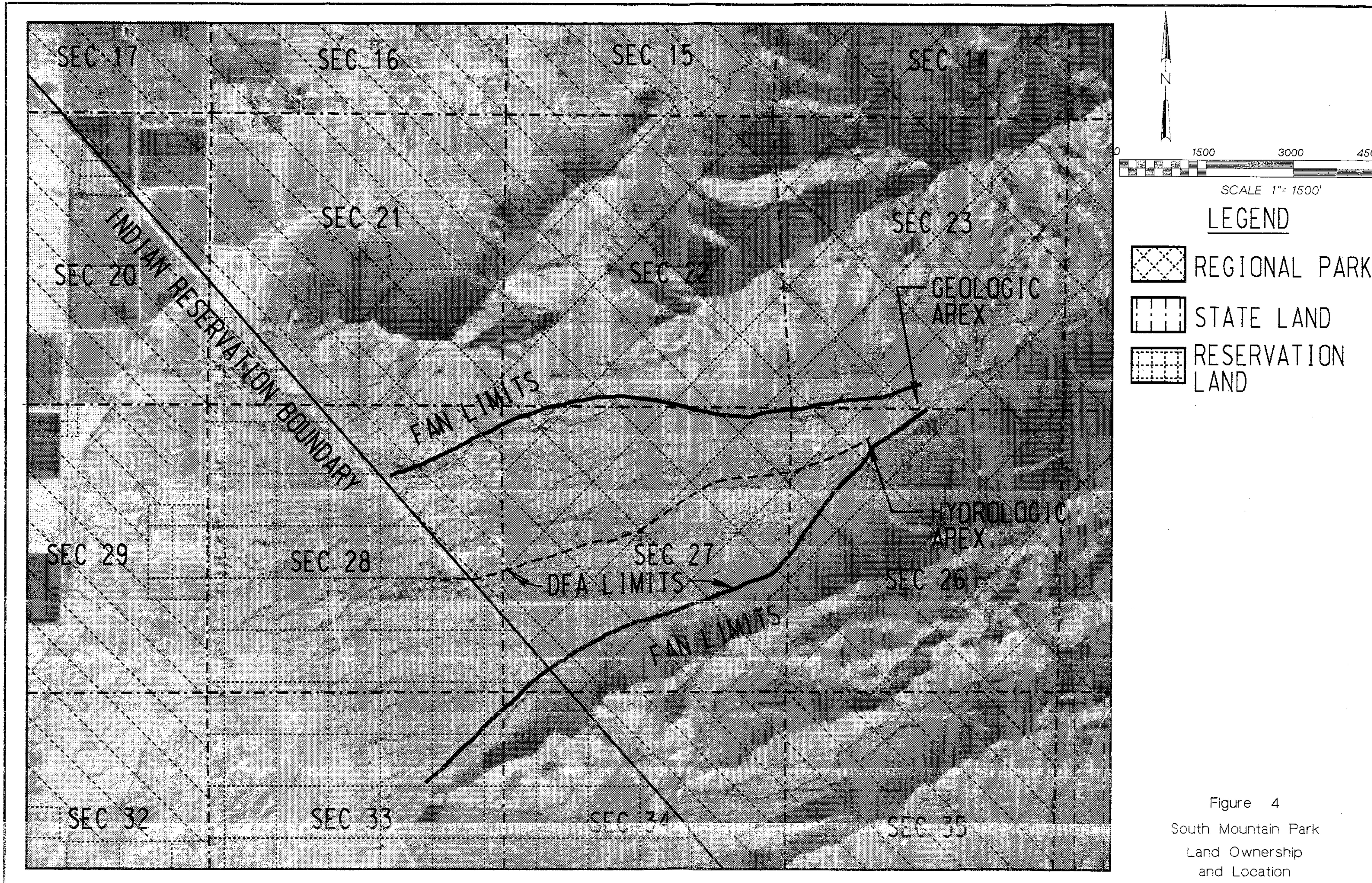

Figure 4
South Mountain Park
Land Ownership
and Location

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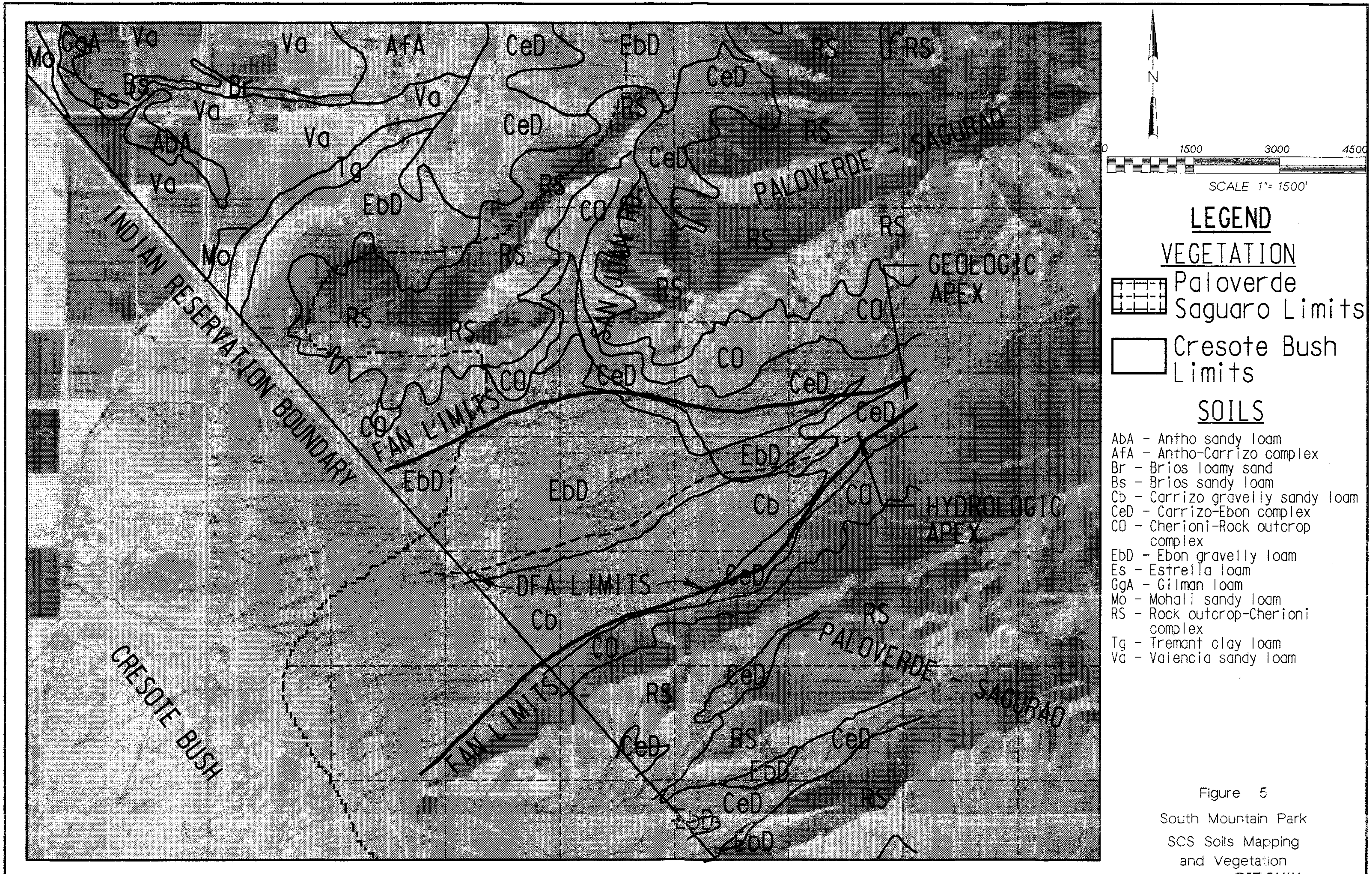

Figure 5
South Mountain Park
SCS Soils Mapping
and Vegetation

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percent. The Carrizo gravelly sandy loam forms in stream channels and low terraces adjacent to channels. The Ebon gravelly sandy loam forms on 0 to 8 percent slopes on fan terraces. It is dissected by tributary drainageways and is covered by a varnished gravel and cobble desert pavement. The Cherioni-Rock outcrop complex is found along the main ridge on the south side of the site.

Geology. The western half of the South Mountains is the basement of a metamorphic core complex emplaced during the Mazatzal Orogeny and uplifted during Laramide and mid-Tertiary compression (Reynolds, 1985). Geologic units in the western half of the South Mountains (Figure 6) consist of Precambrian metamorphic and granitic rocks, as well as numerous north-northwest trending mid-Tertiary intrusive dikes. Precambrian units include the Estrella Gneiss, which comprises the majority of the rock mass, and the Komatke Granite, which is intruded into the Estrella Gneiss. Both rock units are characterized by steep, crystalloblastic foliation with a northeast to east-west strike, overprinted by Tertiary mylonitization. The intrusive dikes are composed of granite and diorite with a well developed mylonitic fabric. These dikes were emplaced approximately 25 m.y. during the unnamed mid-Tertiary orogeny. Relatively flat-lying late Tertiary to Quaternary surficial deposits surround the range and comprise the country material for the distributary flow system.

Very little detailed information regarding depth to bedrock was available for the South Mountain Site. Two drilling logs from wells on the piedmont at the site indicate that the thickness of alluvial fill rapidly increases toward the center of the site. A general map showing thickness of alluvium indicates that bedrock is buried by less than 400 feet of sediment (USGS, 1973). Bedrock outcrops were not observed in or between channels below the hydrologic apex. Depth to bedrock information is summarized on Figure 6.

Hydrology. At the hydrologic apex, the South Mountain Park site drains 2.0 square miles of the western slope of the South Mountains. Peak flows generally occur in response to summer monsoonal rainfall, with winter frontal storms producing very little runoff. This relationship is confirmed by both anecdotal and systematic data available for the site.

Good historical rainfall records are available for the South Mountain Park site (Table 5 and 6). Near continuous precipitation gauging has been collected since October 1961 from a USGS gauge located just east of the watershed, and a FCDMC gauge located near San Juan Vista. Supplemental precipitation information is available at three other nearby FCDMC gauge sites. However, due to the extreme aerial variability of monsoonal rainfall, the applicability of data from these other basins is questionable.

There is no existing stream gauge at the South Mountain Park site. However, some flood data are available. The USGS stream gauge in South Mountain Park is located on an equivalent-sized basin (2.1 square miles) which shares a common divide with the fan site. Therefore, the flood histories should be fairly similar. The flood of record at

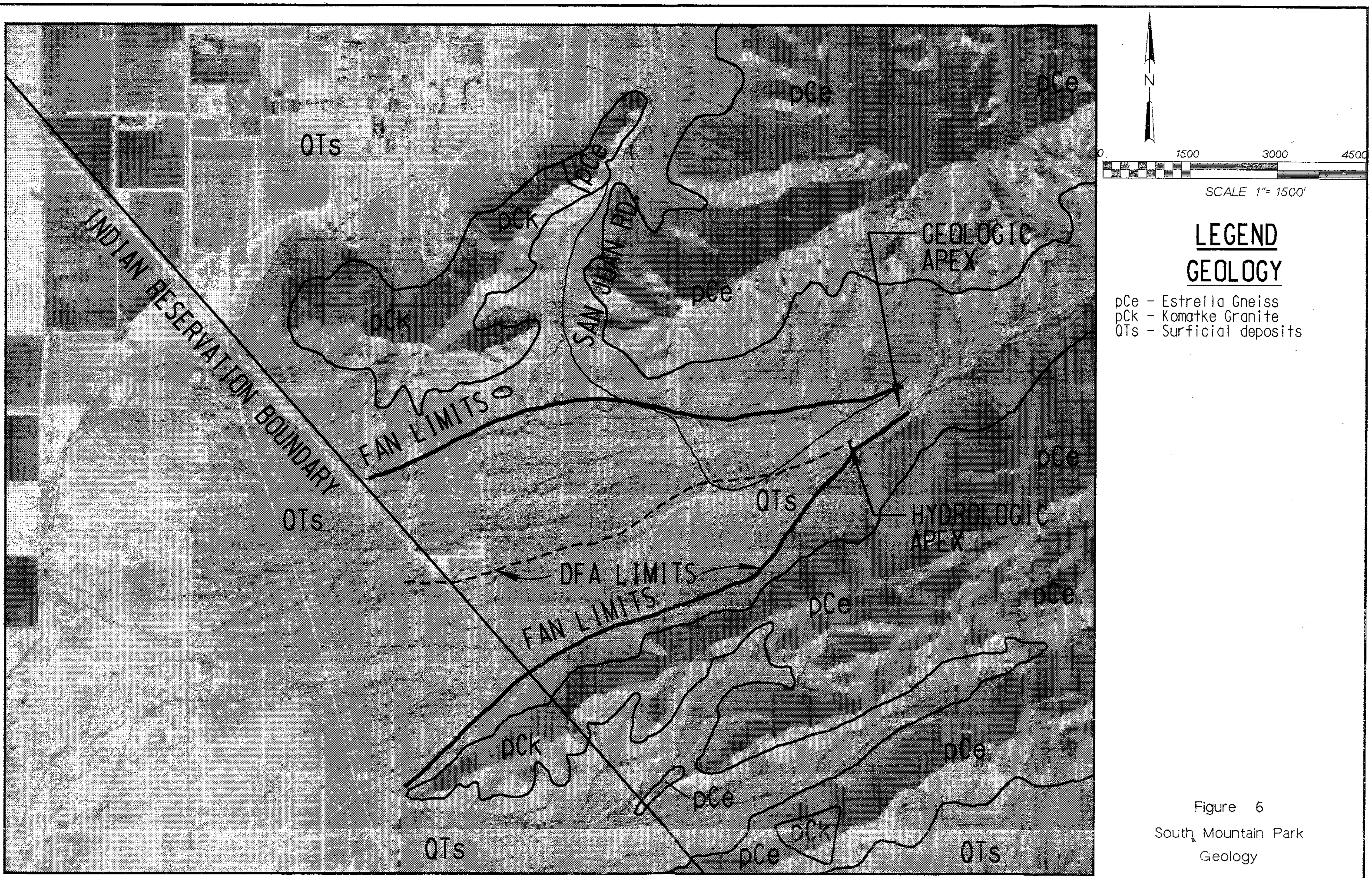

Figure 6
South Mountain Park
Geology

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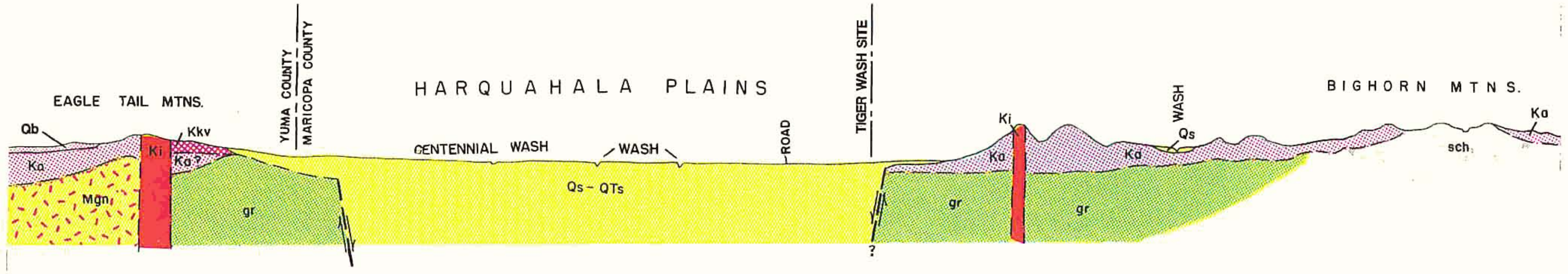

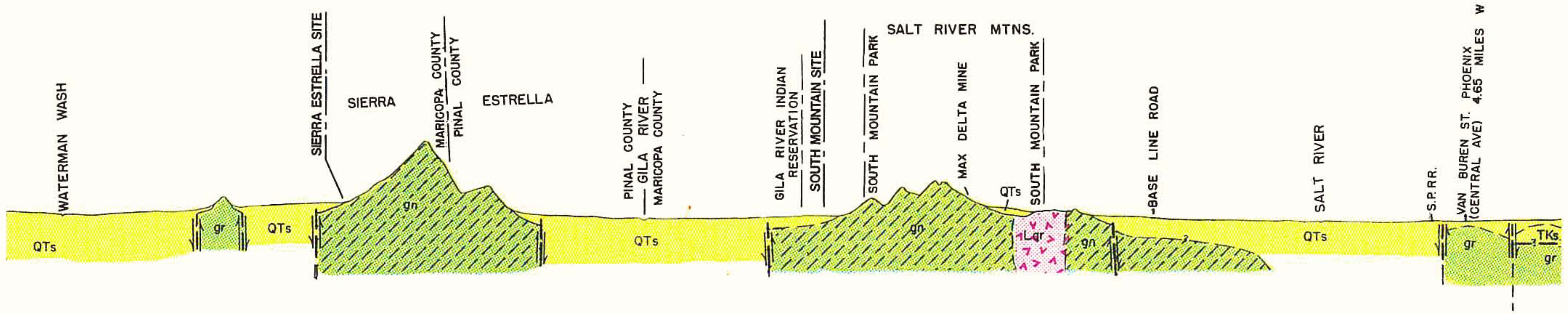

EXPLANATION

Qb - BASALT
Locally Includes Tuff & Gravel

Ka - ANDESITE
Locally Includes Tuff & Agglomerate

Mgn - DIORITE PORPHYRY

Ki - DIKES AND PLUGS

Kkv - KOFA VOLCANICS
Flows, Dikes & Plugs Of Andesitic To Rhyolitic Composition

gr - GRANITE & RELATED CHRYSTALLINE ROCKS

Qs - SILT, SAND & GRAVEL

QTs - SAND, GRAVEL & CONGLOMERATE

sch - SCHIST

gn - GRANITE GNEISS
Locally Includes Diorite, Rhyolite & Greenstone

Lgr - GRANITE & RELATED CRYSTALLINE ROCKS

TKs - SANDSTONE, SHALE & CONGLOMERATE
Includes Some Basalt

Figure 6a

GEOLOGIC CROSS SECTIONS

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the gauged watershed occurred on August 15, 1990 when 2.05 inches of rain fell in a 3-hour period. This rainstorm resulted in a peak flow rate of 1,200 cfs at the gauge.

Anecdotal flood records yield valuable information. The primary wash rarely flows during winter general storms. Summer storms produce the largest flood peaks. Runoff remains channelized above the hydrologic apex, occasionally reaching depths of 6 to 8 feet. Tributary streams carry heavy sediment loads, and deposit sandy debris on the San Juan Vista Road dip crossings. Below the apex, park personnel reported that sheet flooding occurs after several hours of rainfall, a phenomenon which has occurred only a few times in the past 20 years. Most times, runoff is confined to the channels (Seherer, 1991).

Field evidence for flooding is limited. Coarse bedload in the channel above the hydrologic apex indicates high velocity flow. However no paleostage indicators higher than 3 feet were observed. Given that park personnel have observed flood stages up to 8 feet, floodwater must be extremely flashy and deprived of fine sediment, and the channel banks must be very resistant to erosion. Below the hydrologic apex, vegetative debris caps most channel banks and flood silts extend up to 50 feet into overbank areas. This indicates that the most recent flood was mostly conveyed within channels, but that some overbank flow also occurred. Flow depths were generally less than 2 feet, with no consistent trend in depth or width downfan. This flood debris probably corresponds to the August 15, 1990 storm. No paleoflood data were collected at the South Mountain Park site.

Hydrologic modeling of the site watershed using HEC-1 was provided by the FCDMC and is summarized in Table 9. Flow rates varied from 271 cfs for the 2-year, 24-hour storm to 2,718 cfs for the 100-year, 6-hour storm. Complete discussion of the derivation flood peak information is provided in a report by the FCDMC (FCDMC, 1991).

Manning's ratings of the channels using the flow rates supplied by the FCDMC at the site indicate hydraulic capacity decreases rapidly just upstream of the hydrologic apex. Below the hydrologic apex the existing channels have cumulative capacity for the entire 100-year flood, though no one channel can convey the 100-year peak flow. The approximate floodplain is shown in Figure 7.[5] Velocities estimated by Manning's ratings of the 100-year or channel capacity discharge range from 8 feet per second (fps) above the hydrologic apex to 13.7 in a channel in the distributary flow area.

[5] Not to be used for regulatory or design purposes.

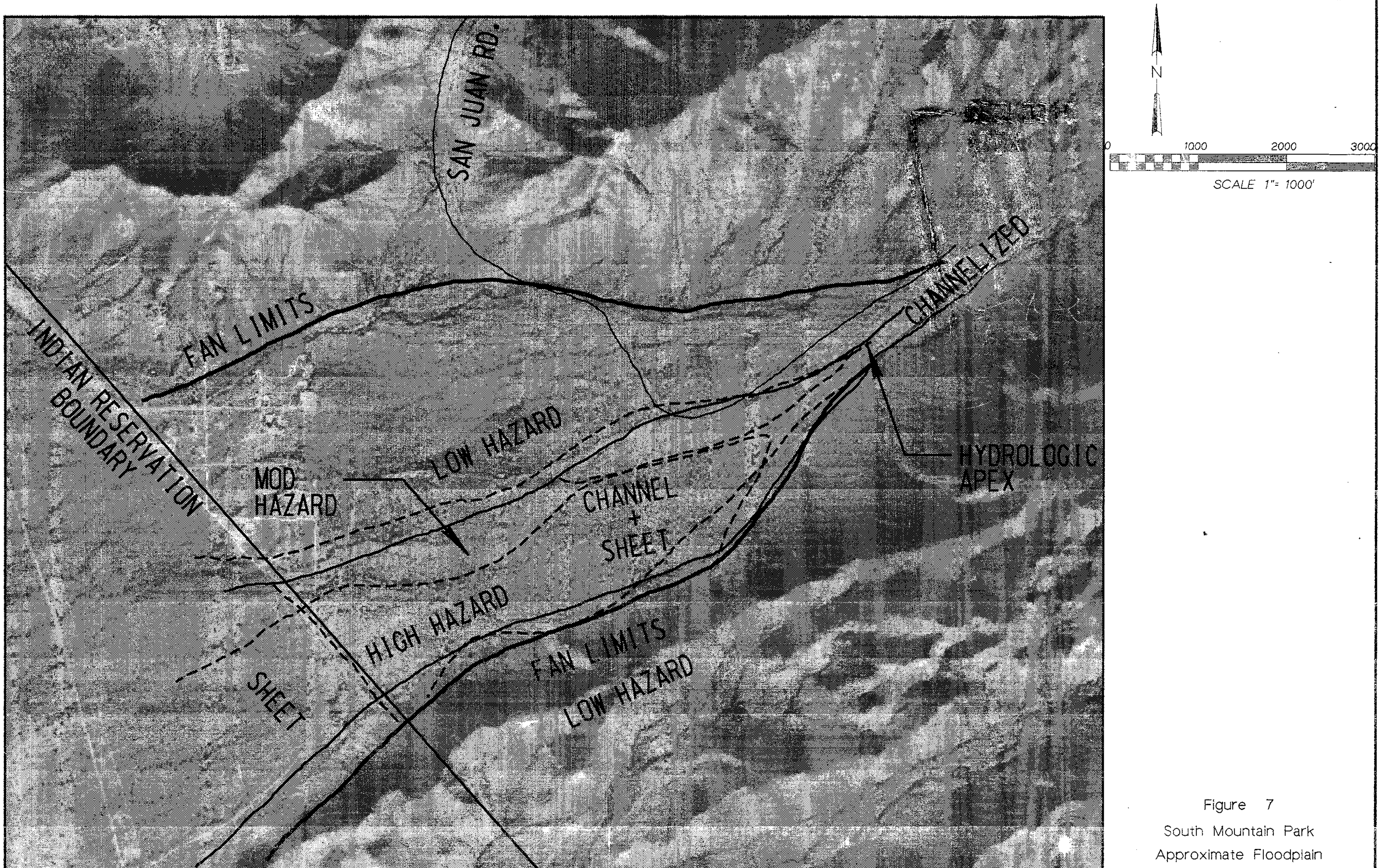

Figure 7
South Mountain Park
Approximate Floodplain

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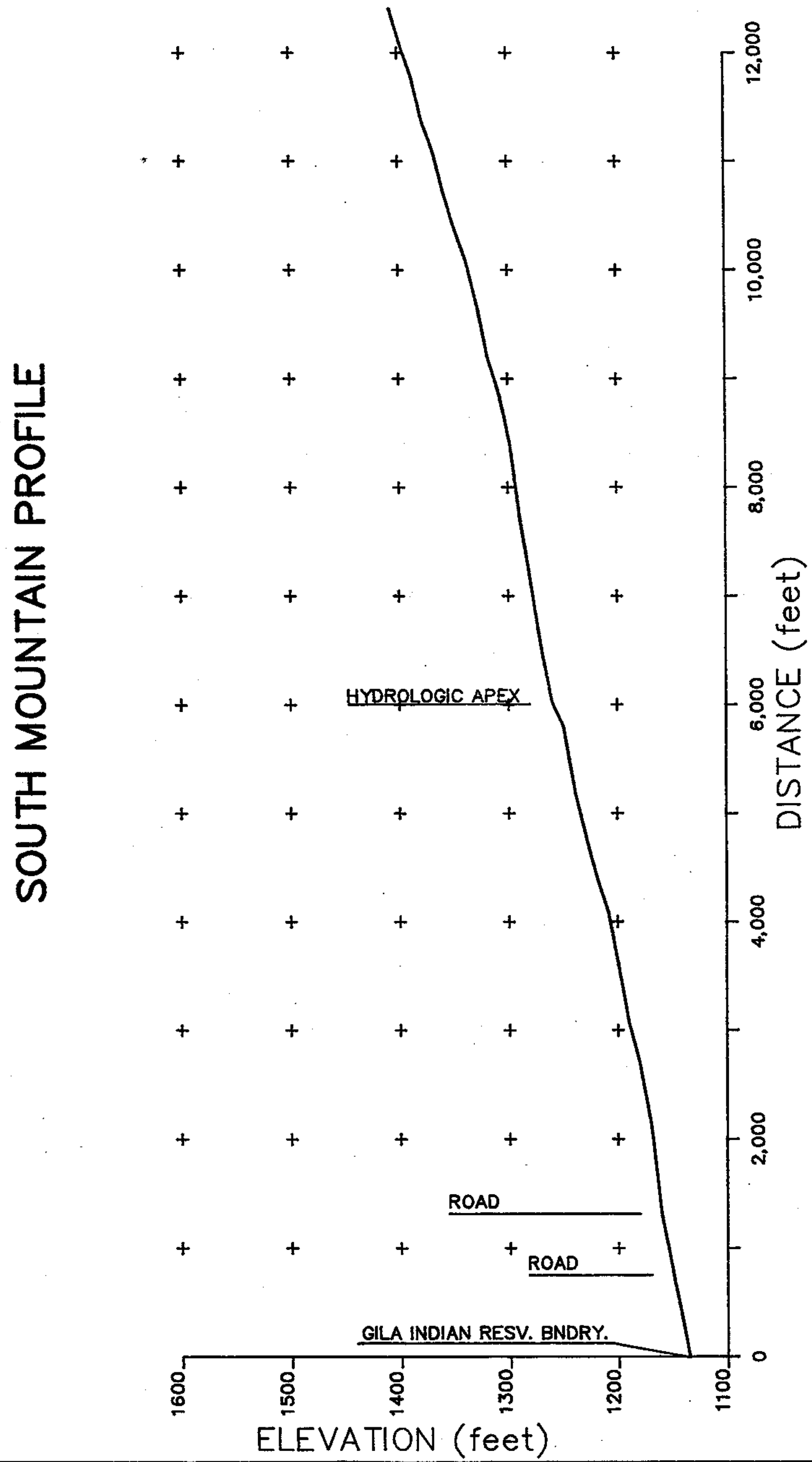
Table 9 Peak Discharge Estimates (cfs)[1], South Mountain Site		
Recurrence Interval (Years)	24-Hour Rainfall	6-Hour Rainfall
2	271	294
5	555	720
10	1013	1023
25	1593	1701
50	2013	2213
100	2412	2718
[1]Discharge values shown are taken directly from HEC-1 model output provided by FCDMC and do not reflect actual significant figures.		

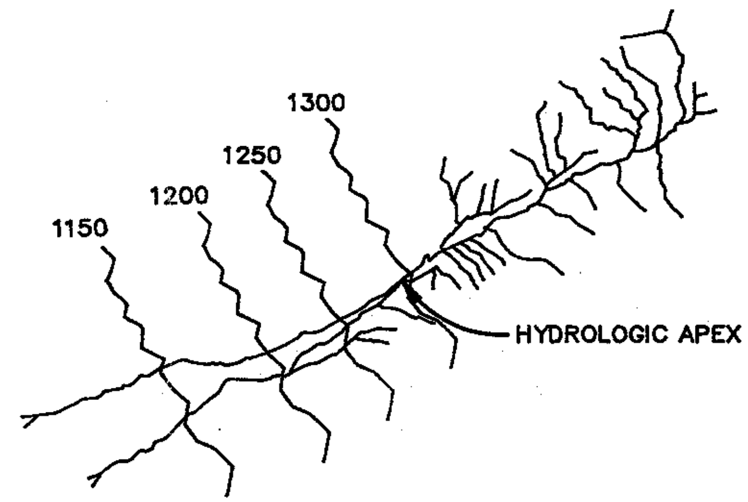
Geomorphology. The South Mountain Park distributary flow system is located almost entirely within the canyon formed by the westward extensions of the South Mountain front range and main ridge. The drainage pattern in the watershed is trellis above the hydrologic apex, distributary immediately below the apex, and dendritic in the lower piedmont near and downstream of the park boundary. The site has no true geologic apex, because the mountain front is located downstream of the distributary system.

The primary channel is a third order stream which drains west toward the Gila River floodplain (Figure 8). The stream is extremely straight above the hydrologic apex (Sinuosity[6], S=1.04), and only slightly more sinuous below the hydrologic apex (S=1.07 to 1.12). The longitudinal profile of the primary channel reveals several slope changes. Channel slope in the upper channel is steep (0.02895 ft./ft.). Slope decreases gradually (0.01724 ft./ft.) in the reach immediately above the hydrologic apex, as bank height decreases, and width increases. At the hydrologic apex, where the distributary pattern begins, channel slope abruptly increases (0.02424 ft./ft.) and remains constant to the park boundary.

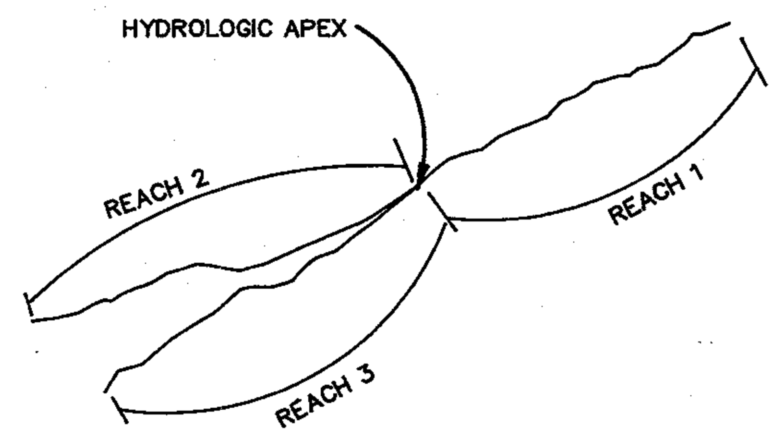
The hydraulic geometry of stream channels on the alluvial fan was analyzed using field measurements. Channel geometry, including width, bank height, and flow depth as indicated by flood debris was measured every 100 feet in each channel or distributary flow path downstream of the hydrologic apex. In addition, data collection transects of the total fan widths were made every 300 to 500 feet between the geologic apex and the toe of the fan. In these transects, channel geometry, soil and vegetation characteristics, flood debris, and other geomorphic parameters were recorded.

[6]Sinuosity is the ratio of streamlength to valley length.





CHANNEL PATTERN



CRENULATION INDEX

CONTOUR ELEV.	ALONG CONTOUR	BEGIN TO END	CREN. INDEX
1130	4010	2400	1.671
1140	3490	2100	1.662
1150	2510	1900	1.321
1160	2330	1800	1.294
1170	2990	1400	2.136
1180	2990	1500	1.993
1190	2800	1600	1.750
1200	4080	1600	2.550
1210	3340	1700	1.965
1220	3790	1800	2.106
1230	4240	1830	2.317
1240	3680	1780	2.067
1250	4010	1470	2.728
1260	2600	1350	1.926
1270	1670	870	1.920
1280	2420	710	3.408
1290	1250	440	2.841
1300	1800	320	5.625

SINUOSITY

REACH #	IN-STREAM LENGTH	BEG-END LENGTH	SINUOSITY
1	2.490	2.40	1.038
2	3.160	2.83	1.117
3	2.786	2.60	1.072

FIGURE 8

SOUTH MOUNTAIN
CHANNEL PATTERN
SINUOSITY, PROFILE
& CRENULATION INDEX

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Channel geometry on the fan follows no specific relationship or trend (Figure 9). Channel width, depth, and flow area values oscillate with distance downstream as channels combine and split. These channel parameters appear to be controlled by vegetation which may limit widening, or by armoring and caliche which may limit deepening. Because of these controls on deepening, headcutting occurs as more resistant layers form mini-waterfalls until less resistant material beneath them is removed. Stream capture by headcutting is also an important process for the formation of channel patterns and channel geometry at the site. Clearly, water discharge is only one of the independent variables shaping channel geometry.

The fan appears to be composed of very coarse clastics with finer matrix material, probably from successive debris flow deposition caused by rapid tectonic uplift and weathering in the mid-Tertiary through the Pleistocene. Lack of buried Pleistocene surfaces indicates that early Holocene debris flow activity probably did not impact the site. A very thin mantle of coarse sand and gravel covering portions of the fan in the distributary flow area may be the only remnant of early Holocene deposition.

Coarse bed and bank material in channels above and below the hydrologic apex have the appearance of historically recent debris flows. However, given the present condition of the hillsides and minimal amount of soil mantle, at the present rates of soil formation debris flows with sufficient material to flow out to the distributary flow area are unlikely. Also, geomorphic evidence indicates that these are not recent deposits. First, the cobble-sized material have caliche coatings, which indicate a short length of transport and an on-fan source. Second, headcuts and bank erosion reveal similar material in-situ on the lower fan. Third, the distributary flow area is inset topographically and the channel pattern has been stable for at least 60 years (Figure 10) according to the photographic record. These facts indicate that progressive deposition has not occurred. Fourth, the apparent bedload below the apex is coarser than the bedload above the apex, indicating that coarse material was not transported through the apex, but is probably erosional lag deposited from bank erosion and bed degradation. Normally, sediment size decreases in the downstream direction. Fifth, no boulder levees or other diagnostic features of debris flows were observed below the hydrologic apex. Therefore, it is more likely that coarse material on the fan surface was emplaced as lag deposits from bank erosion and headcutting.

Abandoned channels are also found in the distributary flow area. These channels are lined by a coarse gravel pavement and/or sparse grass, but still retain a shallow U-shaped geometry. Most of these channels can be traced toward more active channels which have since deepened or been captured by headcutting channels. The presence of desert pavement in the bottoms of the abandoned channel indicates that they have been abandoned, or have not carried sediment laden or erosive runoff, for a long time. Desert pavement takes from several hundred to thousands of years to develop.

Because of the existence of cutbanks and headcuts, in addition to abandoned channels and large diameter sediment (d50 > 0.5 ft.) in the floodplain, the site bears some

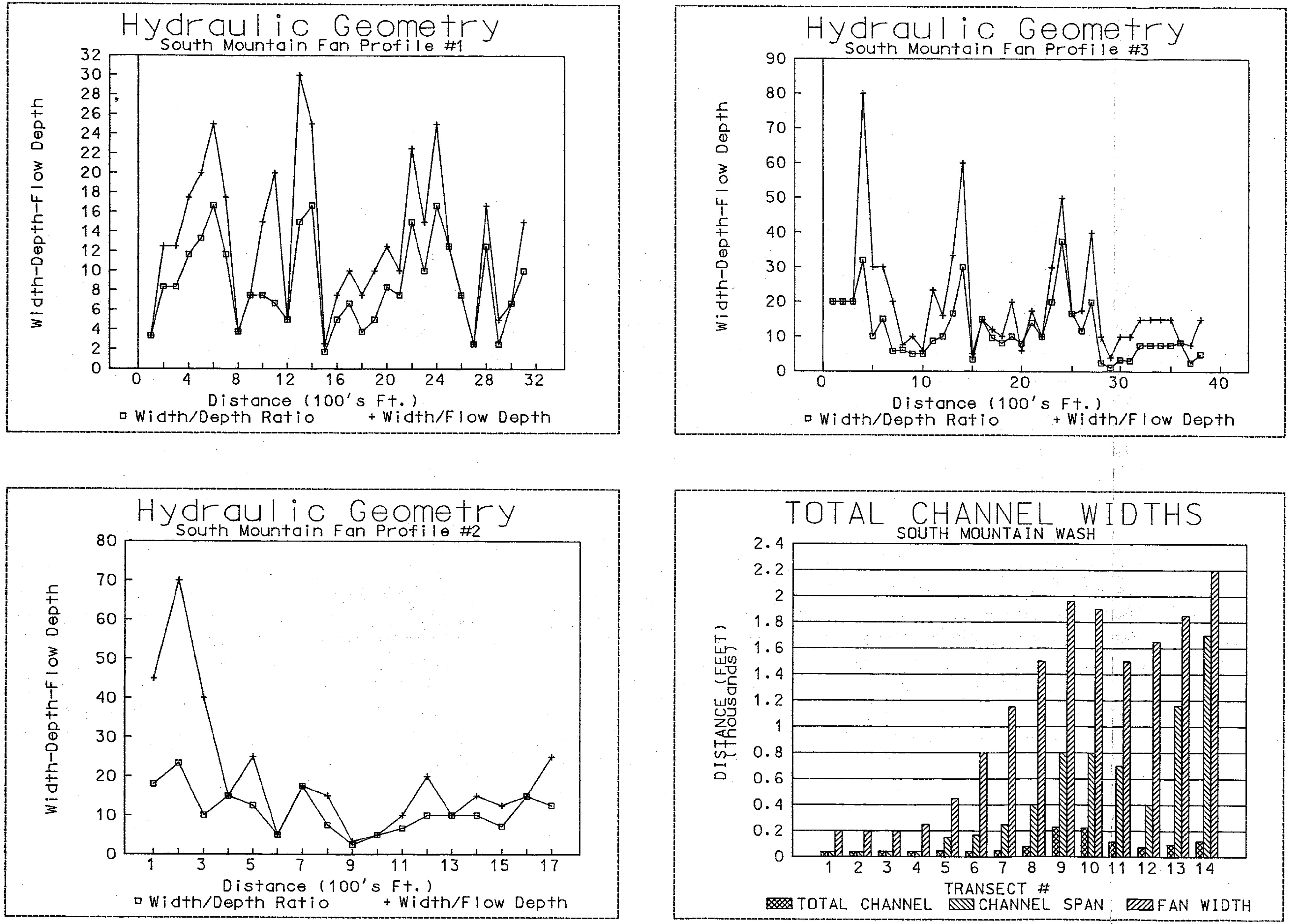

Figure 9
South Mountain Park
Channel Geometry

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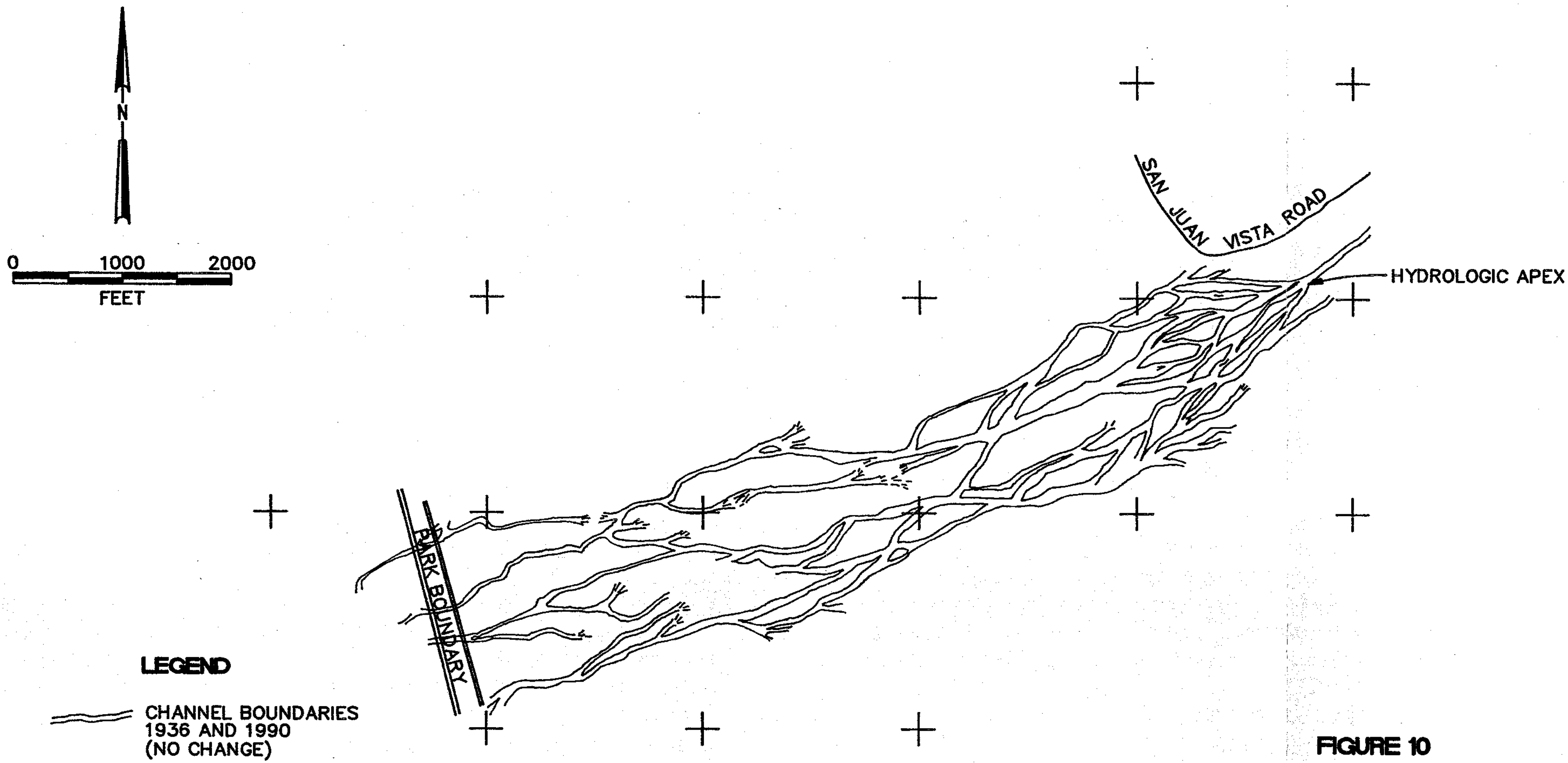

FIGURE 10
SOUTH MOUNTAIN PARK
HISTORIC CHANNEL SHIFTING

1936 CHANNEL PATTERN
IS IDENTICAL TO 1990
CHANNEL PATTERN

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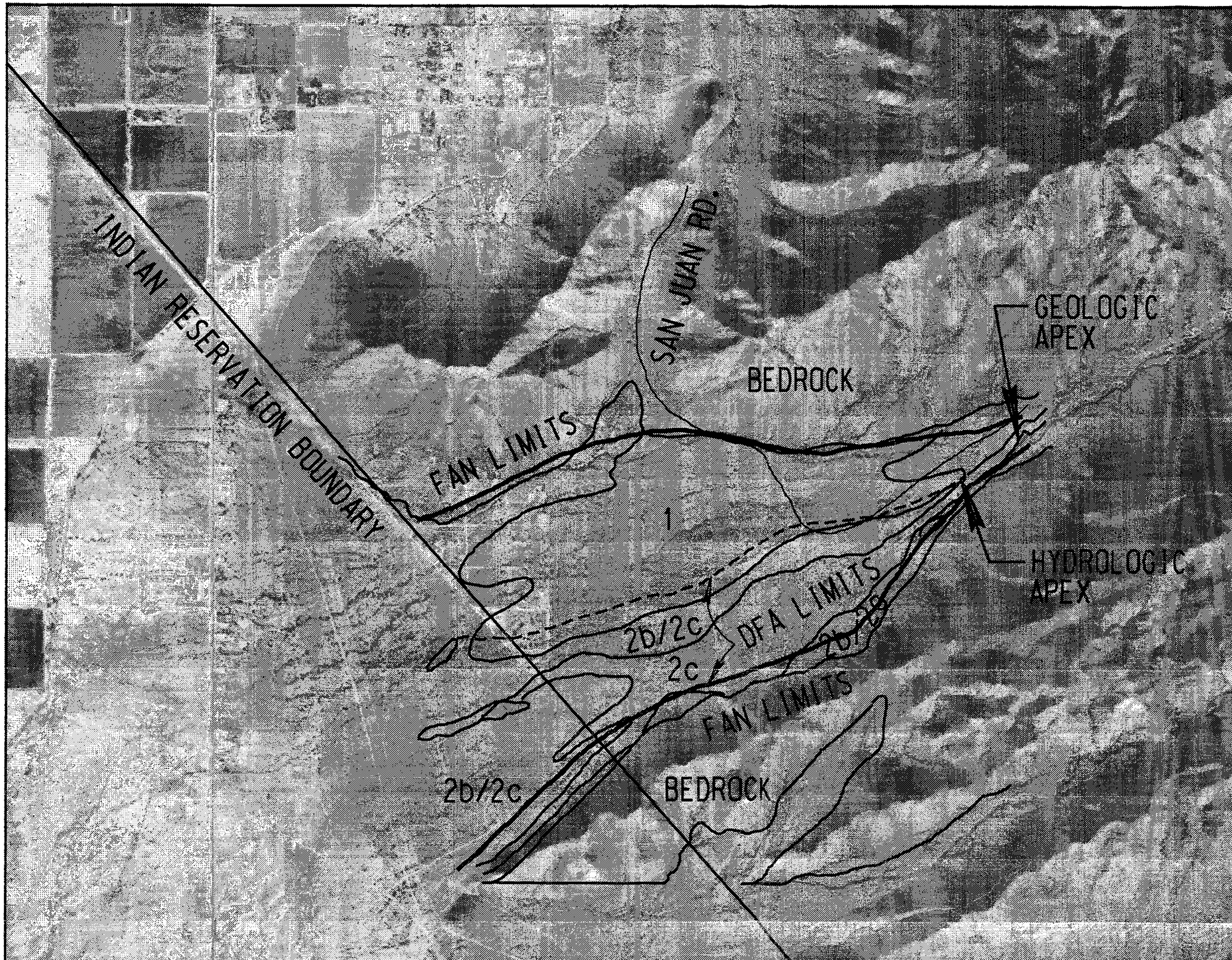
resemblance to an active fan. However, geomorphic evidence reveals that erosion, rather than deposition, is the dominant process at the South Mountain Park site. First, older surfaces at the site are not being buried by deposition. Second, older surfaces at this site are always topographically higher, even where they occur as "islands" in younger areas. These "islands" would not have been left on an aggrading surface. Third, the channel slope in the distributary area is steeper than the upper and lower channelized areas. The steeper slope causes headcutting and increased transport capacity, rather than the decreased capacity required for deposition. A slope decrease with concurrent decrease in capacity is seen immediately above the hydrologic apex. Fourth, the channel pattern and dimensions are almost identical in 1936, 1970, and 1990 aerial photographs. The prehistoric abandoned channels were caused by headcutting and stream capture rerouting flow to steeper, higher conveyance flow paths. Fifth, the fact that channels abandoned before 1936 are still visible is further evidence that overall deposition is not occurring. Finally, evidence for extensive sheet flooding, such as silt, mud, or debris deposition, is lacking in the distributary area. Significantly, the crenulation index is not significantly different above (1.92-3.41) and below (1.32-2.55) the apex, indicating that the fan is well incised throughout.

There are three prominent geomorphic surfaces (Figure 11) at the site which can be correlated to terraces along the primary watercourse. The 2c surface is the active channel and interfluves subject to erosion and frequent flow. The 2c surface has little or no soil development, pavement, or varnish. The 2b/2a surface represents a surface which is somewhat incised, has slight pavement and isolated varnished areas, and is slightly elevated above the 2c surface. This surface is infrequently flooded by overbank and sheet flooding, but may have some tributary channels which flow in response to rainfall. The 1 surface is elevated 3 to 4 feet above the 2b/2a surface. The terrace slope between the 1 and 2b/2a surface is often covered by angular to sub-angular boulders which may be varnished. The surface top is a heavily varnished pavement with stage IV caliche formed at depth as exposed in stream cuts. This surface is not flooded by water from the primary drainage.

Correlation of stream terraces can be made to the geomorphic surfaces in the distributary flow area by tracing their margins upstream. Several divisions of the 2b/2a surface are visible above the apex as stair-stepped topographic rises between the top of bank and the 1/1b surface. These stair steps are often defined by heavily varnished boulder levees. The individual rises slope gently away from the channel, showing the arched surface of the Pleistocene fan surface. No other apparent geomorphic characteristics distinguish these subdivisions of the 2b/2a. A single fill terrace at 1.5 to 2 feet above the existing channel bottom lines both banks of the channel. This terrace is composed of recently deposited fine sand to gravel and provides rooting soil for much of the vegetation that lines the channel.

The dominant geomorphic process at the site is erosion as evidenced by the fact that the more active surfaces are inset significantly into the older Pleistocene surface. Isolated remnants of the 1/1b surface occur within the 2b/2a surfaces. These isolated older remnants are not being buried, but rather, they occur as isolated topographic



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SCALE 1"= 1500'

LEGEND

GEOMORPHOLOGY

2c - Channel fill youngest
2b - Floodplain
1 - Pleistocene surface
Bedrock oldest

Figure 11
South Mountain Park
Geomorphic Surfaces

rises. Further, the younger surfaces are littered with coarse angular to sub-angular boulders and cobbles, some of which have caliche coatings. These bouldery deposits are located in or near channels, as well as in some overbank areas. They are obviously too large to have been deposited by overbank or sheet flow, and do not exhibit debris flow characteristics. Therefore, they probably represent erosional lag left after fluvial deflation of the older surface. Active headcuts and recent stream captures observed at the site are further evidence of active erosion.

White Tank Mountains

Location. The White Tank site is located on the southwestern piedmont slope of the White Tank Mountains (Figure 1). The White Tank Mountains are located approximately 30 miles west of Phoenix, about 10 miles north of the Town of Buckeye. The watershed drains the western mountain slopes and flows southwesterly toward the Hassayampa River. The White Tank Mountains are administered by the Bureau of Land Management and the Maricopa County Parks Department, although portions of the site watershed and alluvial fan are privately held (Figure 12).

Access. Access to the site follows paved highways and graded dirt roads. To reach the site, take Interstate 10 west to exit 114 (Miller Road). Take Miller Road north less than 0.25 mile, and turn west on a graded dirt road. Continue west and northwest to the first powerline road. Veer north on powerline road for 3.0 miles past several bedrock knobs, then turn north on a privately maintained dirt road. Proceed north 0.8 miles, and turn west at a "Y" in the road. The primary channel of the White Tanks site below the distributary flow area crosses the road here in a culvert/dip crossing. Turn north after the crossing and travel 0.6 miles to a "No Trespassing" sign. Turn east at the sign and go 0.7 miles to another powerline road, then turn northwest toward the distributary flow area.

To reach the hydrologic apex, travel northwest through the widest portion of the distributary flow area for 0.6 miles and turn east on a dirt road which parallels the wash. Travel 0.8 miles, then turn south through the wash. The apex is located 0.2 miles downstream from this crossing. The upper portion of the watershed is accessed by staying on the road which parallels the wash.

Selection Criteria. Although the White Tank Mountains site was not highly rated in the selection matrix, subjective factors make this site an acceptable data collection site. Fan terraces and distributary flow systems are by far the most common type of alluvial fan in Maricopa County. This site offers opportunities to gauge both. Because runoff recombines in the fan terrace downstream of the DFA, flow attenuation and transmission losses in the DFA can be gauged. The geomorphology and geology of the area have been thoroughly studied. Portions of the area have the potential to develop within a 20 to 50 year period. The site also has a large watershed with reaches which contain paleoflood sites.

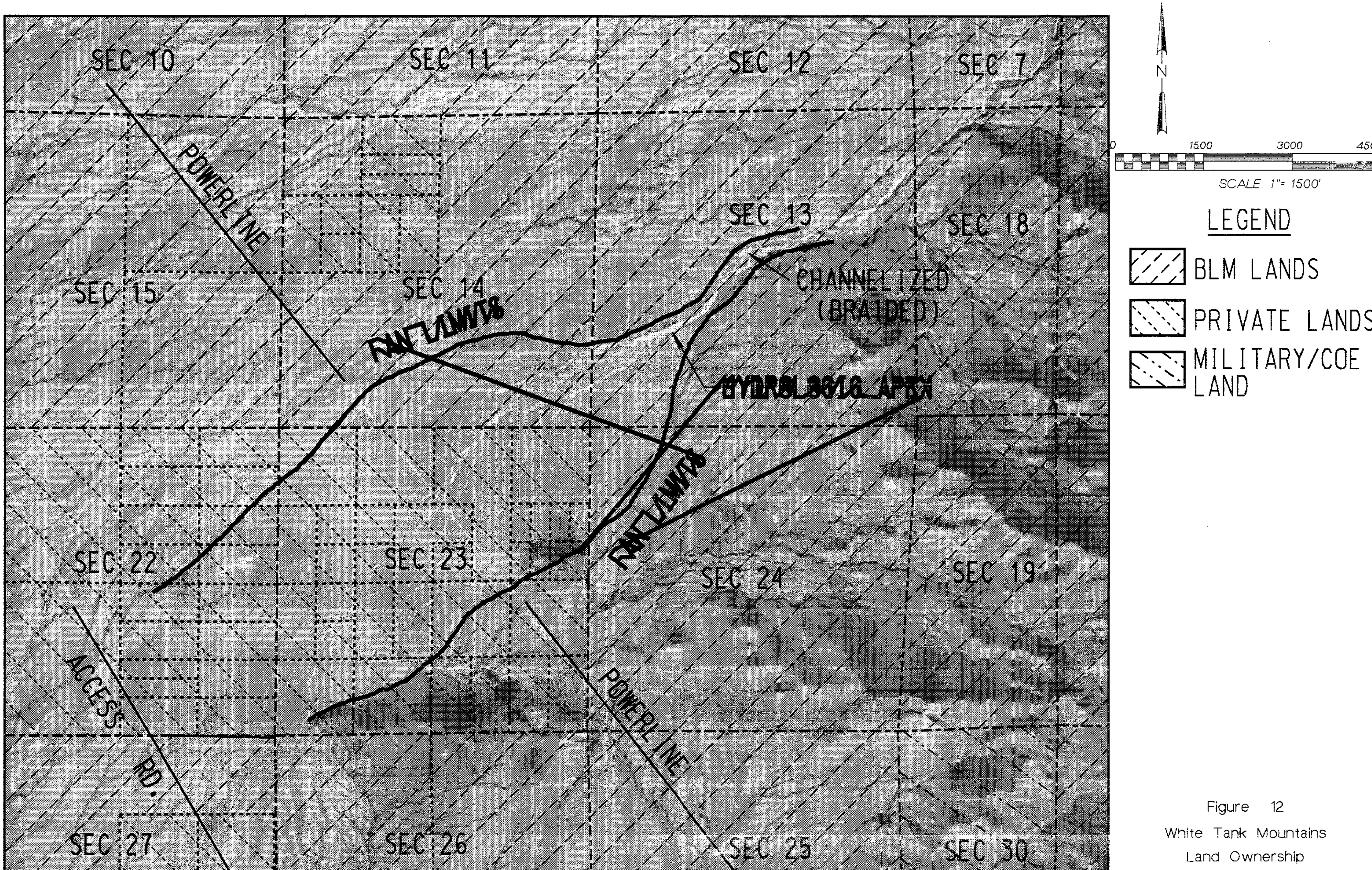

Figure 12
White Tank Mountains
Land Ownership
and Location

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Vegetation. Vegetative communities found at the White Tank Mountains site (Figure 13) are typical of the region. Dense, leaf-bearing vegetation line channel banks. Sparse cacti and creosote/bursage dominate older surfaces and terraces. Well developed desert pavement and infrequent runoff presumably limit plant growth on the older surfaces. Grasses and annuals may be found within the more frequently wetted distributary and sheet flow area. Specific plant types were summarized in Table 4.

Soils. The soils at the White Tank Mountains site (Figure 13) belong to the Gunsight-Rillito-Chuckawalla General Soil Association. The Gunsight-Rillito-Chuckawalla Association is a gently sloping to moderately steep gravelly and very gravelly loamy and clayey unit found on fan terraces. Two basic soil complexes from the Gunsight-Rillito-Chuckawalla General Soil Association occur in the project area. The Antho-Carrizo-Maripo sandy loam and very gravelly sand is found in major drainageways and floodplains. This sandy unit has rapid permeability, severe erosion hazard, is subject to channelization, and deposition during occasional flooding. The Momoli-Carrizo, Gunsight-Rillito, Denure-Momoli-Carrizo, Pinamt-Tremont, and Ebon-Pinamt complexes are found on fan terraces. These units are slightly to moderately calcareous, have moderate to high permeability, and are subject to slight erosion hazard. The SCS maps the entire White Tank Piedmont as a fan terrace, rather than a recent or active alluvial fan.

Geology. Like the South Mountains, the White Tank Mountains comprise the lower portion of a metamorphic core complex. The Precambrian gneiss and granites which form much of the mountain area were emplaced during the Mazatzal Orogeny (Table 8). The mountains uplifted, intruded, exposed to erosion during Laramide and mid-Tertiary faulting. Basin and Range deformation further exposed bedrock, as well as caused some injection of basaltic rock.

Rock units exposed in the White Tanks (Figure 14) include the Precambrian Estrella Gneiss, the Cretaceous(?)-aged White Tank granite (Brittingham, 1985), numerous isolated Tertiary sills and dikes of varying composition (felsic, porphyritic, and mafic), and mid-Tertiary basalts. These rock suites are lithologically similar to the northern Sierra Estrella Mountains and the western South Mountains. The Estrella Gneiss, which forms most of the bulbuous rounded peaks and core of the White Tank Mountains, is composed of undivided schists and granite units. Its northwest trending lineation and shallow dipping mylonitic foliation is typical of the lower range of a metamorphic core complex. Abundant talus derived from the unit covers most hillslopes. An extensive Precambrian granite with similar properties is usually mapped together with the Estrella Gneiss.

Ridges formed by mid-Tertiary aged sills and dikes 1 to 10 meters thick occur throughout the mountain area. Small outcrops of resistant Tertiary basalts occur on the western slopes and in inselbergs along the western bajada. These inselbergs control drainage patterns on the western and southern margins of the project site.

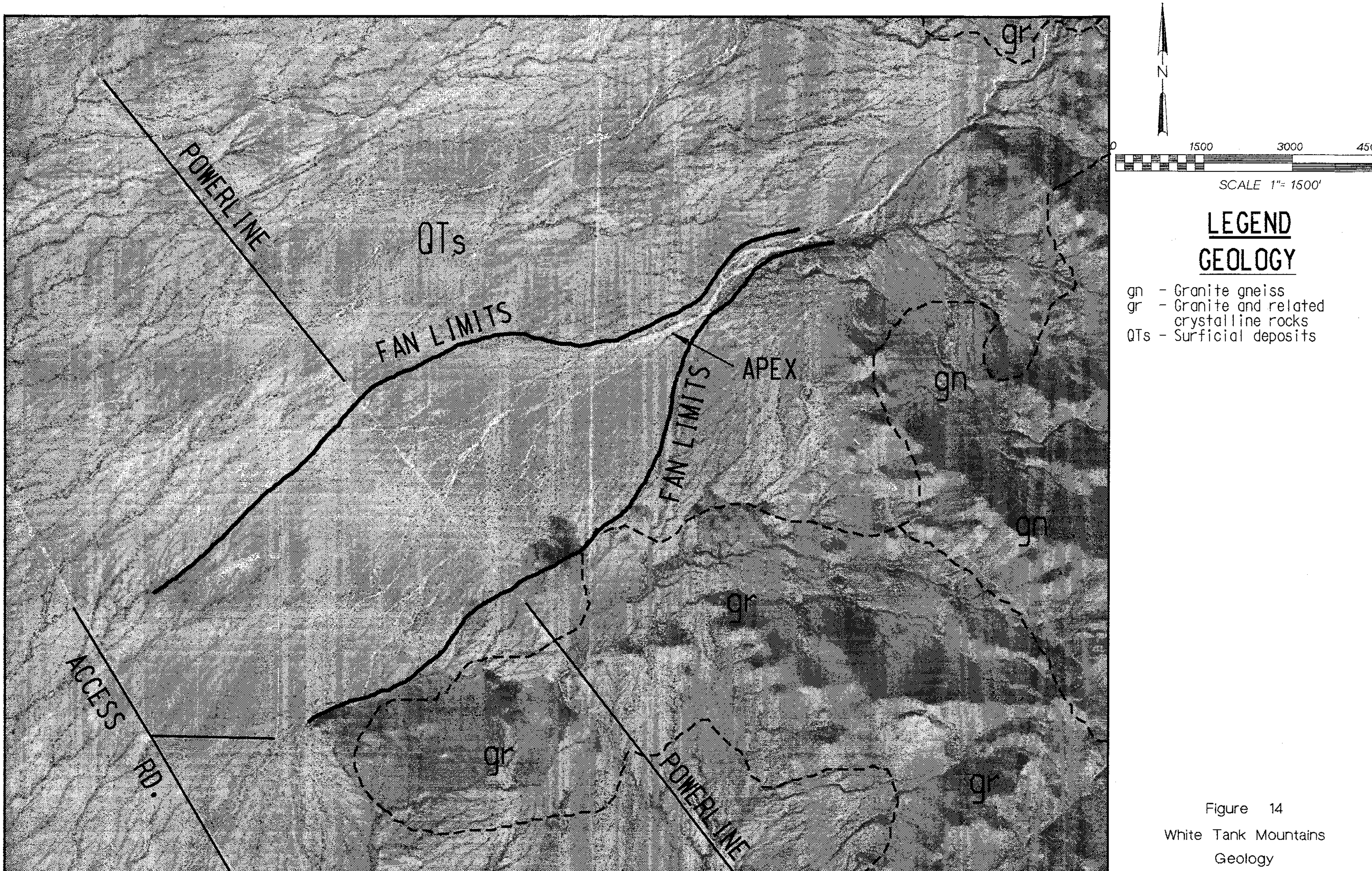

Figure 14
White Tank Mountains
Geology

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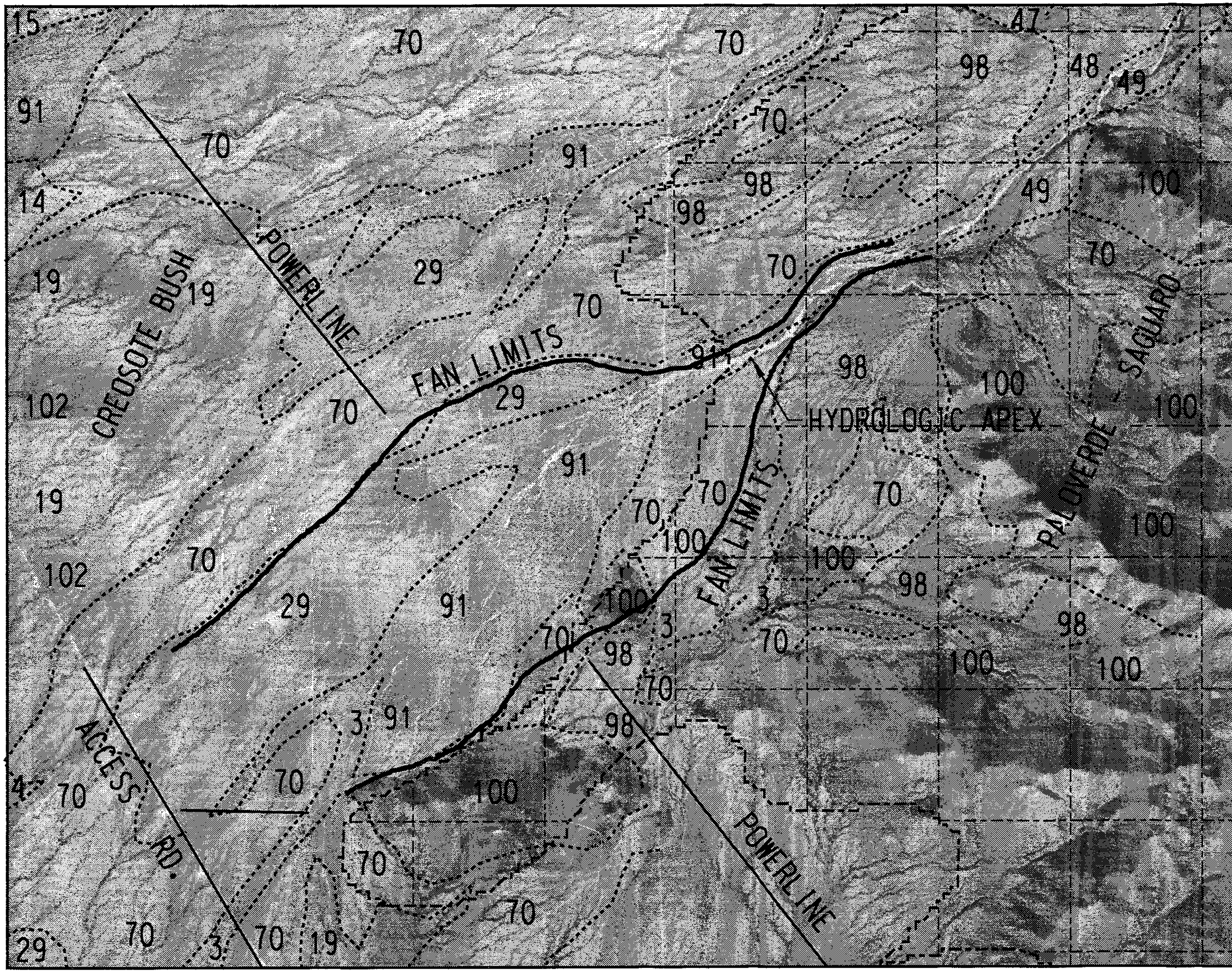

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LEGEND

VEGETATION

Paloverde Saguaro Limits

Cresote Bush Limits

SOILS

3 - Antho-Carrizo-Maripo complex
4 - Antho-Carrizo-Maripo complex
14 - Carrizo very gravelly sand
19 - Chuckawalla-Gunsight complex
29 - Denure-Momoli-Carrizo complex
47 - Ebon-Gunsight-Cipriano association
48 - Ebon-Pinamt complex
49 - Ebon-Pinamt complex
70 - Gunsight-Rillito complex
92 - Momoli-Carrizo complex
98 - Pinamt-Tremant complex
100 - Quilotosa-Vaiva-Rock outcrop complex
102 - Rillito gravelly loam

Figure 13
White Tank Mountains
SCS Soils Mapping
and Vegetation

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Depth to bedrock data for the site were available from ADWR well log information and a map published by the USGS (1973). Depth of alluvium varies from zero to 400 feet in the distributary flow areas. Because several inselbergs are located on the site, the actual depth to bedrock is probably highly variable. The two well logs for the site record varying depth to bedrock from 10 to 600 feet within a 10-acre parcel. Bedrock only crops out in the channel above the hydrologic apex, and where the channels abut the inselbergs. Depth to bedrock information is summarized in Figure 14.

Hydrology. The White Tank Mountains site drains a watershed of 5.63 square miles at its hydrologic apex. As with the South Mountain site, the smaller size of the basin predisposes it to respond more intensely to monsoonal rainfall. Unfortunately, little or no historical or systematic flood data are available for the site or the region. The nearest precipitation gauges are shown in Table 5. Data from USGS recording gauges have not been reduced and are currently unavailable.

Anecdotal accounts of flooding are limited. The Bureau of Reclamation maintains the powerline road which traverses the widest part of the distributary flow area. Road maintenance crews report being stranded for several hours by a large flood in 1966. They also indicate that flooding is generally confined in the larger stream channels with limited overbank flooding. Smaller channels appeared to be aggrading. Floods leave deposits of sand and silt on the road. Channel erosion or coarse material deposition have not been problems. Runoff ceases within a few hours of the end of rainfall (Blackford, 1991). Some additional flood information may be available from private landowners who have inhabited portions of the piedmont for at least 20 years.

Peak flow information at the apex provided by the FCDMC is summarized in Table 10. Peak discharges range from 232 cfs for the 24-hour 2-year storm to 4,892 cfs for the 24-hour, 100-year storm assuming logarithmically weighted losses. Log-weighted loss parameters were used to more accurately portray the soil units in the watershed which have highly variable textural components. Complete discussion of the derivation of these flood peak estimates is provided in a report prepared by the FCDMC.

Manning's ratings of channel sections using 100-year discharge data provided by the FCDMC reveal a significant decrease in hydraulic capacity near the hydrologic apex. Above the apex, the channel had more than sufficient capacity for the 100-year flood. Downstream of the hydrologic apex, the cumulation capacity of all the distributary channels is less than the 100-year flood. The distributary channels have cumulative capacity for the 10-year flood, though no single channel had capacity for greater than the 2-year event. Approximate floodplain limits for the site are shown in Figure 15.[7] Manning's velocity estimates range from 6-7 fps for the 100-year flood in the channel above the hydrologic apex to 9.6 fps at channel capacity in a channel on the distributary flow area below the hydrologic apex.

[7] Floodplain limits are not for regulatory or design purpose.

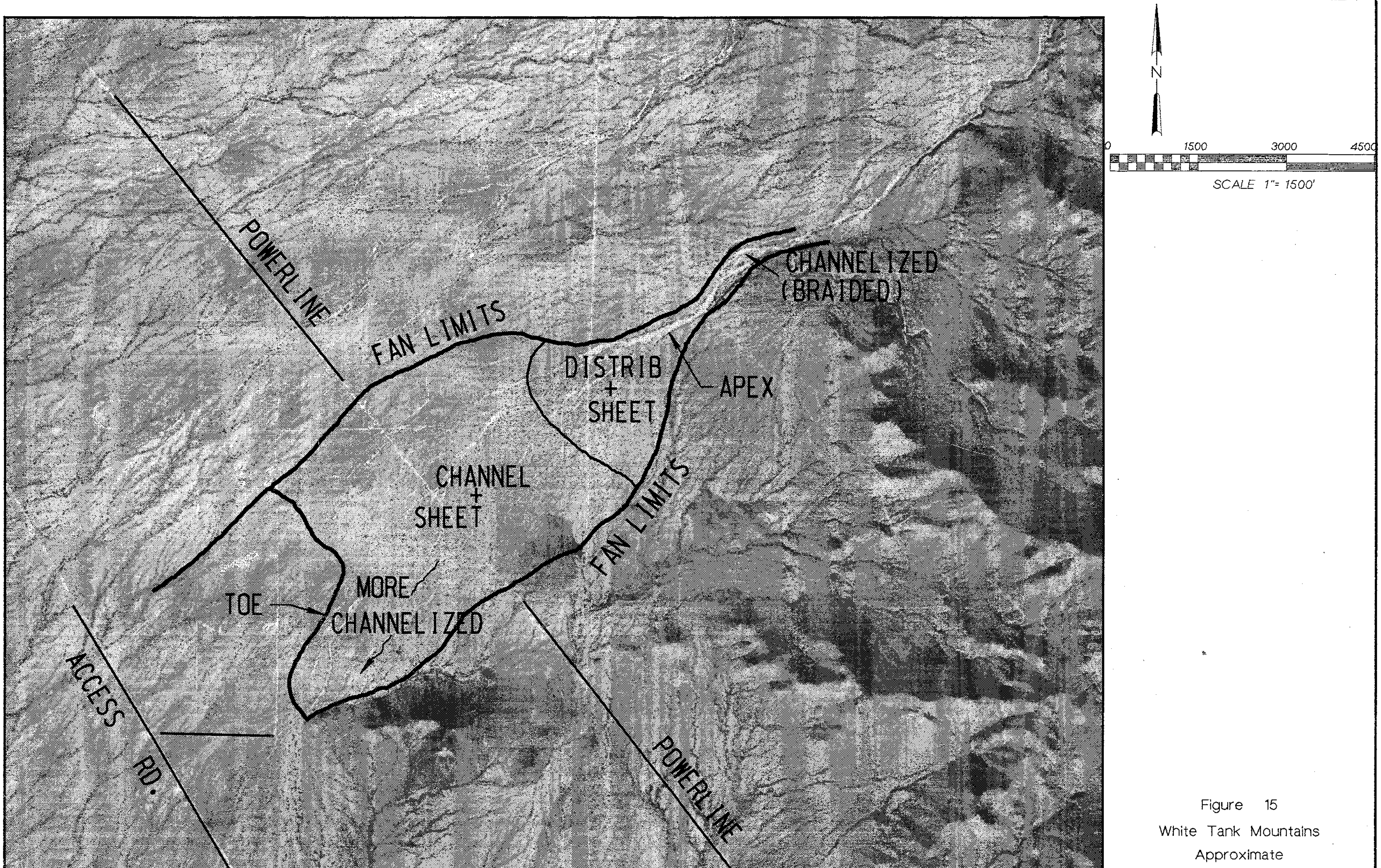

Figure 15
White Tank Mountains
Approximate
Floodplain Limits

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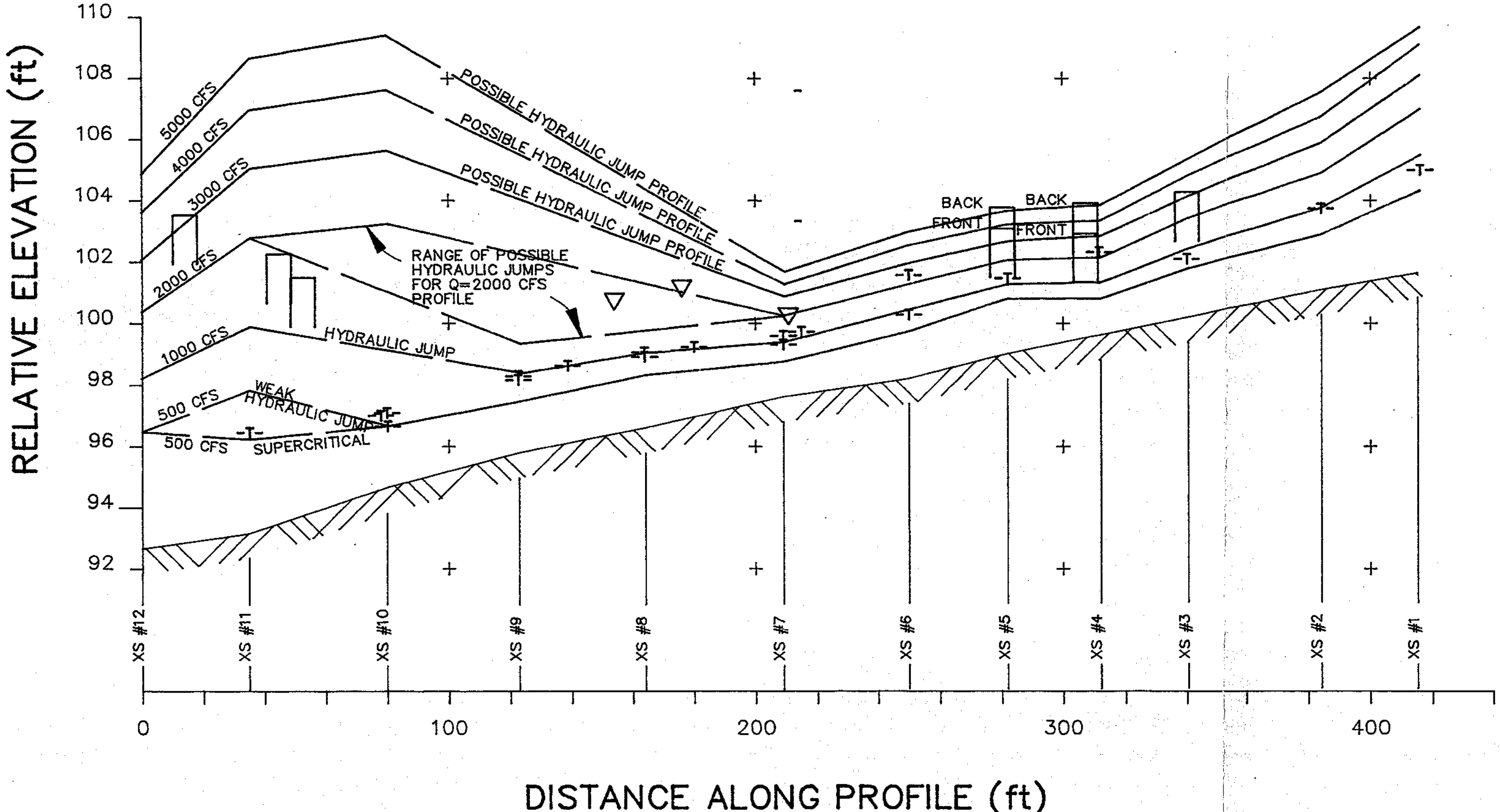
Table 10 Peak Discharge Estimates (cfs), White Tank Mountains Site		
Recurrence Interval (Years)	24-Hour Rainfall	6-Hour Rainfall
2	232	266
5	454	385
10	1082	669
25	2402	1408
50	3518	2230
100	4892	3348
[1]Discharge values shown are taken directly from HEC-1 model output provided by FCDMC and do not reflect actual significant figures.		

Paleoflood Survey. A paleoflood survey was made of the canyon reach two miles upstream of the hydrologic apex. At the paleoflood reach, the channel is a steeply sloping (0.022 ft/ft) sand gravel bed stream. The channel banks through most of the reach are composed of resistant carbonate-bound bouldery Pleistocene soils. The terrace slopes are covered with cobbles and boulders, as well as Saguaro and other cacti. The downstream end of the reach is completely controlled by bedrock, as a bedrock constriction narrows the flow width from 70 to 100 feet wide to less than 30 feet. A tributary joins the main channel near the upstream end of the reach.

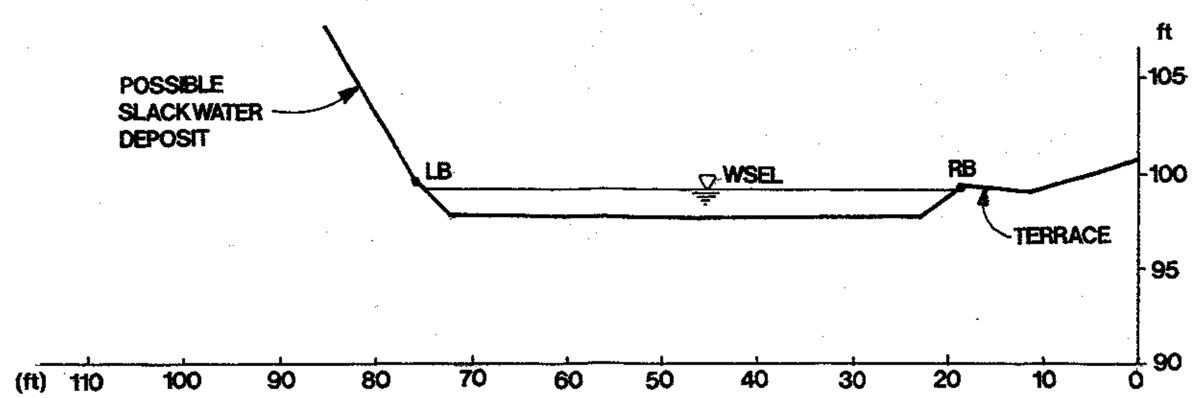
Several types of highwater marks were found in the paleoflood reach. A sandy slackwater deposit is located in the channel expansion just downstream of the tributary confluence. Because of the small size of the watershed and the bedrock type, fine grained sediment such as silt and clay are not abundant. Therefore, the slackwater deposit is composed primarily of sand and some fine gravel. Three sandy flood units, separated by thin gravelly talus lenses, were observed by examining the soil profile in an excavated section of the deposit. A second highwater mark was formed by an inset gravelly sand terrace which appeared to mark the elevation of a more recent flood. Finally, a slope break on the north bank slope marking the transition from channel erosion processes to slope erosion processes was used as maximum highwater mark.

Water surface profiles were computer using the computer model HEC-2 (HEC, 1988) and were compared to highwater marks found in the reach (Figure 16). The upper half of the reach experiences supercritical flow due to the steep slope. The bedrock constriction at the lower end of the reach forces a hydraulic jump upstream of the constriction, and critical depth in the constriction for flow rates over 500 cfs. Because of the hydraulic jump, the water surface is unstable. Also, the exact location of the jump is difficult to predict. Therefore, correlation of highwater marks between the



LEGEND

-T-	Terrace
–	Possible Slackwater
▽	Slope Break
⊓	Slackwater Deposit



TYPICAL CROSS-SECTION

FIGURE 16

WHITE TANKS PALEOFLOOD WATER SURFACE PROFILES

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upper and lower reach is difficult. However, the existence of the jump explains the otherwise anomalous elevations of the slackwater deposits just upstream of the bedrock constriction.

Based on the slackwater elevations, the largest flood preserved in the reach peaked at between 2,000 and 4,000 cfs. More accurate calibration of this flood is not possible due to uncertainties in the water surface profiles caused by the hydraulic jump. Using the most conservative interpretation of the slackwater record the largest flood preserved could have been no greater than 5,000 cfs. A more recent flood of 500 to 1,000 cfs emplaced the inset sandy terrace.

No absolute age determinations were made for any of the paleostage indicators collected in the reach. Relative age estimates, however, can be made. Based on the lack of mature vegetation, the lack of an organic horizon on top of the slackwater deposit, and lack of other soil characteristics, the flood of record probably occurred within the past 100 years. Because no vegetative flood debris was found in conjunction with the higher deposits, the flood probably did not occur within the past 20 years. If these age estimates are correct, the flood of record may be the flood responsible for the extensive channel erosion at the hydrologic apex seen by comparing the 1942 and 1972 aerial photographs.

The slackwater record in this reach may be geologically short for several reasons. The paleoflood reach experiences high velocity supercritical flow and the excessive turbulence of hydraulic jumps. Therefore, the stratigraphic flood record may be periodically wiped clean by channel erosion. The small size of the watershed and rock type do not supply an excessive amount of sediment. Floods on the White Tank piedmont may be more erosive than in streams in other areas. Therefore, larger floods may have occurred in the geologically recent past which are not preserved in the reach.

Paleoflood discharge estimates compare very well with the peak flow estimates made by the FCDMC using HEC-1. Even though the paleoflood record may be short, floods of the same magnitude as the HEC-1 estimates have actually occurred in the watershed. Because the paleoflood reach is located upstream of the concentration point of the discharges listed in Table 10, the watershed is somewhat smaller. Therefore, it may be prudent to use the more conservative HEC-1 discharge estimates based on the log-weighting procedure.

Geomorphology. The White Tank Mountain site exhibits characteristics of an active alluvial fan, as well as a distributary flow system. The site was originally assigned to the distributary flow system category. However, more detailed consideration of the site geomorphology and flood history revealed characteristics usually indicative of an active alluvial fan. More detailed geomorphic data collection, including trenching of soils, and gauging of a range of flood flows may be required to conclusively assign the site to a specific category. For the purposes of this discussion, the site will be referred to as a distributary flow system.

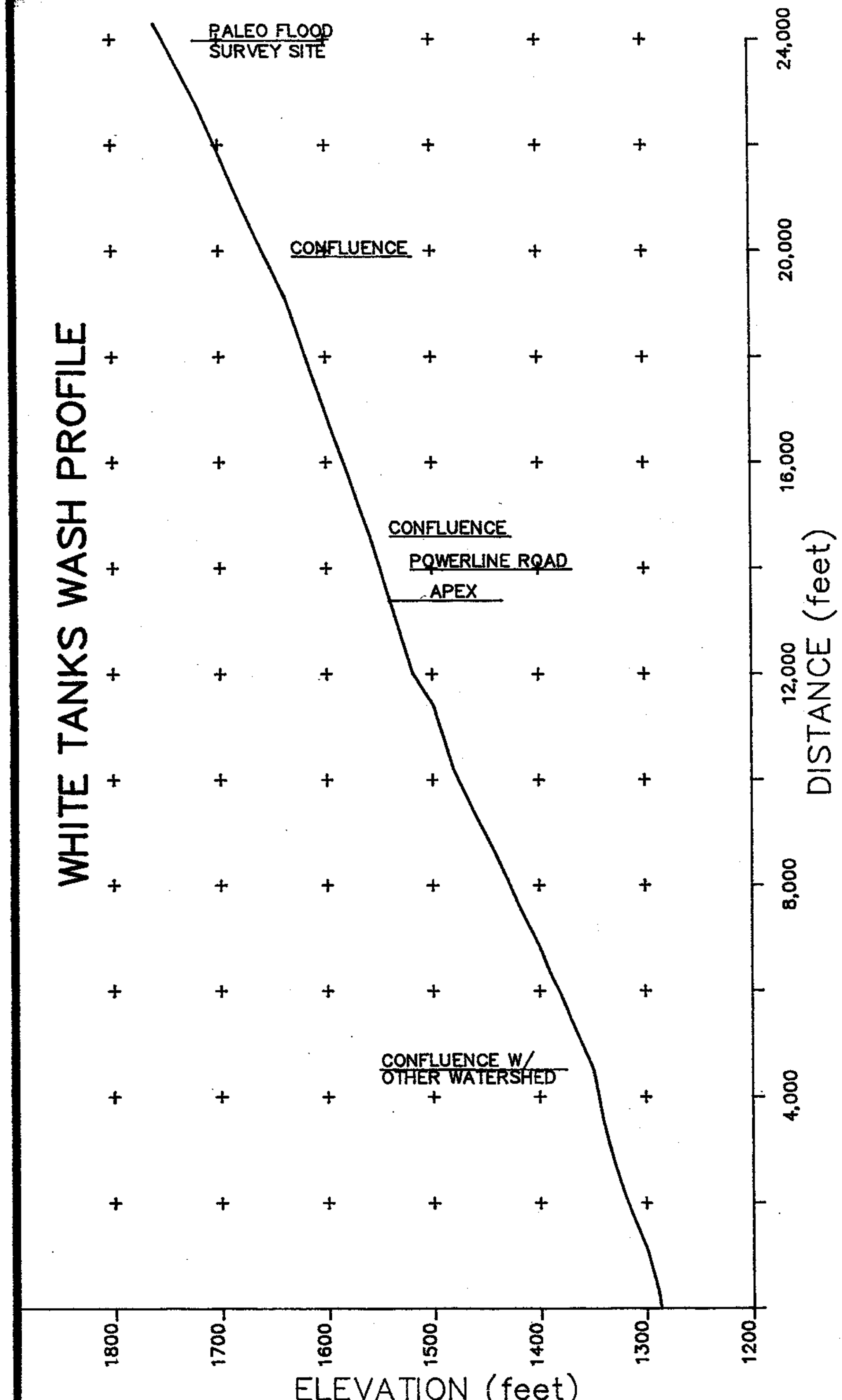
The site is located along an unnamed fifth order stream on the White Tank Mountains' western slope piedmont. The White Tank piedmont is comprised of a partially buried pediment surface near the mountain front, and inactive alluvial fans downslope from the pediment. Inactive alluvial fans were created by secondary entrenchment probably due to base level fall in the Hassayampa River. A zone of distributary flow systems and active alluvial fans occur along the broad intersection of pediment and inactive fans. The project site occurs within this zone.

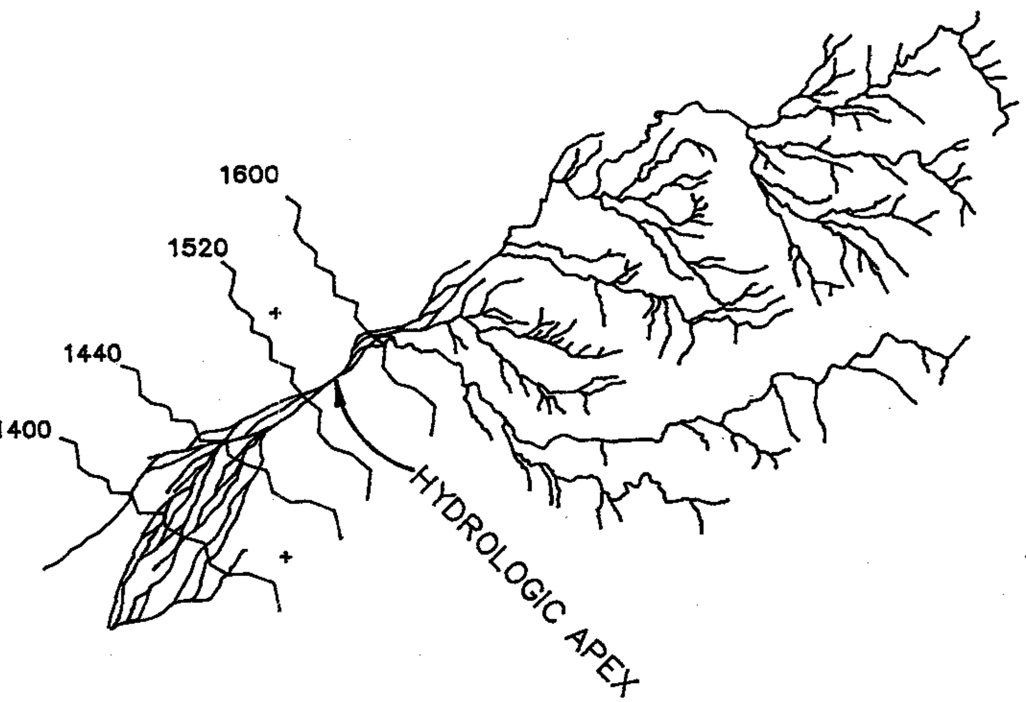
The zone of intersection also applies to other key geomorphic parameters (Figure 17). The pediment surface and lower piedmont exhibit a dendritic stream pattern, with a distributary or anastomosing stream pattern in the junction zone between them. The hydrologic apex occurs just downstream of the probable limit of the pediment. The channels are nearly straight just below the hydrologic apex (Sinuosity S=1.05) and increasingly sinuous upstream and downstream of the apex (Sinuosity S=1.06 to 1.72) on the more dissected surfaces. Channel slope shows a marked increase in slope below the hydrologic apex (0.023 ft./ft.), followed by a return to the upstream channel slope (0.017 ft./ft.) at the point where the channels rejoin and the tributary drainage pattern is re-established (0.014 ft./ft.). The crenulation index also increases in both directions away from the distributary flow area, with the greatest increase in the system direction.

The stream is entrenched in bedrock upstream of the apex on the buried pediment surface. Downstream of the pediment, the channel widens and becomes braided, though still deeply entrenched into a caliche-cemented fan terrace. Below the hydrologic apex, aggradation precludes confining channel banks, allowing the braided channel to laterally extend its limits. After the distributary reach with alluvial control, the channel becomes re-entrenched, with bedrock and/or caliche control.

Sediment transport at the site appears to be limited to typical alluvial processes. No evidence for recent debris flows was found below the hydrologic apex. The braided channel pattern and straight channel alignment indicate high bedload transport. The sediment load primarily consists of sand, gravel, and small cobbles. This pattern fits with the tendency for the granitic bedrock in the watershed to weather to sands and gravels, rather than silts and clays. Coarse sediment is a significant portion of the load even well below the apex, near the upper powerline road, where coarse gravel was observed lodged in flood damaged shrubs.

Though debris flows undoubtably were a major factor in formation of the overall piedmont in the Pleistocene, debris flows are no longer likely in the distributary flow area. However, debris flows may be a factor in the morphology of low-order streams near the headwaters. A single debris flow levee forming a fill terrace upstream of the paleoflood site was noted in the field reconnaissance. Based on examination of watershed conditions and debris flow scars, recent debris flows do not contain enough fine-grained sediment or water to obtain the runout distance required to reach the distributary flow area, which is located several miles downstream of the mountain front.

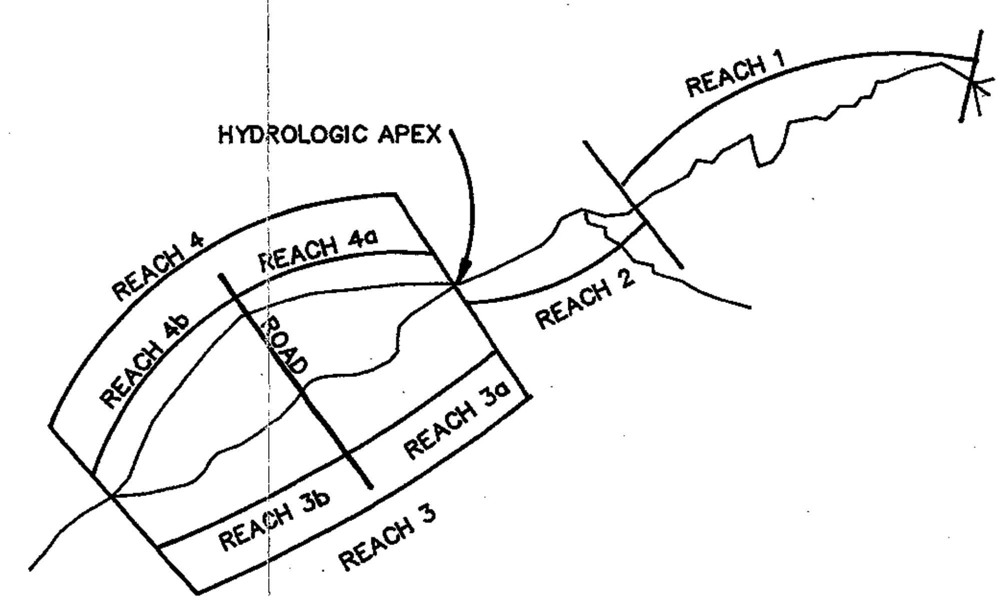




CHANNEL PATTERN

CRENULATION INDEX

CONTOUR ELEV.	ALONG CONTOUR	BEGIN TO END	CREN. INDEX
1320	12100	7290	1.660
1360	13530	7190	1.882
1400	8780	7710	1.139
1440	8950	6460	1.385
1480	6850	5730	1.195
1520	5560	4320	1.287
1560	8990	5570	1.614
1600	11950	5210	2.294



SINUOSITY

REACH #	IN-STREAM LENGTH	BEG-END LENGTH	SINUOSITY	
1	6.667	4.95	1.717	
2	2.264	2.14	1.058	
3	4.577	4.37	1.047	ENTIRE BRAID
3a	2.413	2.38	(1.014)	ABOVE ROAD
3b	2.164	1.98	(1.093)	BELOW ROAD
4	4.627	4.37	1.059	ENTIRE BRAID
4a	2.488	2.37	(1.050)	ABOVE ROAD
4b	2.139	2.08	(1.028)	BELOW ROAD

FIGURE 17

WHITE TANKS WASH
CHANNEL PATTERN
SINUOSITY, PROFILE
& CRENULATION INDEX

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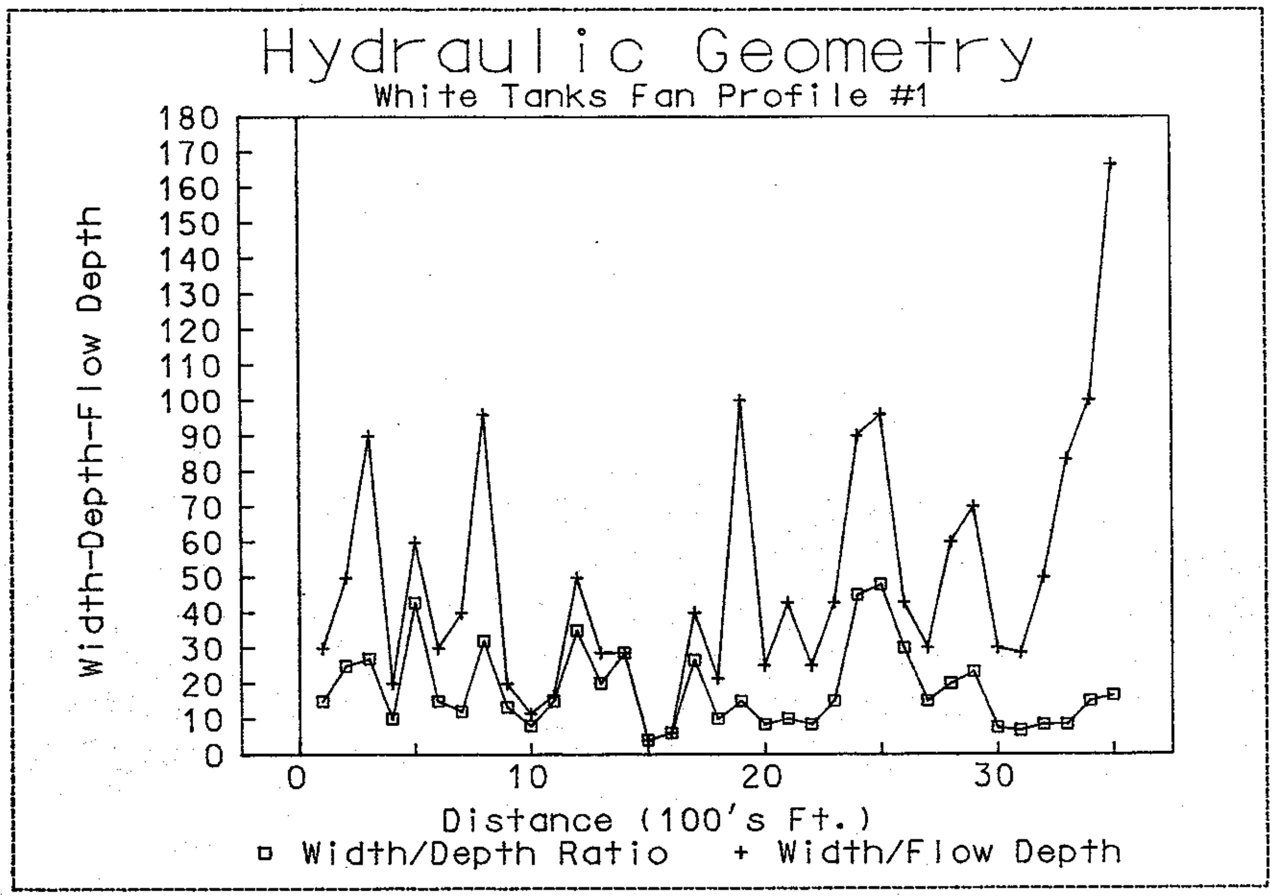
The hydraulic geometry of stream channels on the alluvial fan was analyzed using field measurements. Channel geometry, including width, bank height, and flow depth as indicated by flood debris was measured every 100 feet in each channel or distributary flow path downstream of the hydrologic apex. For each of addition, data collection transects of the total fan widths were made every 300 to 500 feet between the geologic apex and the toe of the fan. For each of these transects, channel geometry, soil and vegetation characteristics, flood debris, and other geomorphic parameters were recorded.

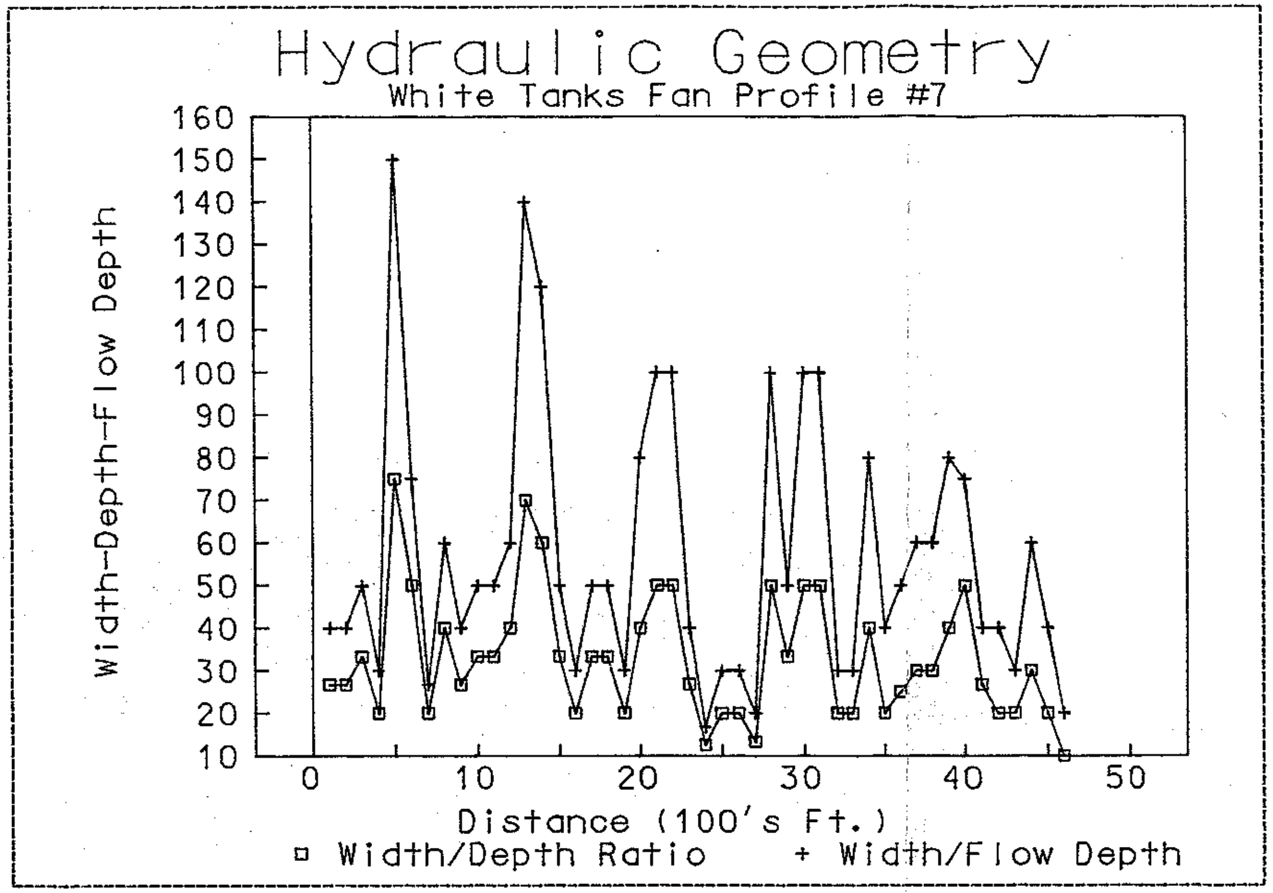
Channel geometry in the distributary flow area is not governed by any apparent predictable relationship (Figure 18). Channel width, cumulative channel width, depth, flow area, and width/depth ratio vary considerably from point to point with distance downfan as the anastomosing channels split and recombine. The overall trend, ignoring oscillations, is for width, depth, individual channel capacity, cumulative channel capacity, and sediment size to decrease downstream to the point where the tributary pattern begins to surface. Downstream of this point, which is located downstream of the upper powerline road, cumulative channel capacity begins to increase. These relationships indicate that overbank and sheet flow are significant components of flooding. This hypothesis is supported by field evidence of overbank sand and vegetative debris deposition throughout the distributary flow area.

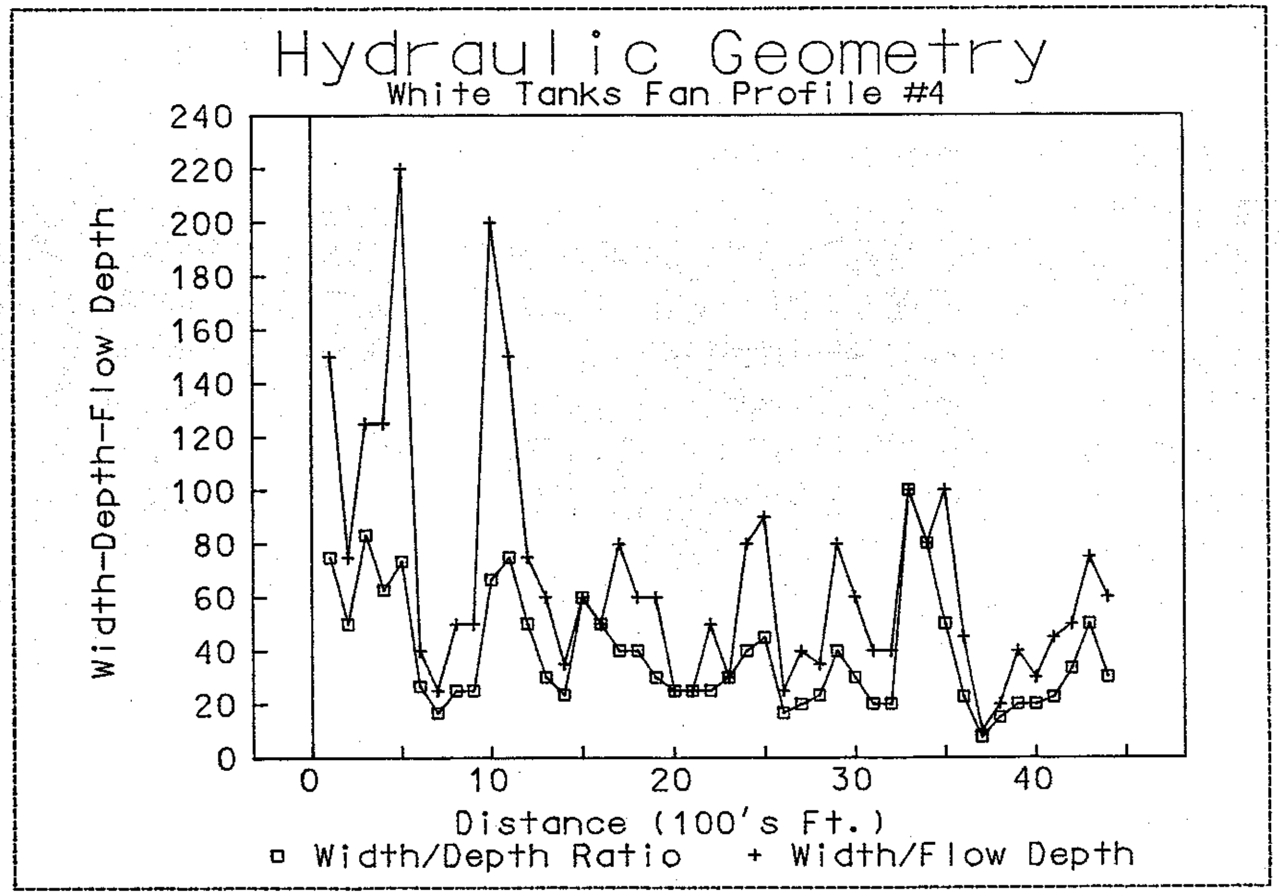
Dominant geomorphic channel processes include bank erosion and general aggradation. Extreme bank erosion between 1953 and 1972 widened numerous channels and scoured out new channels. It is unclear from the photographic record whether all of this erosion is the result of natural processes. The linear pattern of erosion, together with road building and development activities concurrent with the period of channel erosion, may indicate a more anthropogenic origin.

Shifts in dominant flow paths have also occurred within the photographic record period (Figure 19). The cause of these shifts is unknown. They are not simple avulsions. Natural dams formed of fallen trees and vegetation were observed in two channels with sediment piled up behind them. However, rather than cause avulsions, these dams simply diverted floodwater over and around them, and the floodwater continued down the original channel. Furthermore, the channel shifts observed on historical photographs usually exploited existing minor channels, increasing their capacity by widening and deepening them. The implications of these channel shifts are treated more fully in the Discussion section of this report.

A tendency for aggradation in the distributary flow area is seen as younger surfaces override and deposit material on older surfaces, particularly along the southern margin of the fan. The lack of defined channel banks along most of the distributary channels, and overbank deposition of silty sands indicate aggradation. Upstream of the apex, channels are degrading in geologic time, as seen by the formation of terraces and by frequent bank failures which expose paleosols. However, braiding in the channel just above the apex is evidence of the heavy sediment load.







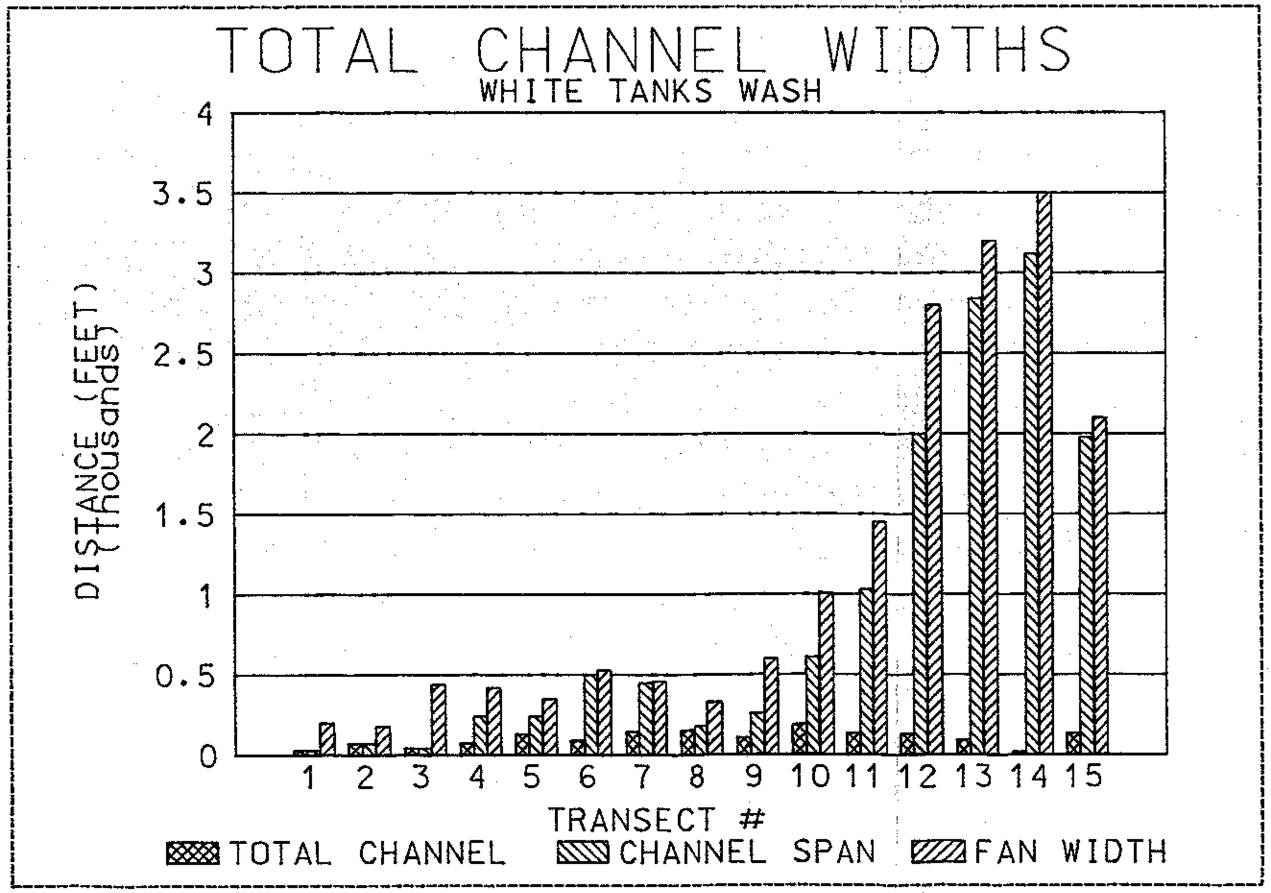


Figure 18
White Tank Mountains
Channel Geometry

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Several terraces can be traced along the primary channel toward the mountain front. Terrace surfaces occur not only at the channel margins, but in two cases as islands in the primary channel. This unusual phenomenon indicates that the channel pattern was also braided during the period the terraces were being formed, and that erosion to the new bed elevation was swift, with downcutting exceeding lateral planation. Channel terraces are located from several feet to 10-15 feet above the existing channel bottom. The lowest terrace is composed of cobbles and boulders in a sandy matrix, and probably corresponds to the 2a surface found in the distributary flow area. The lack of significant soil development and similar soil composition to the existing channel bottom sediment indicate that it is a geologically recent fill terrace. Debris flow levees were found on the margin of this terrace above the paleoflood site. Therefore, emplacement of the terrace may be related to a pulse of sedimentation which included debris flow activity. No geologically recent debris flow evidence was observed near or below the hydrologic apex.

The higher stream terraces are strath (erosional) terraces formed of soils with stage III or IV caliche, and with desert pavement on the surface. These terraces are remnants of Pleistocene and Tertiary-aged surfaces. The soils in these terraces bear no resemblance to active channel deposits. Aggradation is burying these surfaces in the distributary flow area.

Geomorphic surfaces were also mapped at the site (Figure 20). The youngest surface, the 2c surface, is the active channel and interfluves. It has little or no soil development, and is subject to frequent erosion and scour. The 2b surface is less frequently flooded due to slight topographic elevation above the 2c surface. The 2b has slight surface reddening, is more sparsely vegetated, and is not traversed by numerous channels. Flooding on this surface consists of overbank and sheet flooding. The 2b surface may be analogous to the 100-year floodplain. The 2a surface has only limited exposure at the site. It is characterized by more soil reddening, development of a desert pavement surface with some desert varnish, and development of an incipient dendritic drainage pattern. In the lower distributary area, the 2a surface is partially buried by recent aggradation. The 1b and 1 surfaces are of Pleistocene age and are distinguished from each other primarily by the degree of tributary incision and dissection. The 1 and 1b surface have well-developed desert pavement and desert varnish, subsurface caliche formation, are elevated above the 2c-2a surfaces, and are dissected by tributary drainages. These surfaces grade into the upper terraces lining the channel above the apex.

At the lower limit of the distributary area, the 1 and 1b surfaces again dominate the piedmont, as channels become incised in a secondary entrenchment prior to entering the Hassayampa floodplain. Some investigators postulate that this secondary entrenchment is the result of base level fall on the Hassayampa River, in conjunction with reduction of sediment supply to the piedmont during the late Holocene. The geomorphic surfaces of the western White Tank piedmont have also been mapped by the Arizona Geological Survey (Field and Pearthree, 1991).

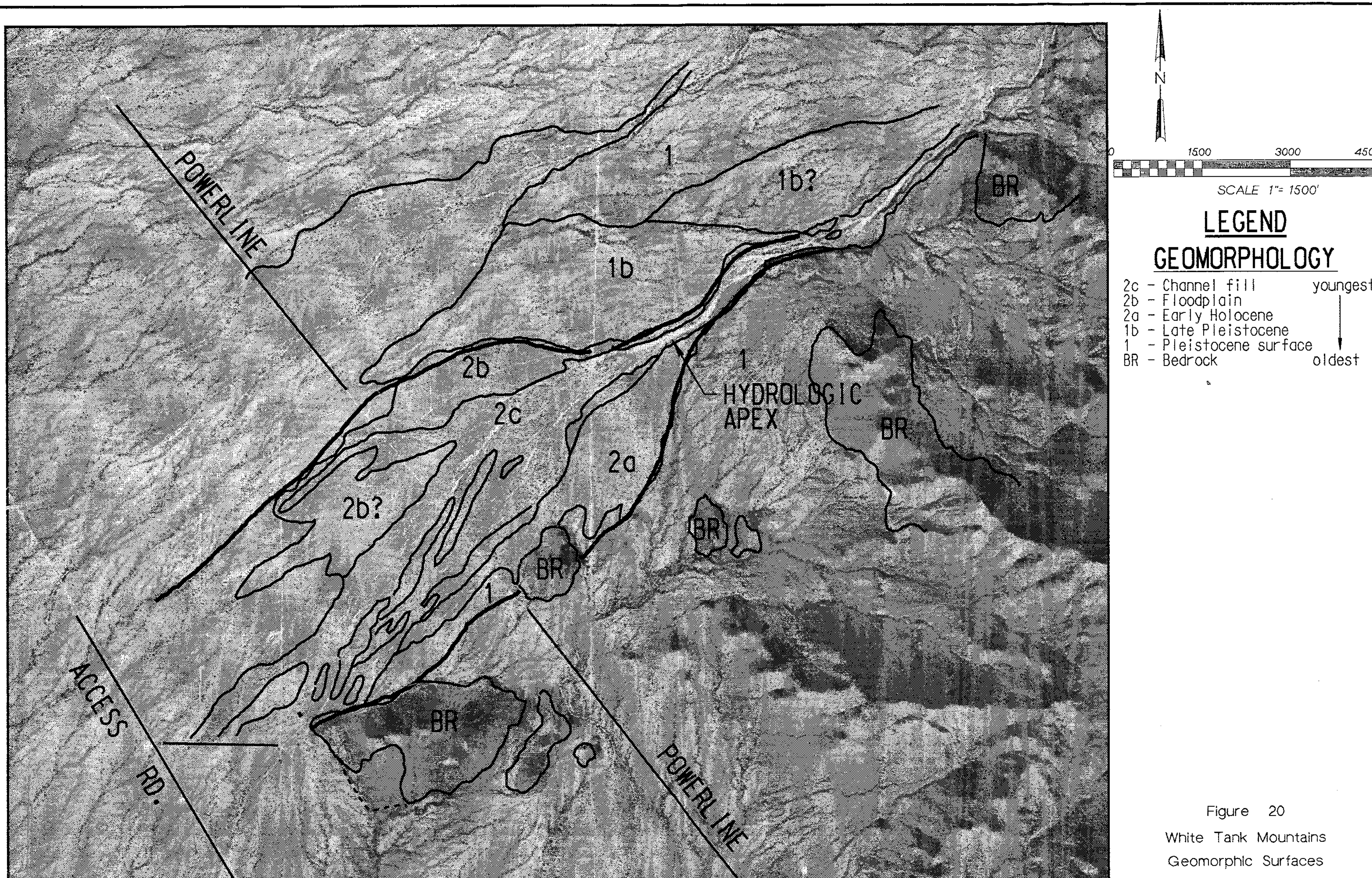

Figure 20
White Tank Mountains
Geomorphic Surfaces

CH2M HILL

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Tiger Wash

Location. The Tiger Wash distributary flow system and active alluvial fan is the westernmost site, located along the Maricopa-La Paz County line. The site lies primarily west of Eagle Eye Road approximately 22 miles west of the Town of Tonopah and 21 miles south of Aguila. Tiger Wash, also known as Rogers Wash, drains the upper Harquahala Valley located between the eastern slopes of the Harquahala Mountains and the western end of the Bighorn Mountains. Tiger Wash flows southerly into the Tiger Wash Detention Basin. Overflows from the Tiger Wash Detention Basin flow across the Central Arizona Project syphon to Centennial Wash, a major tributary to the Gila River. The Bureau of Land Management, the State of Arizona, and private interests manage the land at the site (Figure 21).

Access. The site area can be reached via publically maintained paved roadways. From Phoenix, take Interstate 10 west to exit 81 (Buckeye-Salome Highway). Proceed northwest 9 miles to Eagle Eye Road and turn due north. Eagle Eye Road follows a shallow ridge between the east and west braids of the distributary flow paths. The active alluvial fan is located along the western braid. Access to the active alluvial fan apex is an unmarked dirt road (heading west) located approximately 3 miles north of the intersection of Buckeye-Salome Highway and Eagle Eye Road. The apex access road is located between the cattle guard and a well travelled dirt road to a large stock pond east of Eagle Eye Road. Access to the distributary flow apex is through the upper abandoned gravel pit located upstream of the dip crossing on Eagle Eye Road.

Selection Criteria. The Tiger Wash alluvial fan was selected because it is an active alluvial fan and a distributary flow system, is likely to remain natural, has good all-weather access, and has a good historical and paleoflood record. It has a clearly defined apex, a single and multiple channel reach, and a well-defined sheet flooding area. In addition, there are opportunities to collect sediment samples and monitor flow attenuation.

Vegetation. Vegetative communities found at the Tiger Wash site (Figure 22) are typical of the region. Dense, leaf-bearing vegetation line channel banks. Sparse cacti and creosote/bursage dominate older surfaces and terraces. Well developed desert pavement and infrequent runoff presumably limit plant growth on the older surfaces. Grasses and annuals may be found on the more frequently wetted active alluvial fan. A unique feature of vegetation at the Tiger Wash alluvial is that the density and height of vegetation in the overbank dramatically increases in the more frequently flooded areas. Specific plant types found at the site were summarized in Table 4.

Soils. Soils on the Tiger Wash fan belong to two general soil groups: the Gilman Association, and the Momoli-Carrizo-Denure Association. The Gilman Association (Figure 22) is described as a nearly level, rarely flooded, moderately to rapidly permeable, moderately calcareous loamy soil found on floodplains and active alluvial fans. It includes the Brios-Carrizo loamy sand/very gravelly sand, and the Gilman

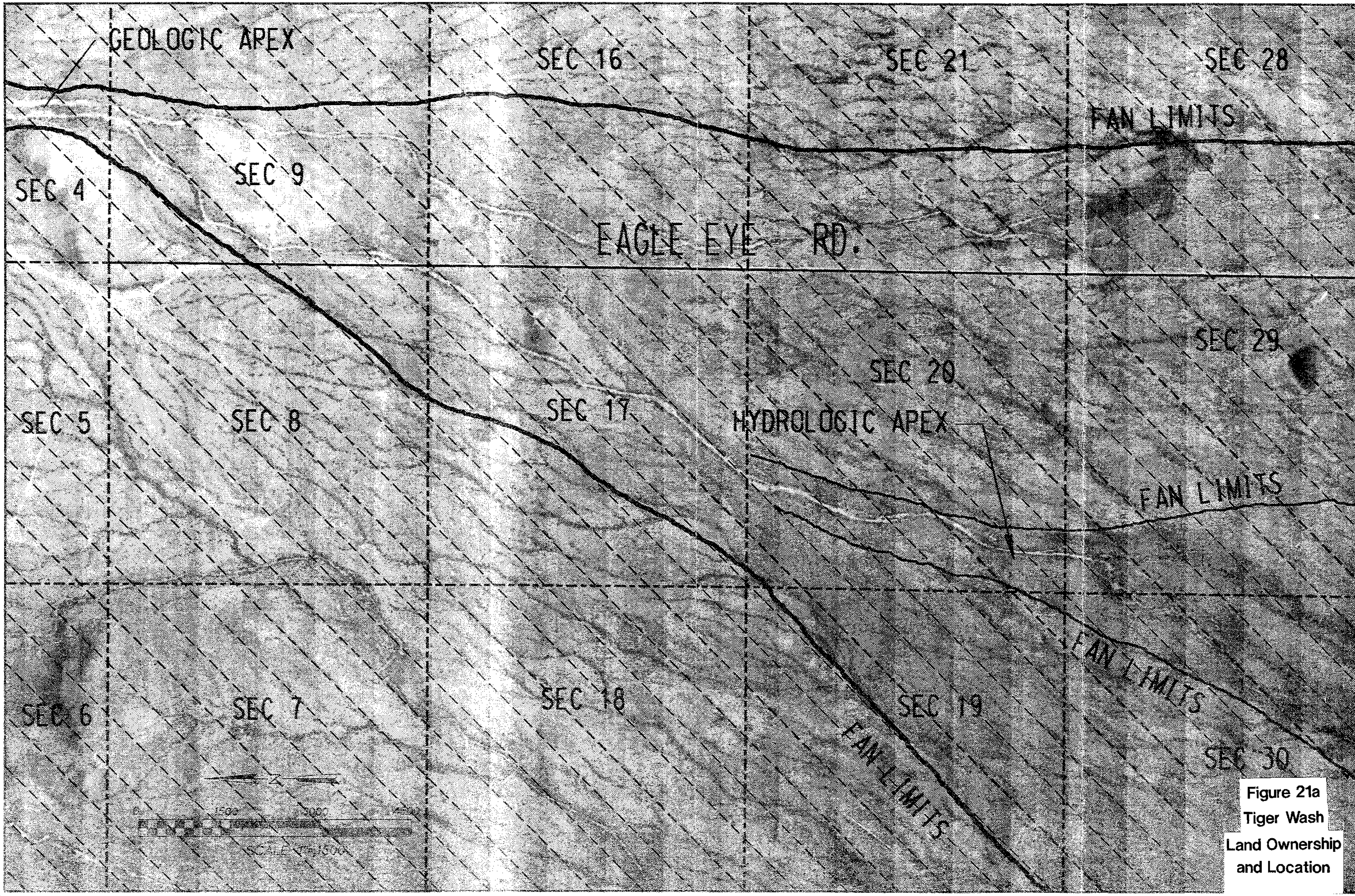

Figure 21a
Tiger Wash
Land Ownership
and Location

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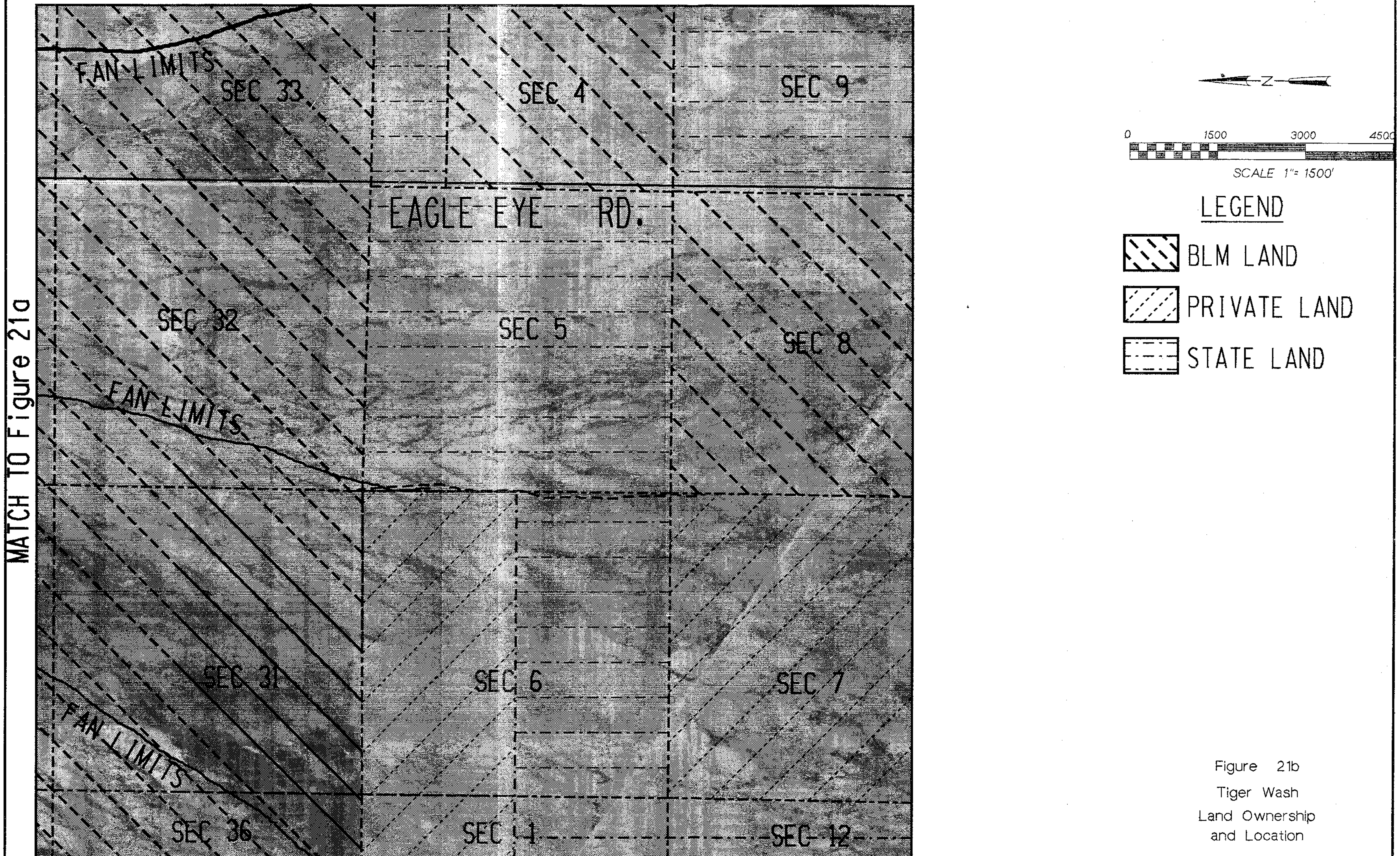
CH2M HILL



LEGEND

BLM LAND

PRIVATE LAND

STATE LAND

Figure 21b
Tiger Wash
Land Ownership
and Location

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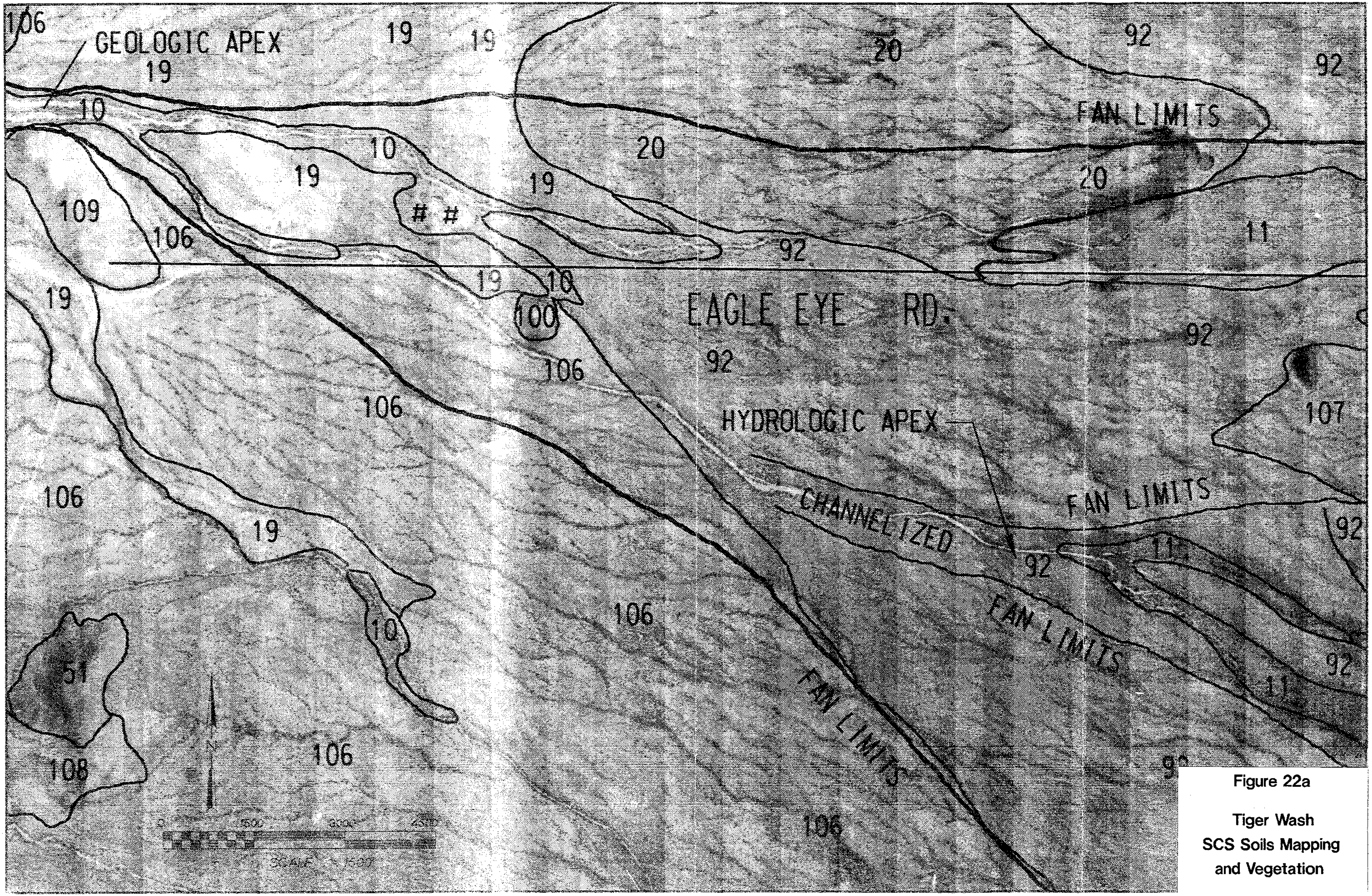

Figure 22a

Tiger Wash
SCS Soils Mapping
and Vegetation

CH2M HILL

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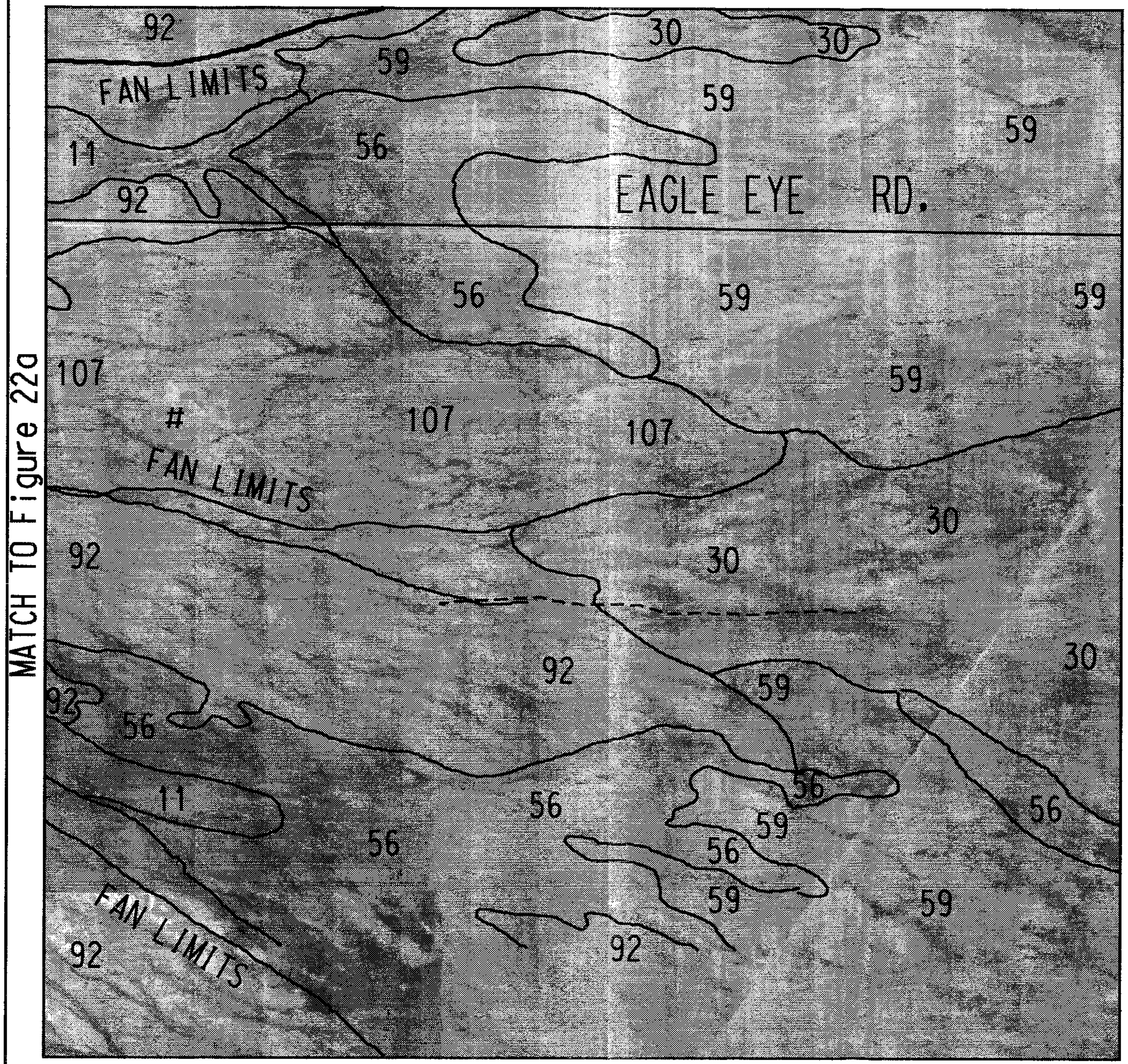

Z

0 1500 3000 4500

SCALE 1"= 1500'

LEGEND

VEGETATION

☐ Cresote Bush Limits

SOILS

10 - Brios-Carrizo complex
11 - Brios-Carrizo complex
19 - Chuckawalla- Gunsight complex
20 - Chuckawalla- Gunsight complex
30 - Denure-Momoli-Carrizo complex
51 - Gachado-Lomitas complex
56 - Gilman loams
59 - Gilman-Momoli-Denure complex
92 - Momoli-Carrizo complex
100 - Quilotosa-Vaiva-Rock outcrop complex
106 - Sal-Cipriano complex
107 - Sal-Cipriano complex
108 - Schenco-Rock outcrop complex
109 - Schenco-Rock outcrop complex

Figure 22b
Tiger Wash
SCS Soils Mapping
and Vegetation

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CH2M HILL

loams. This unit corresponds to the most frequently (but rarely) flooded soils within the unit. The Momoli-Carrizo-Denure Association is described as a nearly level, nongravelly to very gravelly sandy loam found on fan terraces. It includes the Chuckawalla-Gunsight extremely gravelly loam, the Sal-Cipriano very gravelly sandy loam, and the Momoli-Carrizo very gravelly sandy loam. It is generally 80 to 95 percent covered by varnished desert pavement, is moderately to strongly calcareous, particularly at depth, and may have a hardpan at a depth of 20 inches.

Geology. Tiger Wash drains the northern part of the Harquahala Plain between the Harquahala Mountains and the Big Horn Mountains. The Harquahala Mountains are a northeast-trending metamorphic core complex (Figure 23). Precambrian granitic gneiss and granites form the basement of the core complex. To the west, Paleozoic quartzites, and marine sedimentary rocks overlie the Precambrian units and grade stratigraphically upward to Permian-aged fossiliferous limestones. A single outcrop of Paleozoic sedimentary rock is found within the watershed near Eagle Eye Road and the distributary apex adjacent to the upper gravel pit. Isolated cretaceous arkosic conglomerate outliers also occur in the western Harquahalas.

Cretaceous volcanics—agglomerates, tuffs, and lava flows—dipping 10 degrees west are found above the Precambrian basement in the Big Horn Mountains. Tuff deposits are strongly bedded suggesting waterlain deposition. Lava flows are predominately acidic with colored obsidian occurring in the upper layers. A prominent volcanic unit which crops out at the western margin of the Big Horns forms the eastern watershed divide and provides bedrock control for the paleoflood reach.

Inselbergs composed of vesicular olivine basalt found in the alluvial plain provide some control of flow paths of Tiger Wash below and above the fan apex and suggest a shallow depth of alluvium below Tiger Wash. Mountain front retreat by long-term erosion has resulted in formation of a large pediment surface (Metzger, 1957) upslope of the site.

Volcanic bedrock provides a source of fine-grained sediment. The presence of silts and clays is in direct contrast to the other data collection sites which are dominated by rock types which weather to sands. Denudation of the pediment mantle is also a likely source of finer-grained sediment.

Depth to bedrock data were collected by field observation. Bedrock crops out in the channel at the paleoflood survey site, near inselbergs, and in the west channel between the distributary and hydrologic apexes (Figure 23). Bedrock outcrops were not observed in the channels or fan area below the hydrologic apex. No well log or published data regarding depth to bedrock were available.

Hydrology. Tiger Wash drains 85.2 square miles at the USGS gauge site and 96.4 square miles at the lower fan apex. Tiger Wash has the largest drainage area of the

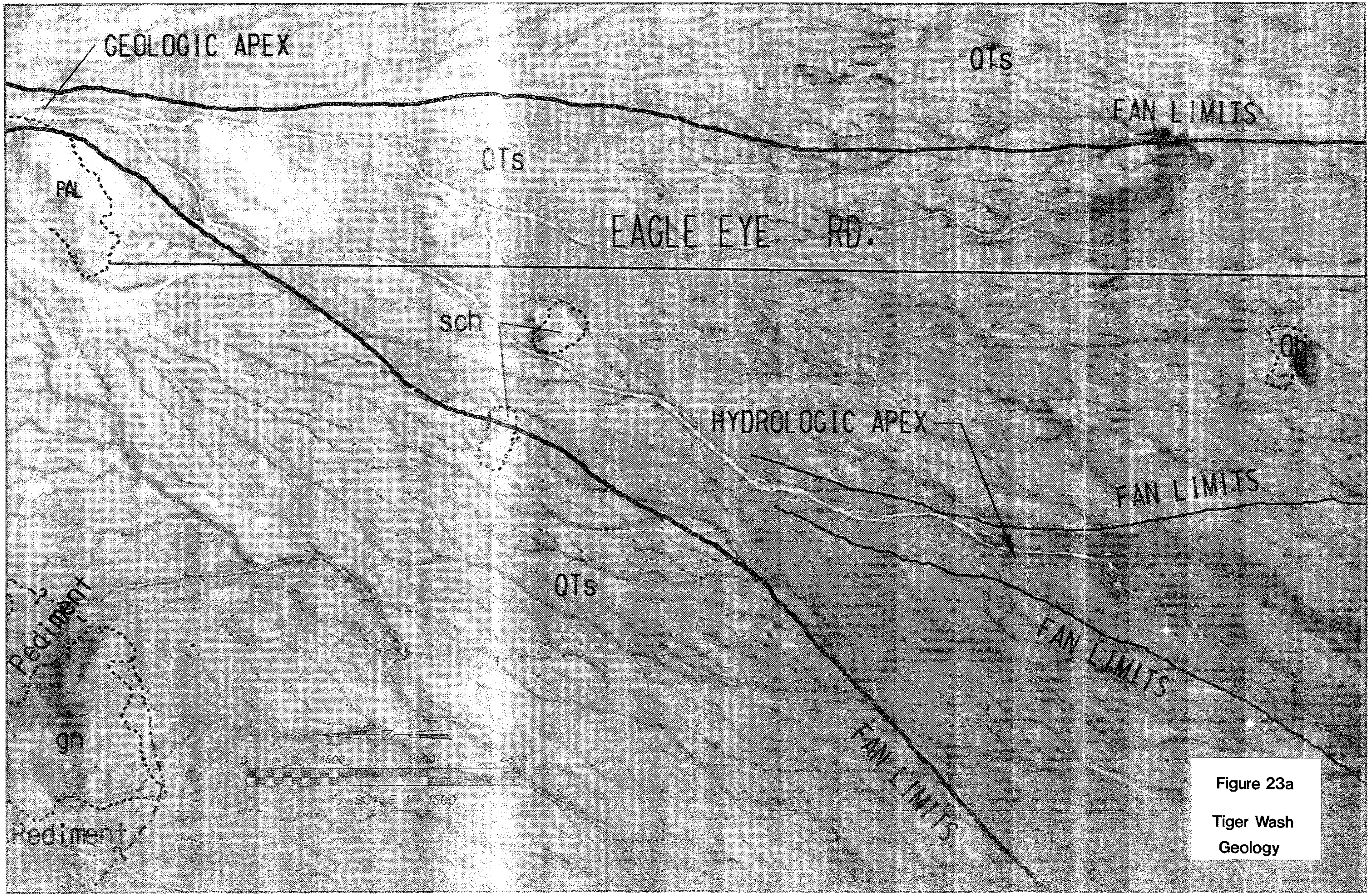

Figure 23a

Tiger Wash Geology

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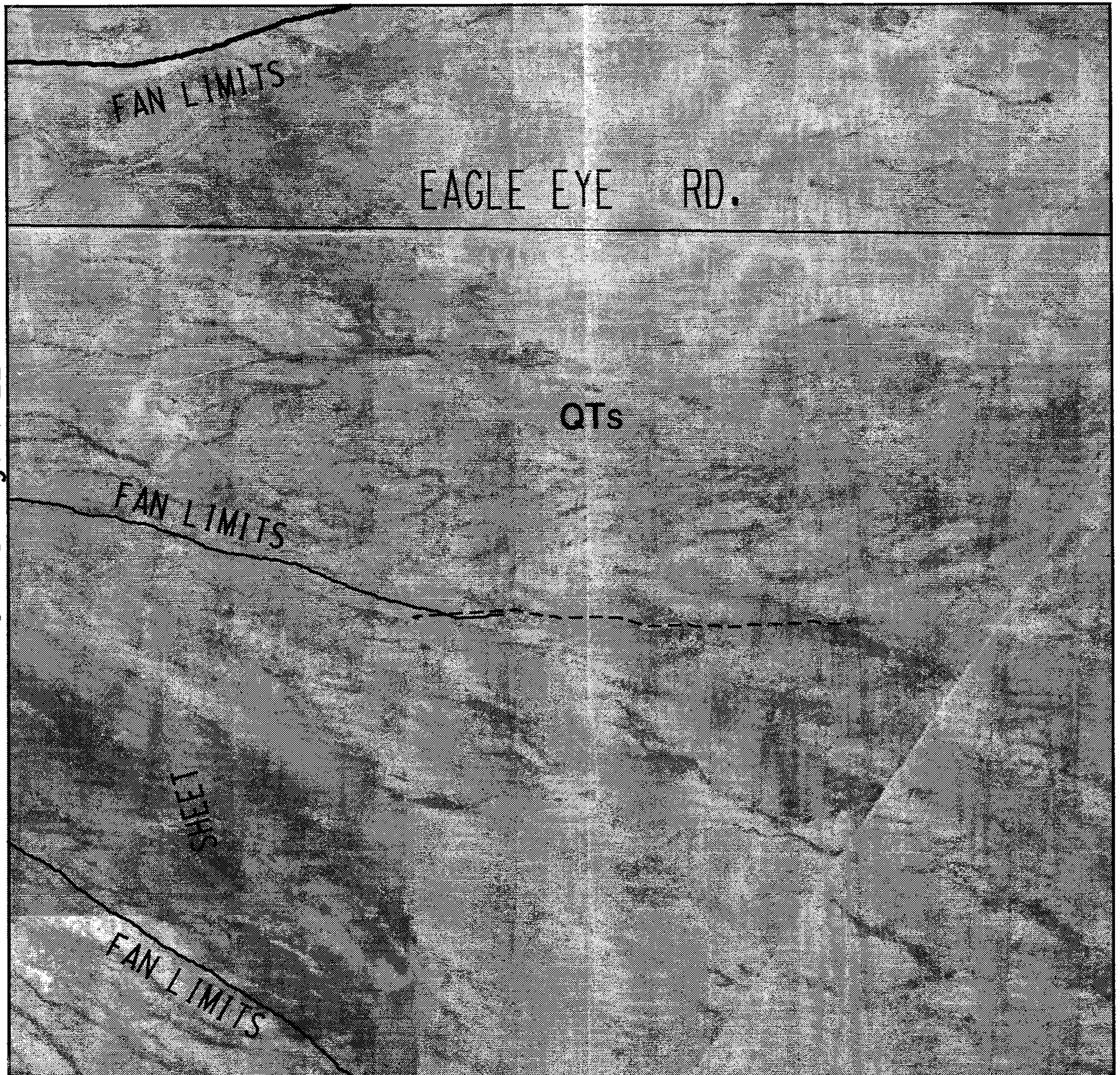
CH2M HILL



MATCH TO Figure 22a

Z

0 1500 3000 4500

SCALE 1"= 1500'

LEGEND

GEOLOGY

gn - Granite Gneiss
PAL - Pediment
Qb - Basalt
QTs - Surficial deposits
sch - Schist

Figure 23b
Tiger Wash
Geology

CH2M HILL

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four sites studied, and therefore is more likely to respond to winter general storms. However gauge records and other data indicate that most floods occur in response to summer monsoonal-type rainfall.

Only one recording precipitation gauge is currently located within the drainage basin. However, the large size of the watershed makes it more likely that precipitation data from adjacent watersheds can be extrapolated to the Tiger Wash basin. Rainfall records applicable to the site are summarized in Table 5. Storm events with a one-day total depth of greater than one inch are summarized in Table 7.

Flood data are available from several sources. The USGS maintained a crest stage gauge on Tiger Wash upstream of the fan apex from 1961 to 1979 (Table 6), and recently re-activated the gauge. The largest recorded flood occurred August 20, 1970 and was gauged at 4,550 cfs. No rainfall records for this storm are currently available.

Anecdotal accounts of flooding from the Tiger Wash site were obtained from Maricopa County road maintenance supervisors (Brundage, 1991). Summer floods occur frequently. Most flooding occurs in August and from late October to November. Along Eagle Eye Road, above the Tiger Wash active alluvial fan apex, but below the primary difluence mapped by Hjalmarson (in press), flooding is erosional, washing out the road dip crossing. This portion of Eagle Eye Road was not paved until May 1991, and was more susceptible to damage. The Buckeye-Salome Highway crosses the Tiger Wash active alluvial fan below its apex. At the Buckeye-Salome Highway flooding occurs "everywhere" (sheet flow). Flow depths commonly exceed 3 feet deep and 60 feet wide in the larger swales, with very few areas completely free of water. The Buckeye-Salome Highway is paved and protected by rip-rap to prevent erosion. Deposition of sediment has not been a problem. Flooding is commonly erosional; the highway was washed out in the 1982 flood. Unfortunately, the 1982 flood occurred in the gap between USGS stream gauging and FCDMC precipitation gauging.

Flood debris observed in the field indicates that a very large flood occurred on Tiger Wash in the recent past, perhaps within the last several years. Vegetative debris with some sand and silt still entrapped within it can be found throughout the site area from the paleoflood survey site to the point where channelized flow ceases, well below the fan apex. Vegetative flood debris tends to be washed clean of silt and sand by rain within 10 years of emplacement. Trash and beer cans found within the debris indicate that the flood occurred after 1979. Flood evidence suggests that channelized flow occurs over much of the fan, but that overbank and sheet flooding represent more significant components for larger events.

Flood recurrence interval information based on HEC-1 modeling provided by the FCDMC is summarized in Table 11. Flow peak rates at the fan apex vary from 1019 cfs for the 6-hour, 2-year storm, to 13,323 cfs for the 24-hour, 100-year storm. Peak flow rates at the USGS gauge site upstream of the hydrologic apex vary from 1,579 cfs for the 2-year, 6-hour flood, to 22,120 cfs for the 100-year, 24-hour flood. A draft report provided by the FCDMC discusses more completely the derivation of the peak flow rates. Peak flow rates for the USGS gauge site computed using Bulletin 17B procedures (IACWD, 1981) and the USGS gauged flows are also provided in Table 11. The expected discharge value is the mean of the computed 95 percent confidence limits.

Manning's rating of channel sections using hydrologic data provided by the FCDMC indicate that the channel does not have sufficient hydraulic capacity to convey the 100-year discharge both above and below the apex. The cumulative capacity of all channels below the hydrologic apex progressively decreases downfan. The area of the active alluvial fan just upstream of the Buckeye-Salome Highway has cumulative channel capacity for less than the 2-year flood. Approximate floodplain boundaries are mapped in Figure 24.[8] Manning's velocity rating varied from 9 fps the 100-year discharge in the channel above the distributary flow apex to 1 to 4 fps at channel capacity in minor channels on the active alluvial fan.

Table 11
Peak Discharge Estimates (cfs), Tiger Wash Site

Recurrence Interval (Years)	Bulletin 17B		24-Hour Rainfall		6-Hour Rainfall	
	Computed	Expected	Lower Fan Apex	Gauge Site	Lower Fan Apex	Gauge Site
2	798	798	1,447	2,350	1,019	1,579
10	3,870	4,290	5,756	9,517	4,052	6,564
100	11,400	15,500	13,323	22,120	10,549	17,286

[1]*Discharge values shown are taken directly from HEC-1 model output and do not reflect actual significant figures.*

Paleoflood Survey. A paleoflood survey was made of a canyon reach located 2.6 miles upstream of the distributary apex, and approximately 4 miles upstream of the hydrologic apex for the active alluvial fan. At the paleoflood reach, the channel is a mildly sloping (0.0085 ft/ft) sand, gravel, and boulder-bedded stream. The east bank of the reach is formed by the irregular bedrock cliffs of the Big Horn volcanic rocks. Coves in these irregular bedrock cliffs harbor classic slackwater sites. The west bank is composed of resistant, bouldery Pleistocene or early Holocene soils. Two prominent terraces are found above the west banks, a floodplain terrace, and Pleistocene-aged terrace. The floodplain terrace is capped by silty sand and supports a dense mesquite bosque. The Pleistocene terrace has somewhat varnished intermittent desert pavement, and supports saguaro and other non-riparian species. The bedrock on the east bank provides the only significant control on scour and erosion, although no signs of erosion

[8]Floodplain boundaries not for regulatory or design purposes.

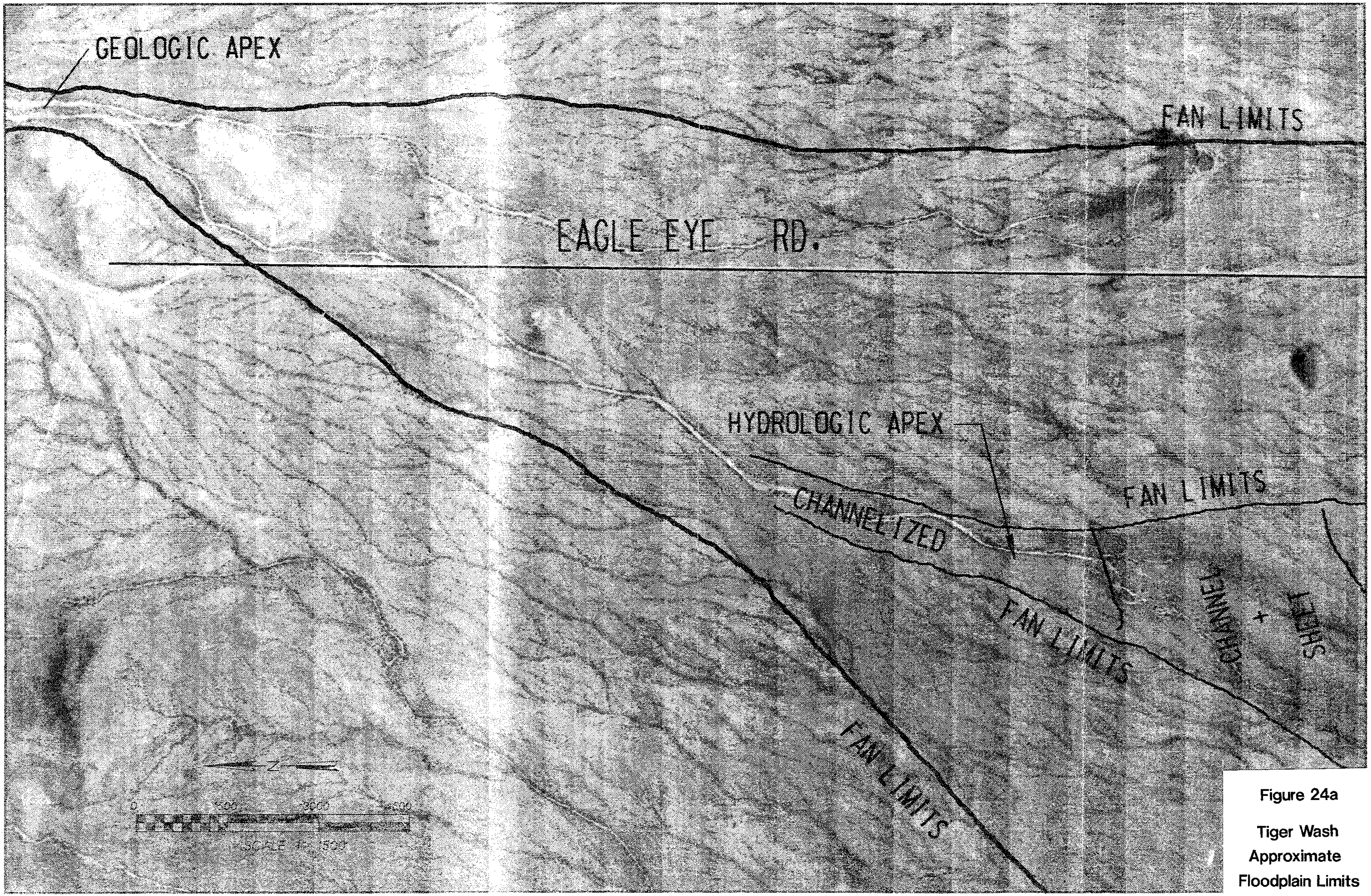
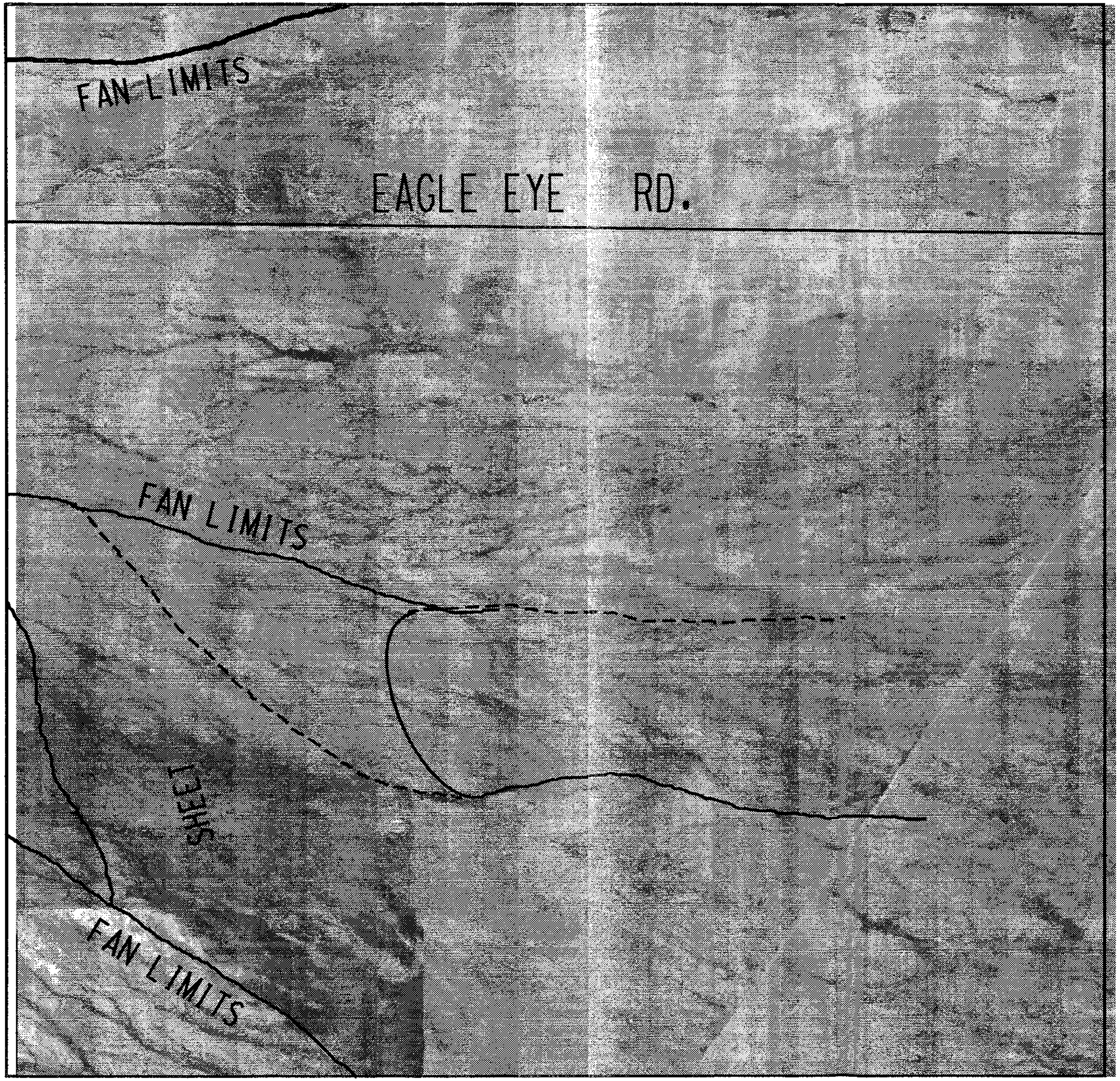


Figure 24a

Tiger Wash
Approximate
Floodplain Limits



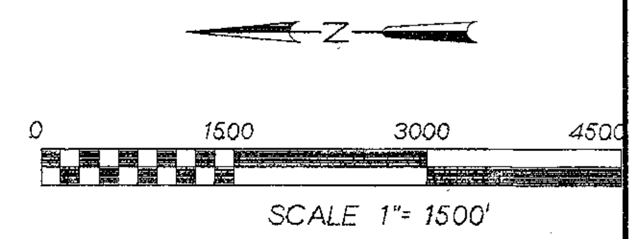


Figure 24b
Tiger Wash
Approximate
Floodplain Limits

CH2M HILL

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of the Pleistocene or floodplain terrace were found. The bouldery composition of the bed may limit bed scour by armoring. A USGS stream gauge is located at the downstream end of the reach.

Several types of highwater marks were found in the paleoflood reach. Classic slackwater deposits are found in bedrock coves on the east bank. A second, inset slackwater sequence was also found. Vegetative flood debris found along the channel banks and lodged in trees marks the elevation of a recent flood. The inset slackwater deposit correlates with the vegetative debris elevation. The two prominent terraces may also be used to estimate flood stage. The floodplain terrace has been flooded frequently enough to accumulate a thick silt cap. The Pleistocene terrace is rarely flooded, allowing varnished desert pavement to develop. A third inset terrace also appears to record a specific flood elevation.

At least five flood deposits are preserved in the slackwater deposit which was trenched and described. The upper two slackwater flood units are capped by a massive silty lens and a discontinuous fine gravel layer. The massive silt is probably the result of deposition associated with ponding on the surface as flood waters receded. The gravel lens was deposited by weathering and erosion of the volcanic cliffs above. The gravels are not flood-related. The lower three slackwater flood deposits exposed in the trench are capped by thick talus layer and a single buried organic soil horizon. An organic horizon is formed by long exposure to the atmosphere and accumulation of plant litter from leaf drop. These horizons take at least 100 years to develop.

Water surface profiles were computed using the computer model HEC-2 (HEC, 1982) and were compared to highwater marks found in the reach (Figure 25). A subcritical water surface profile appears to accurately describe the channel flow conditions, and compares well to the highwater marks observed in the channel.

Based on the high water marks found in the reach, the largest flood preserved in the reach peaked between 10,000 and 13,500 cfs. The minimum flow rate required to inundate the floodplain terrace is 10,000 cfs. A flood of 13,500 cfs would be required to reach the Pleistocene terrace. The five floods preserved in the slackwater deposit sequence mark peak flow rates of approximately 8,000, 7,000, 6,000, 5,000, and 4,000 cfs. The inset terrace corresponds to a peak flow rate of 6,000 cfs. If a flood is responsible for emplacing the inset terrace, it could not be the same flood which deposited the slackwater layer corresponding to the same flow rate. That is, there are two floods preserved which peaked at about 6,000 cfs. The most recent flood which deposited vegetative debris and the inset slackwater deposit probably peaked at 2,000 cfs. Evidence of this flood is preserved throughout the active alluvial fan. Significantly, a flow rate of 2,000 cfs at the paleoflood site completely dissipated, or became sheet flow before reaching the Salome Highway.

No absolute age determinations were made for any of the paleostage indicators collected in the reach. However, organic material datable by Carbon-14 processes was collected from the buried organic horizon in the slackwater deposit. Relative age

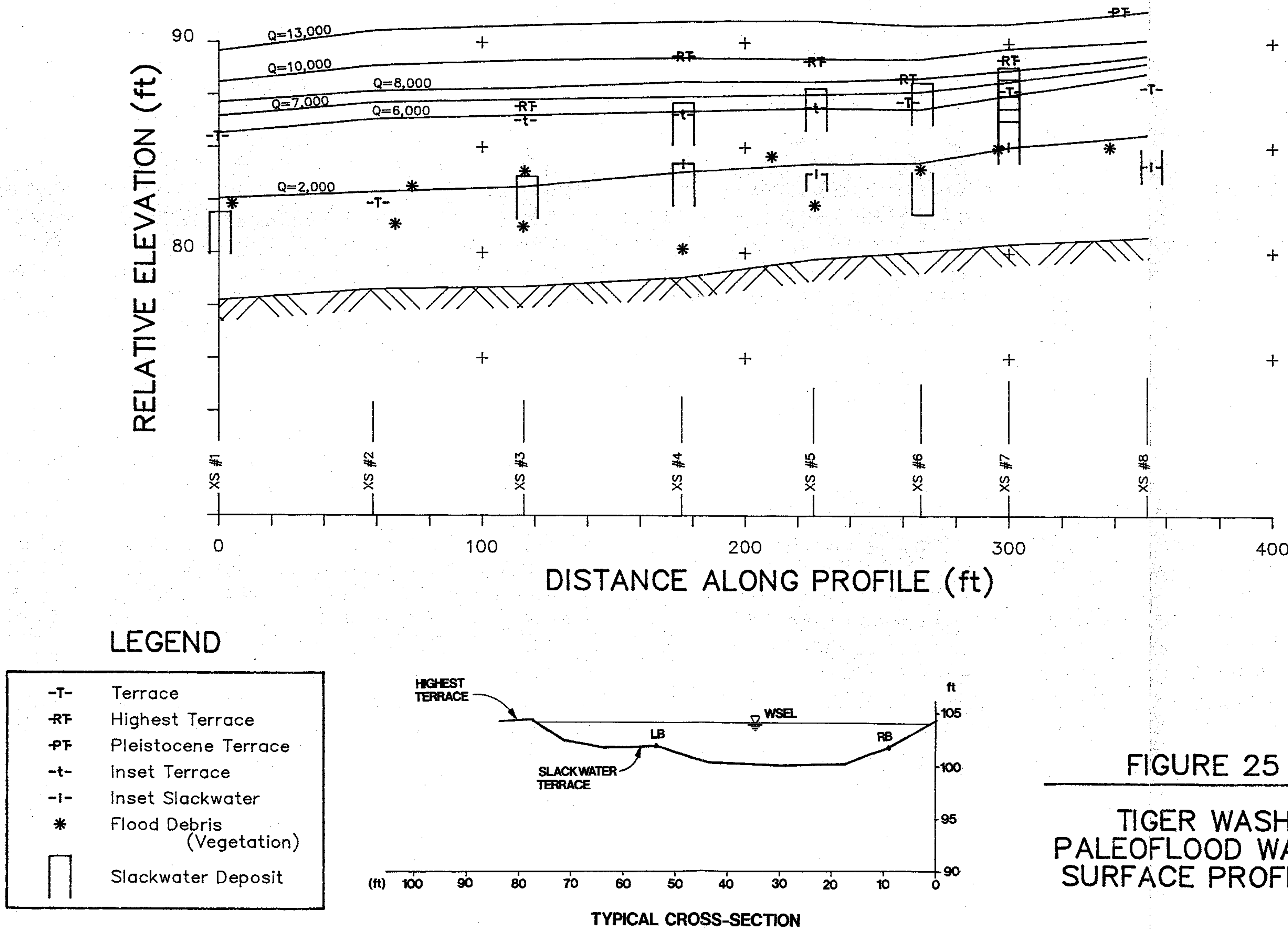


FIGURE 25

TIGER WASH
PALEOFLOOD WATER
SURFACE PROFILES

CH2M HILL

estimates were made. The most recent flood which deposited the vegetative debris probably occurred within the past 10 years, as discussed elsewhere. The upper flood deposits in the slackwater sequence bury mesquite trees which appear to be less than 100 years old. The flood deposits below the buried organic horizon must be older than 100 years because of the mesquite trees rooted in them and because of the time required to develop an organic layer. The Pleistocene terrace provides a maximum age limit of about 10,000 years. No evidence of flooding on this surface was found.

Within the past 100 years, at least three floods between 6,000 and 10,000 cfs, and a single flood at 3,000 cfs have occurred. In the period from 100 to 10,000 years ago, an unknown number of floods have exceeded 10,000 cfs. (the floodplain terrace), and floods at 4,000 5,000, and 6,000 cfs have occurred. Better resolution of these age estimates may be possible using absolute dating techniques.

Paleoflood discharge estimates do not compare very well with the peak flow estimates made by the FCDMC using HEC-1, but compare reasonably well with estimates made using statistical treatment of the USGS gauge record. The USGS record indicates a 100-year flow rate of 11,400 cfs. This flow rate would reach the floodplain terrace, but would not inundate the Pleistocene terrace. The HEC-1 estimates made by the FCDMC are currently being revised. Further comparison of paleoflood estimates and HEC-1 estimates should be made when HEC-1 estimates are revised. Inclusion of data collected from channel transmission loss gauges, not accounted for in the FCDMC HEC-1 model, may lead to a more accurate runoff estimate.

Geomorphology. The Tiger Wash active alluvial fan and distributary flow system is located on a fifth order stream which drains the west extension of the Big Horn Mountains and the southeast slopes of the Harquahala Mountains. The mountain front limits of both ranges are obscured due to pediment formation associated with extensive mountain front retreat. The distal limit of the pediment is not clear, but may be indicated by the position of inselbergs in the alluvial plain.

The drainage pattern may also reflect the pediment-alluvial fan boundary. The mountain slopes and eroding inactive alluvial fans of the upper watershed have a dendritic drainage pattern. Where the stream abuts the volcanic buttes at the western limit of the Big Horns, the channel becomes braided. The channel pattern becomes distributary as it passes between the sedimentary rock inselbergs and splits into two distinct flow paths. Most of the low flow follows the western braid. Flow in the eastern braid is captured by a gravel pit and a stock pond several miles downstream. Flow in the western braid continues downstream in a single channel for several miles to a hydrologic apex at the head of the active alluvial fan. The geologic apex is probably located between the distributary and alluvial fan apexes. A sub-dendritic pattern begins again downstream of the Buckeye-Salome Highway after several miles of undefined sheet flow, and continues to the Tiger Wash Detention Basin immediately upstream of Interstate 10.

Channel slope generally decreases in the downstream direction giving the piedmont a concave profile (Figure 26). Slope decreases slightly upstream of major bifurcations, and increases slightly just downstream of the splits. Channel sinuosity also decreases in the downstream direction from S=1.05 or greater upstream of the USGS gauge to S=1.04 below the distributary apex, to S=1.02 below the alluvial fan apex. The topographic crenulation index also decreases markedly in the downstream direction as the surface of the fan becomes more uniform, and less dissected (Figure 26).

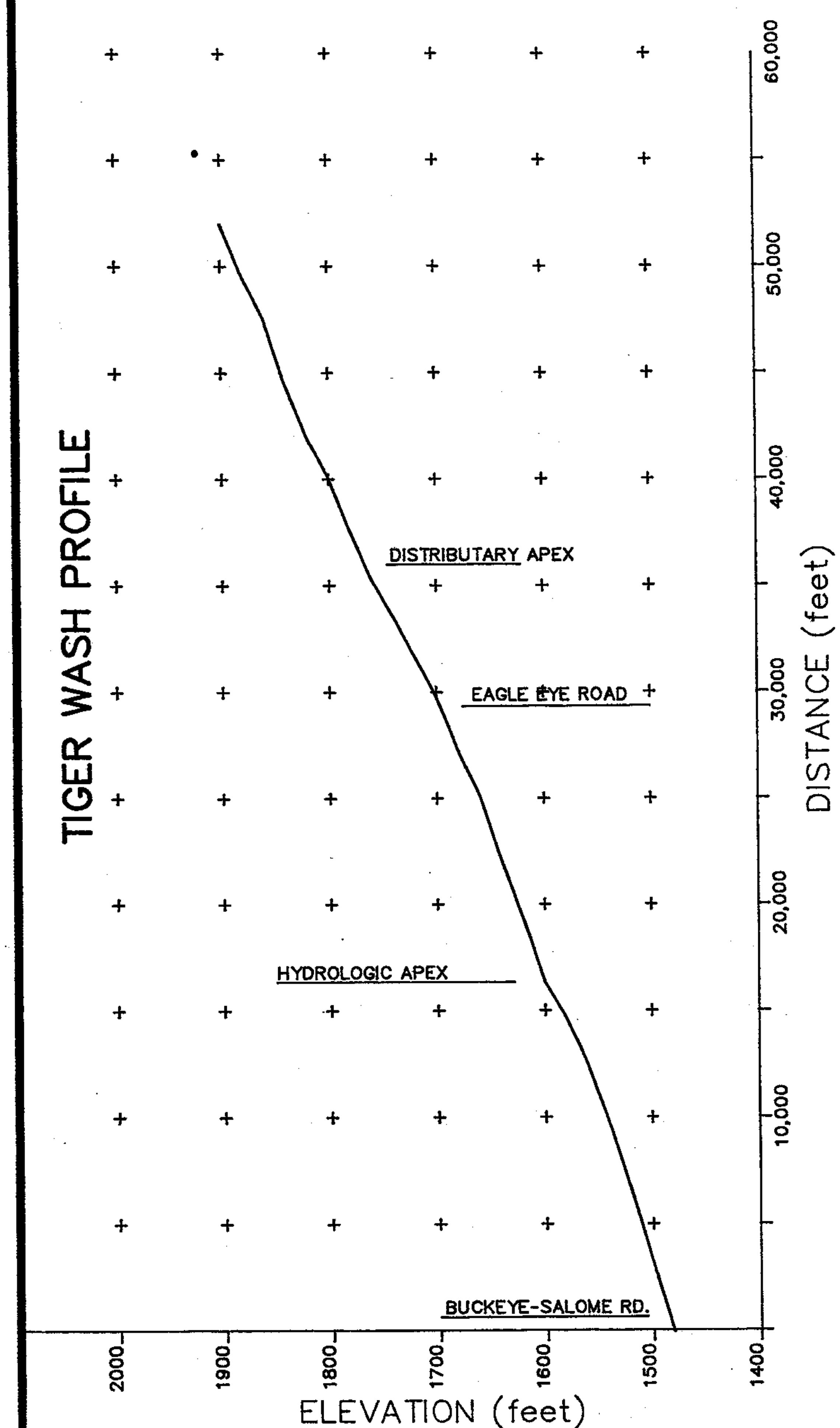
The hydraulic geometry of stream channels on the alluvial fan was analyzed using field measurements. Channel geometry, including width, bank height, and flow depth as indicated by flood debris was measured every 100 feet in each channel or distributary flow path downstream of the hydrologic apex. In addition, data collection transects of the total fan widths were made every 300 to 500 feet between the geologic apex and the toe of the fan. For each transect, channel geometry, soil and vegetation characteristics, flood debris, and other geomorphic parameters were noted.

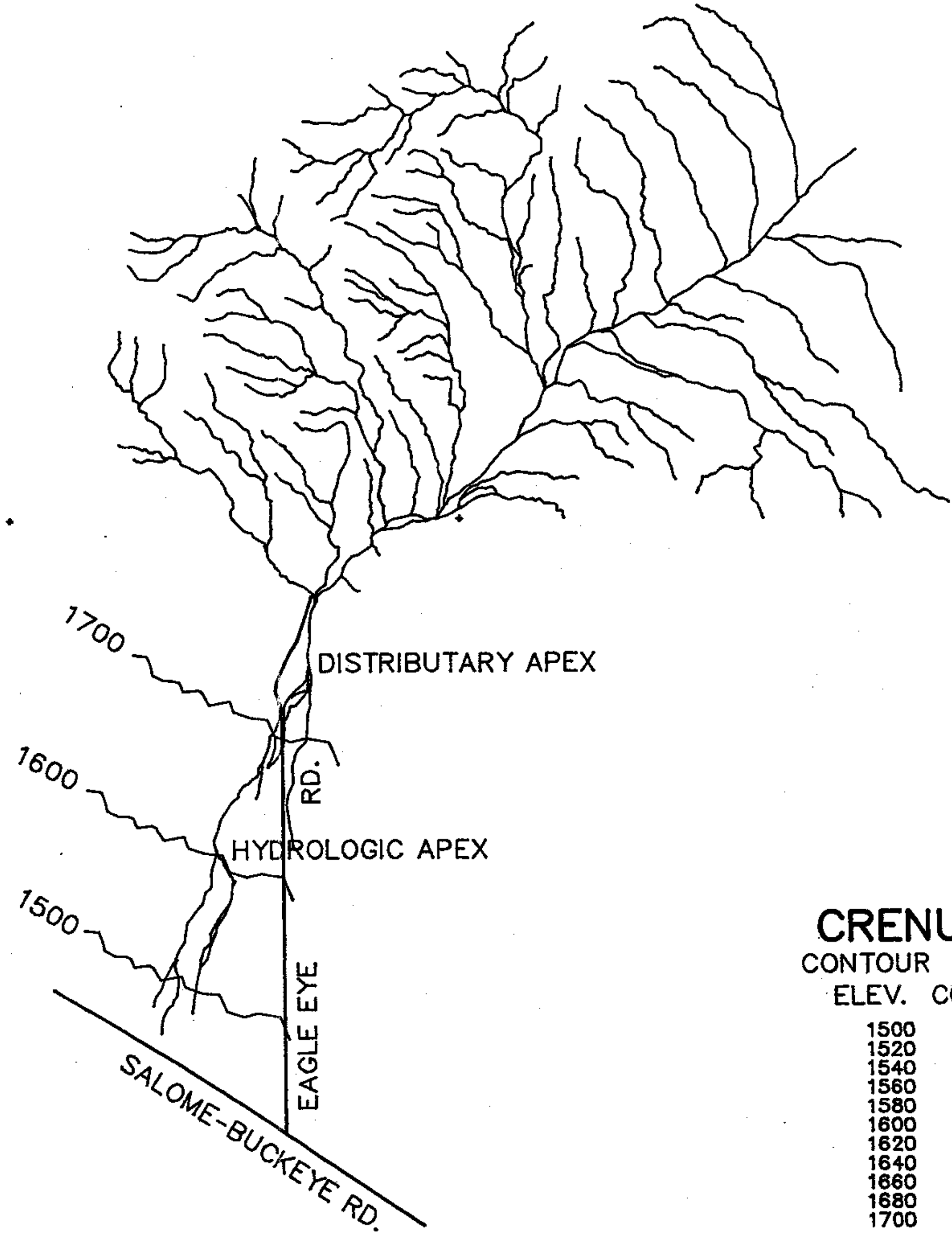
Channel geometry (Figure 27) is not as consistent as other geomorphic parameters in the downstream direction. Channel width, depth, and flow area oscillate rapidly with distance downstream as channels join and split. Some general trends in geometry are present. Channel width, depth, and cumulative flow area decrease downstream, eventually reaching zero flow area as channelized flow ceases and changes to sheet flow. The actual flow width including sheet flooding increases downstream.

Control on channel geometry is not completely lacking though no bedrock is exposed below the volcanic buttes at the USGS gauge. Caliche outcrops in the channel bed and banks form small waterfall-like grade breaks and limit erosion between the distributary and alluvial fan apexes. Isolated carbonate exposures in the beds of recently cut alluvial fan channels limit channels' freedom to adjust.

The channel pattern on the active alluvial fan has shown some marked changes within the period of photographic record (Figure 28). Field evidence for channel movement substantiates photographic records. Recently formed channels have vertical cut banks, cross cut older channels, and are not lined by tree species such as palo verde, ironwood, and mesquite. Cut bank exposures in existing channels also expose the bar and swale stratigraphy of abandoned channels which have since been filled in. Other physical evidence for abandoned channels includes hanging tributaries, channels which were cut off from their source by headcutting and capture, boulder lineations which are sub-parallel from the active channels which trend toward them, and lines of dead vegetation (stumps) and grassed swales.

The channel pattern on the distributary flow system has been stable during the period of photographic record. Changes to the system were caused by human impact. The lower gravel pit captured the distributary braid located east of Eagle Eye Road in early 1979. Evidence for this capture is seen as a large, newly formed delta in the pit visible in the 1979 aerial photographs. Excavation of this pit also eliminated a braid which flowed toward the active alluvial fan.

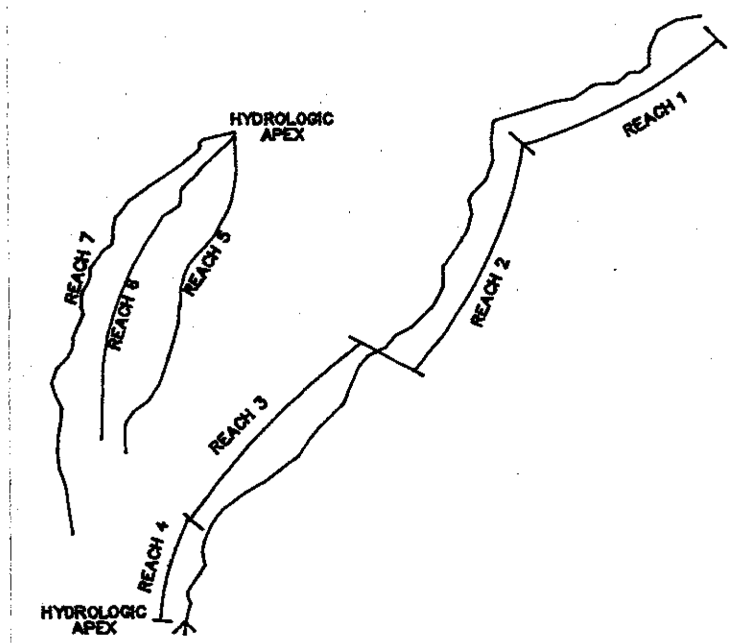




CHANNEL PATTERN

SINUOSITY

REACH #	IN-STREAM LENGTH	BEG-END LENGTH	SINUOSITY
1	4.129	3.88	1.064
2	2.488	2.38	1.045
3	5.970	5.73	1.042
4	3.582	3.45	1.038
5	3.035	2.97	1.022
6	3.333	3.25	1.026
7	3.980	3.89	1.023



CRENULATION INDEX

CONTOUR ELEV.	ALONG CONTOUR	BEGIN TO END	CREN. INDEX
1500	15110	11200	1.349
1520	10830	8800	1.231
1540	9650	7300	1.322
1560	9650	5700	1.693
1580	10630	6500	1.635
1600	12490	7000	1.784
1620	9850	6300	1.563
1640	9700	6900	1.406
1660	20680	6400	3.231
1680	20150	5700	3.535
1700	16900	5800	2.914

FIGURE 26

TIGER WASH
CHANNEL PATTERN
SINUOSITY, PROFILE
& CRENULATION INDEX

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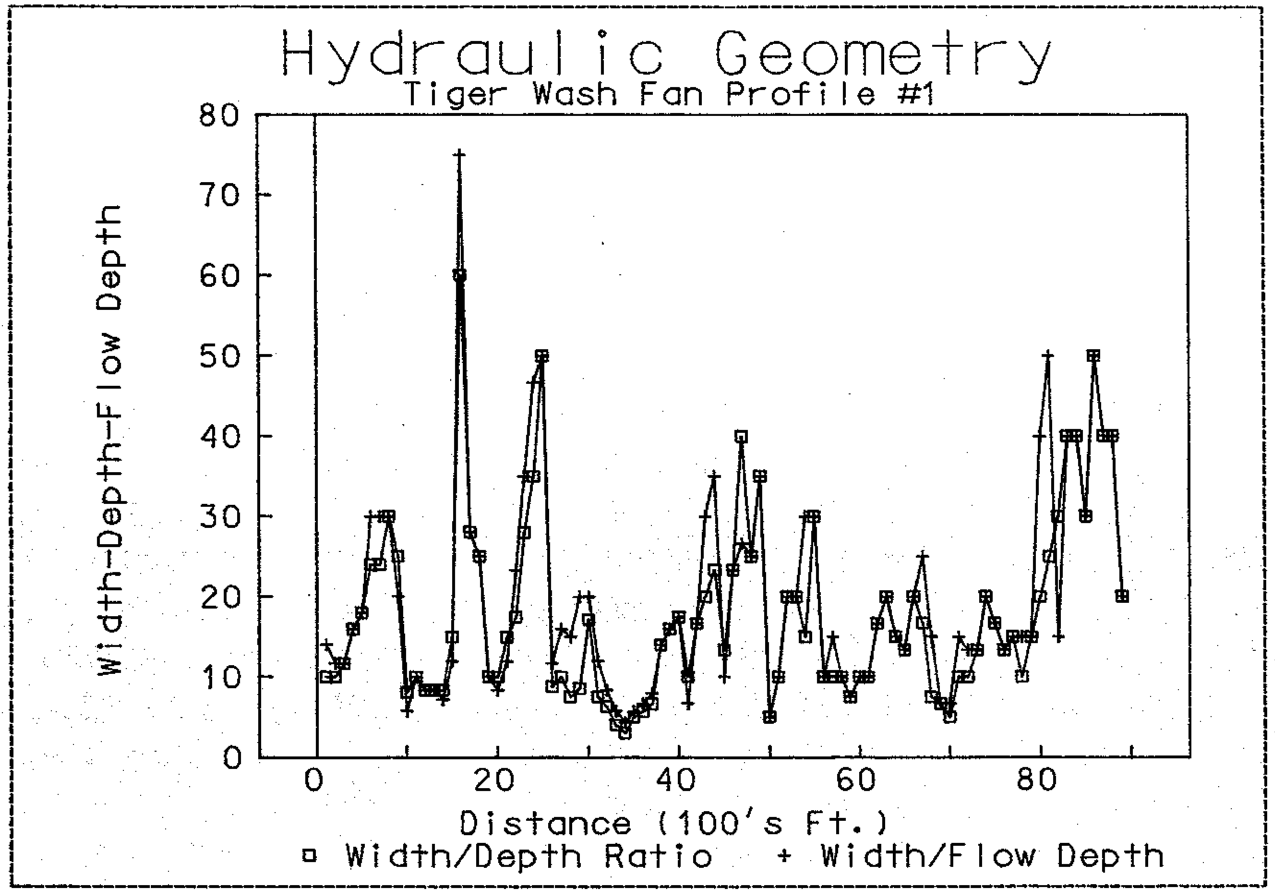
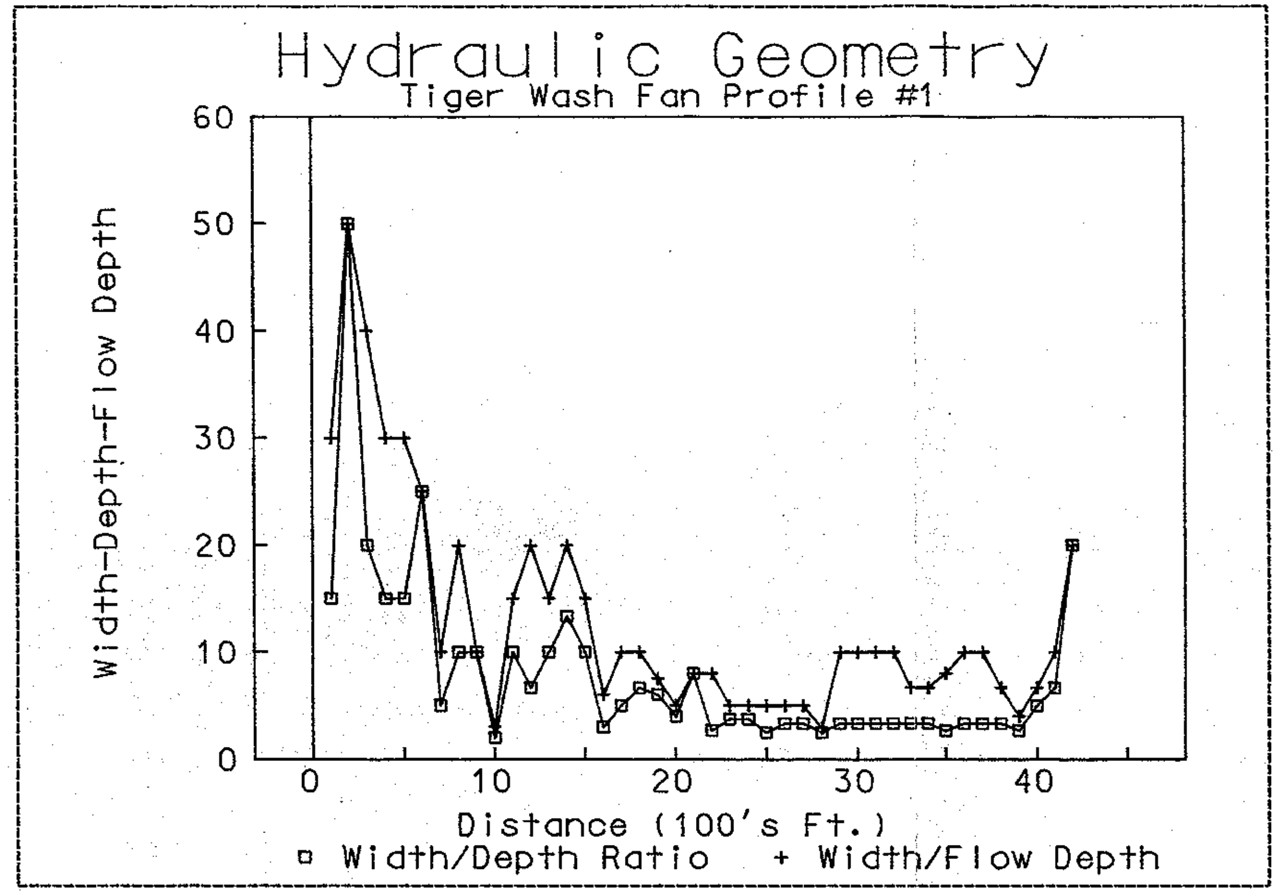
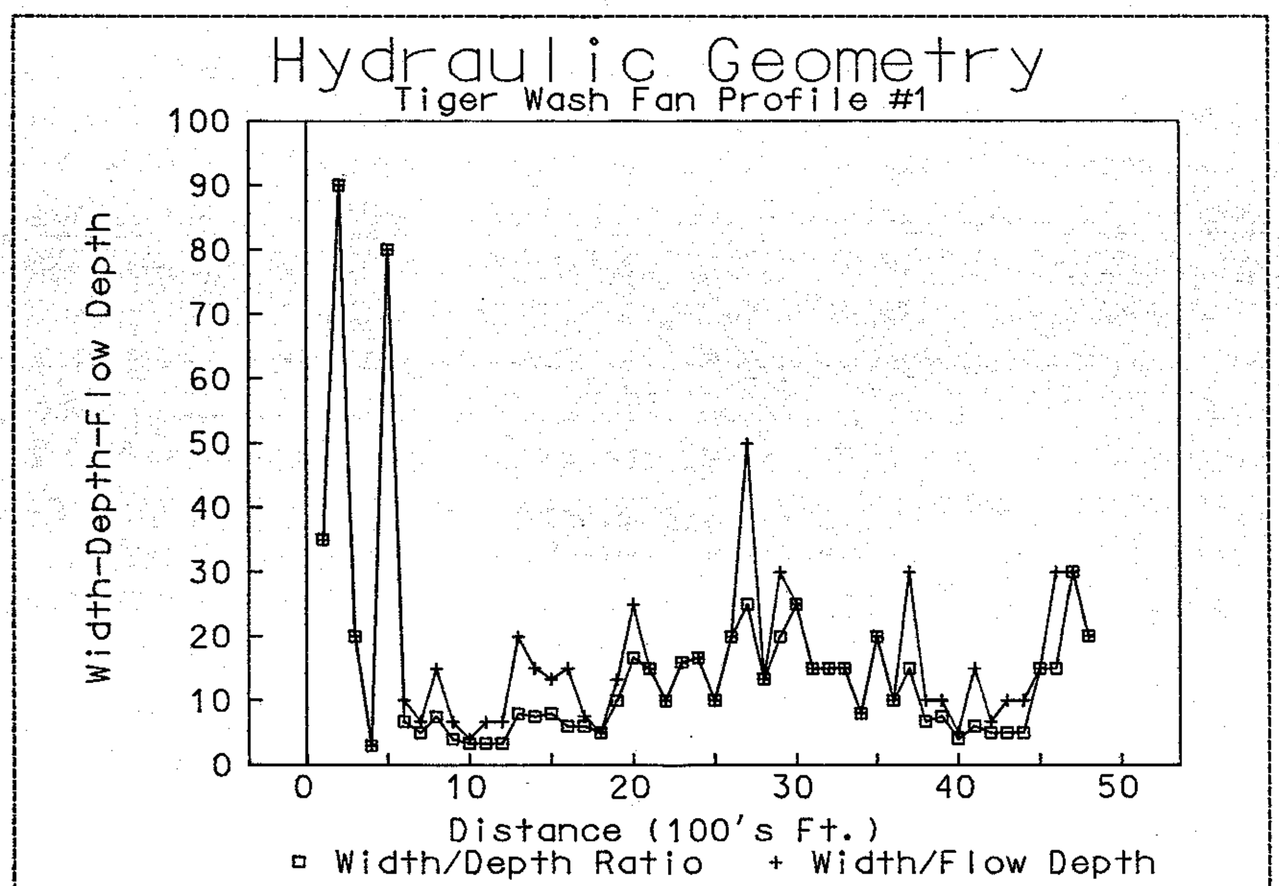
CH2M HILL







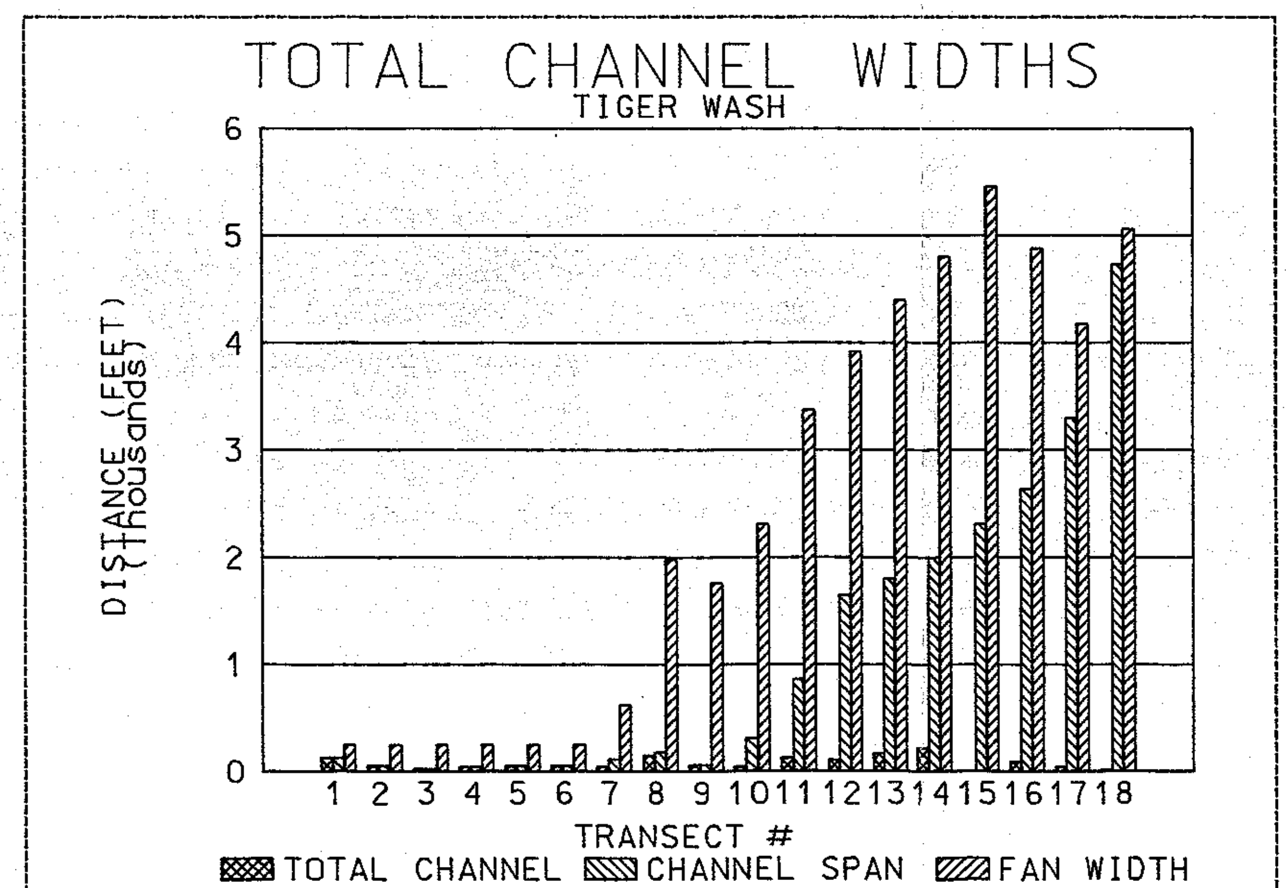


Figure 27

Tiger Wash

Channel Geometry

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CH2M HILL

Channel shifting and migration appears to have exploited or expanded existing channels, in many cases, rather than cut completely new channels. Headward migration and stream capture also appear to be important processes in channel movement. SCS soils mapping of the area shows that the western distributary flow channel bisects a fan terrace (the 2a surface), probably due to a capture of the main stream by an incised channel on the older surface.

The Tiger Wash alluvial fan is composed of a thin aggrading layer of fine-grained alluvium deposited over older coarse-grained deposits. Outcrops of stage IV carbonate surrounding boulders and cobbles in channel bottoms and overbank scour holes indicate that an older surface is buried by recent deposition. Cut bank exposures in alluvial fan channels also reveal a fine-grained layer of recent deposition which thickens in the downstream direction.

Four distinct geomorphic surfaces are mapped for the Tiger Wash site (Figure 29). The 2c and 2b surfaces are of probable late and middle Holocene age, respectively. The 2c surface includes the existing channel beds and interfluves, and the sheet flooding area between the apex and the Buckeye-Salome Highway. This surface is frequently flooded and has little or no soil development. In the upper active alluvial fan the interfluves are blanketed with a 6 to 18 inch layer of recently deposited silty fine sand. Downfan, this layer thickens to several feet. This silty fine sand also covers the 2b surface which serves as the overbank and sheet flow floodplain for the channels in the 2c surface area. The 2b surface is elevated 1 to 3 feet above the channel bottoms near the apex, but merges with the 2c surface in the sheet flow area. The 2b surface is less frequently flooded, though a recent large flood has left evidence of sheet flood depths of 2 to 6 inches. This evidence includes vegetative debris, silty sand deposition, and mudcracked deposits of fine material.

The early Holocene 2a surface is topographically higher than the 2b or 2c surface by 1 to 6 feet. The topographic separation decreases in the downstream direction. In places, 2b deposition overlays the 2a surface. The 2a surface is characterized by fair to well developed desert pavement, and light but occasionally dark desert varnish, surface reddening due to clay illuviation, and stage I or II carbonate development. Recent bank erosion along the western distributary braid above the alluvial fan apex exposes a cross-section of the 2a surface. The channel pattern on the 2a surface is weakly dendritic with slight to moderate incision on the order of several feet.

A Pleistocene surface, 1 or 1b, is exposed at the extreme margins of the site. This surface is characterized by dark desert varnish, and well developed desert pavement, a strongly dendritic drainage pattern, and moderate to deep dissection. In places, dissection of this surface has removed some of the prominent surficial features. This surface is probably transitional to the pediment surface.

The Tiger Wash alluvial fan is actively aggrading. Older geomorphic surfaces are buried by recently deposited silts. Vegetative flood debris was observed on surfaces

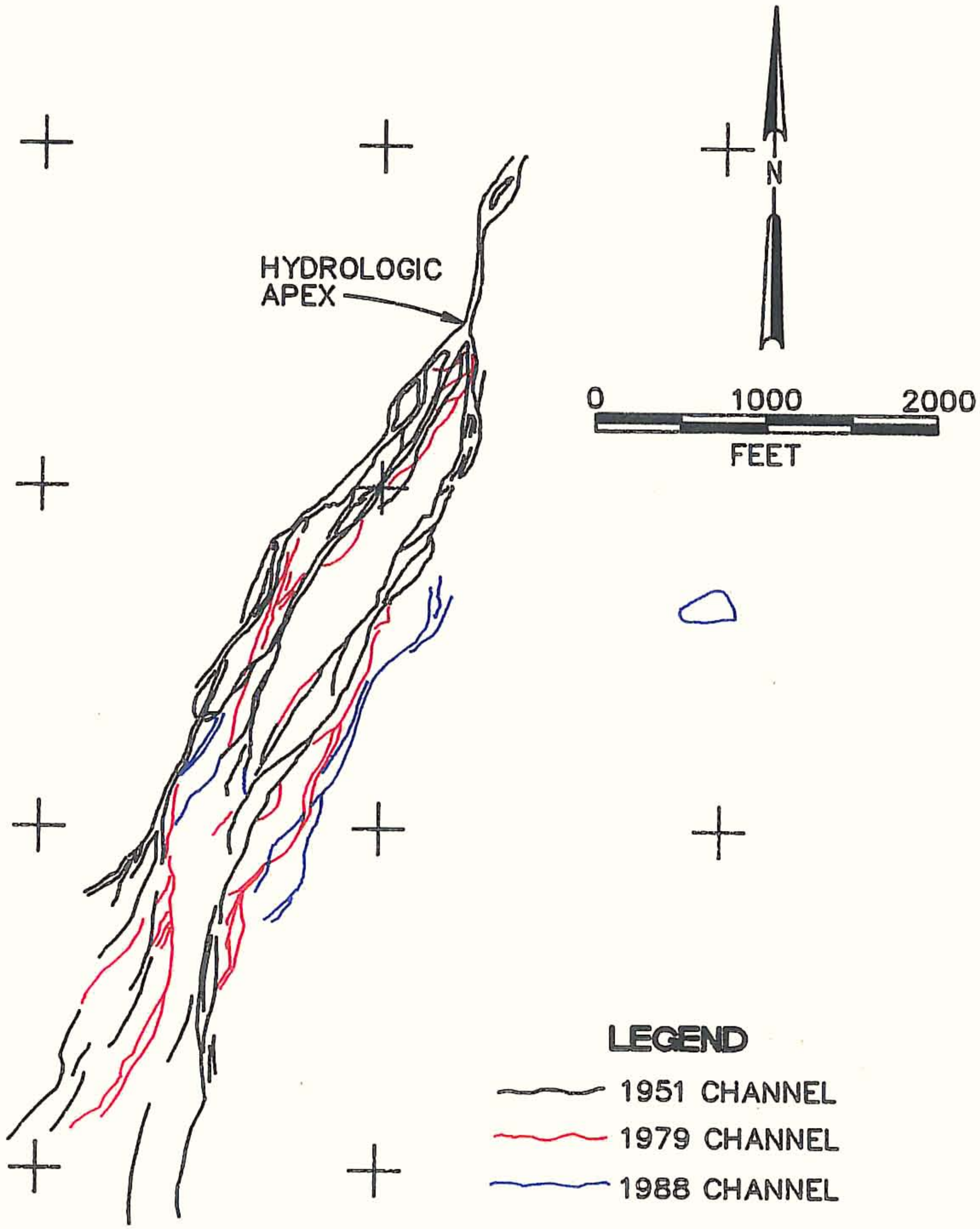

FIGURE 28

TIGER WASH
HISTORIC CHANNEL SHIFTING
1951-1988

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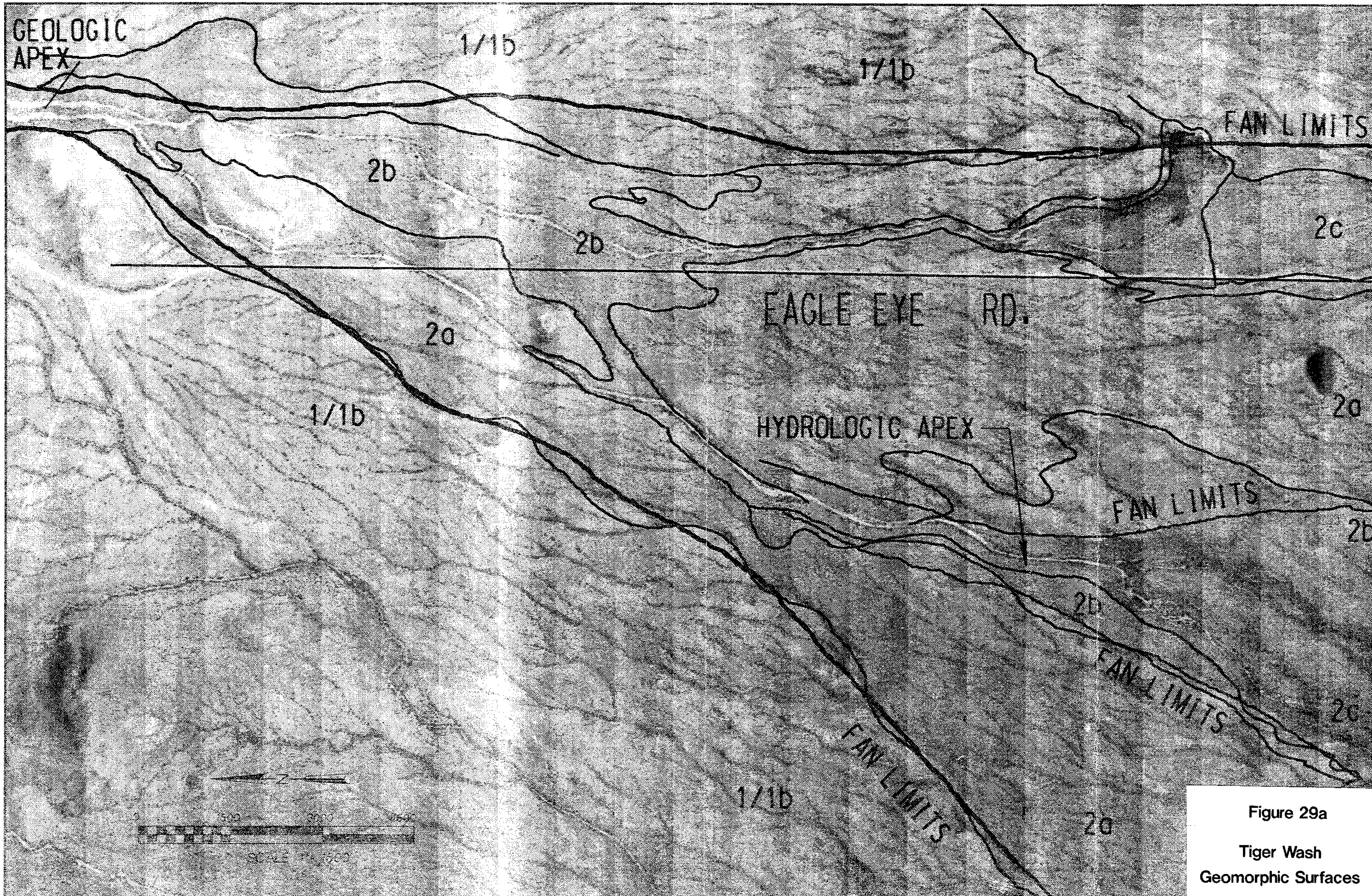
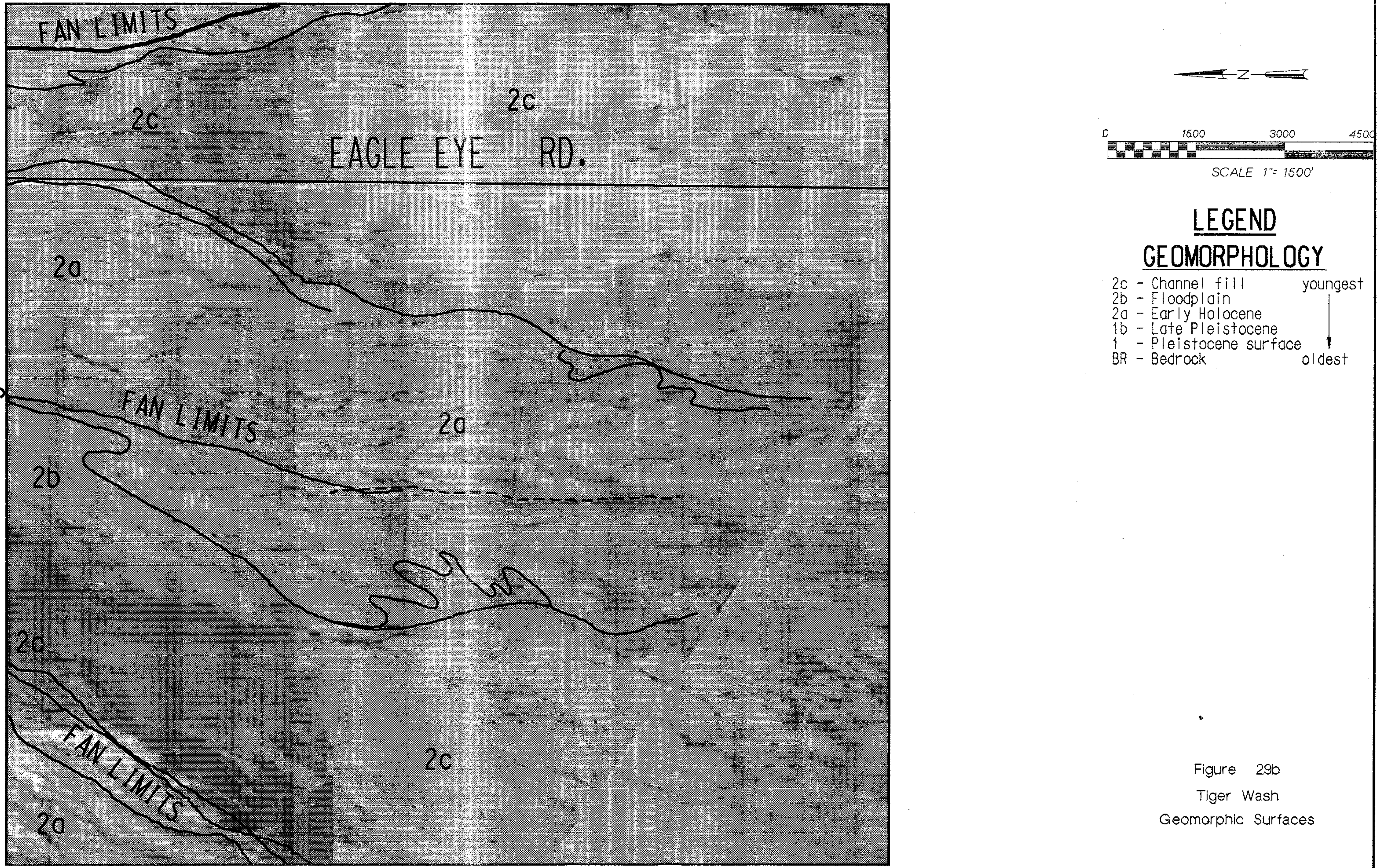


Figure 29a

Tiger Wash Geomorphic Surfaces



LEGEND

GEOMORPHOLOGY

2c - Channel fill youngest
2b - Floodplain
2a - Early Holocene
1b - Late Pleistocene
1 - Pleistocene surface
BR - Bedrock oldest

Figure 29b
Tiger Wash
Geomorphic Surfaces

with dark desert varnished and thick pavement surfaces. A 6 to 18 inch silty sand layer over the active portion of the fan covers a cobbley gravelly sandy subsurface which was presumably deposited during a different climatic period and associated flow regime. This silty surface layer is identical in appearance to the slackwater silts found deposited in the paleoflood survey. This silty material is representative of the suspended and wash load of Tiger Wash. Abandoned channels are filled. It is unclear whether this filling is the cause or result of channel shifting and overbank deposition.

Sierra Estrella

Location. The Sierra Estrella active alluvial fan is located on the western side of the Sierra Estrella at the eastern margin of Rainbow Valley (Figure 1). The nearest town is Mobile, located 17 miles south of the site. The upper watershed borders the Gila Indian Reservation boundary. The remainder of the site lies on BLM-leased land (Figure 30).

Access. Access to the site is via paved public roads and publicly maintained dirt roads in poor condition. From Phoenix, take Interstate 10 west to the Estrella Parkway exit. Travel south to the end of the pavement on Estrella Parkway. Continue south approximately 4 miles, past and around a large stock pond and several bedrock knobs to the east. The road then follows a fallow field and dry swale for approximately one mile and then intersects a fence line. Turn east at the fenceline and proceed to a large bermed channel and dip crossing. After crossing the channel, jog south then east and follow the winding, well-tracked dirt road to the Salt River Project (SRP) powerline seen in the distance. Turn east at the SRP powerline. Follow the powerline road about 2 miles east to the point where the powerline road turns southeast. The braids of the fan cross the road at this point. A jeep trail breaks off to the northwest which leads to the hydrologic apex.

Site Selection. The west side of the Sierra Estrella Mountains has a number of apparently active alluvial fans, unlike the other mountain ranges in the County. Comparison of this fan to other Maricopa County fans will yield important information regarding formation of active fans. This fan is different from many of the other active alluvial fans in Maricopa County in that it is located immediately adjacent to the mountain front. However, the Sierra Estrella site may be more like active fans located in Nevada and southern California, and thus will serve as a comparison with what FEMA considers to be "typical" fans.

Vegetation. Vegetative communities found at the Sierra Estrella site (Figure 31) were typical of the region. Dense, leaf-bearing vegetation lines channel banks. Sparse cacti and creosote/bursage dominate older surfaces and terraces. Well developed desert pavement and infrequent runoff presumably limit plant growth on the older surfaces. Grasses and annuals may be found on the more frequently wetted active alluvial fan.

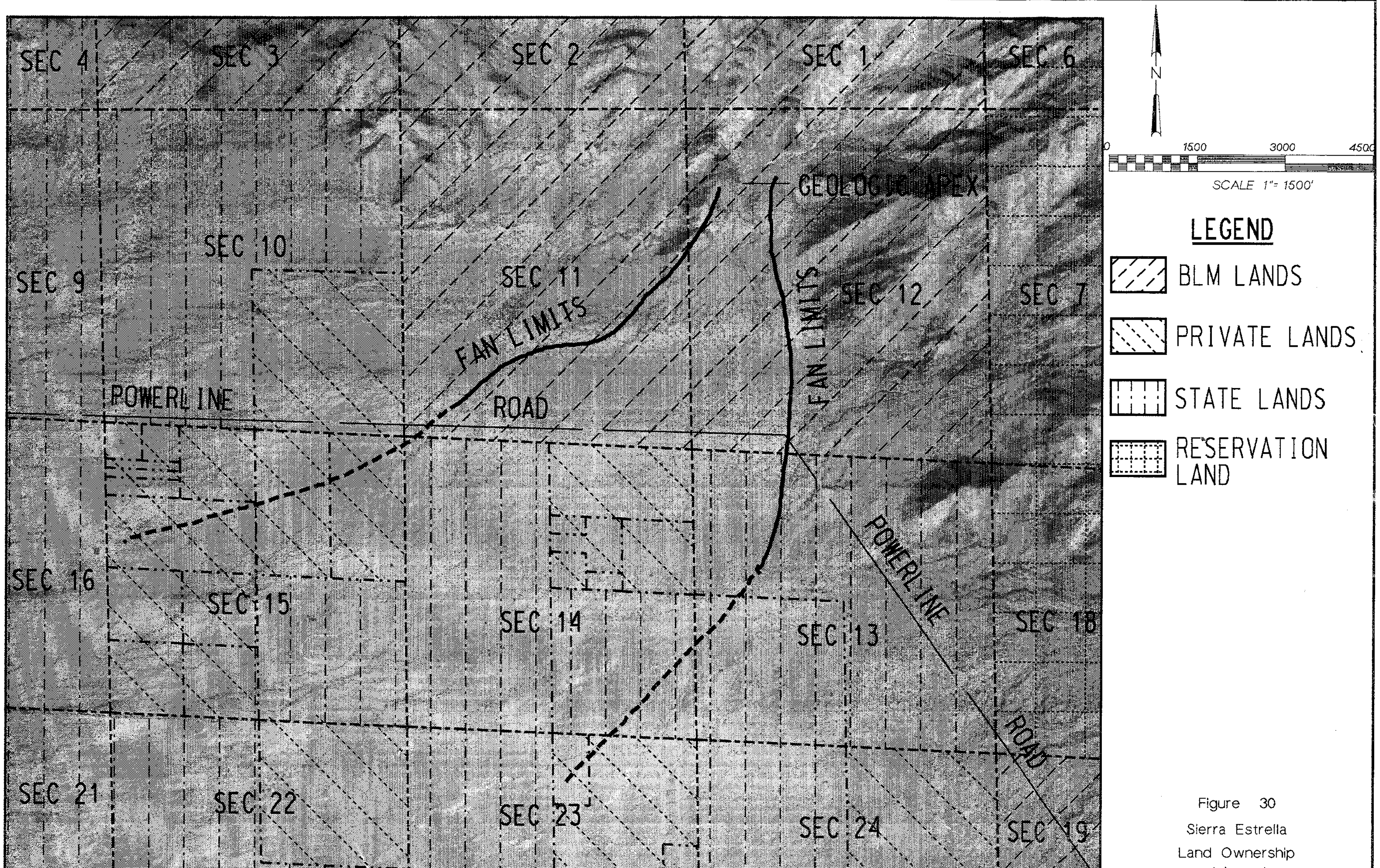


Figure 30
Sierra Estrella
Land Ownership
and Location

CH2M HILL

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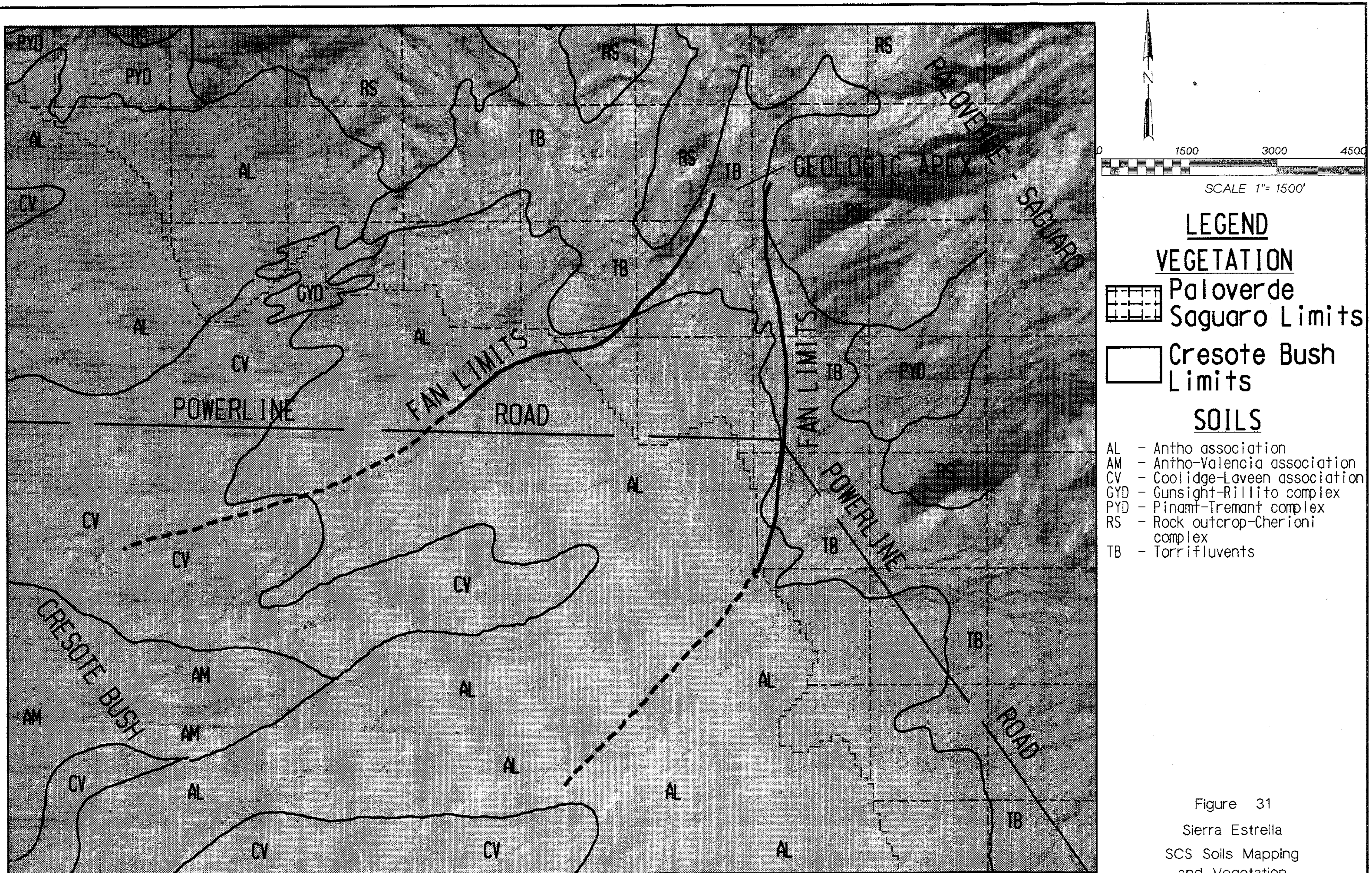

Figure 31
Sierra Estrella
SCS Soils Mapping
and Vegetation

CH2M HILL

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More dense stands of Palo Verde in the sheet flooding zone attest to more frequent flooding in this area than at other sites. Specific plant types found at the site were summarized in Table 4.

Soils. Soils on the Sierra Estrella active alluvial fan belong (Figure 31) to three general soil groups: the Torrifluvents Association, the Antho-Valencia Association, or the Coolidge-LaVeen Association. Torrifluvent soils are nearly level to gently sloping gravelly, stoney, and cobbly throughout and are found on recent alluvial fans at the base of mountains. They are subject to frequent overflow and are dissected by channels 3 to 25 feet deep. Gravel content may be 35 to 80 percent. The Antho-Valencia Association is described as nearly level sandy loams on recent alluvial fans and valley plains. It includes the Antho gravelly sandy loam on slopes of less than 1 percent with a dendritic surface drainage pattern with channels 1 to 3 feet deep. The Coolidge-LaVeen Association occurs in isolated portions of the distal portion of the Sierra Estrella piedmont. This unit is described as old alluvial fans (fan terraces).

Geology. The Sierra Estrella are a northwest-trending, fault block bounded mountain range typical of the Basin and Range province. The geologic history of the range is typical of the region. The parent rocks were probably shallow marine sedimentary units such as graywacke and shales, in addition to volcanic deposits, deposited near the margins of the proto-North American basement. During the Mazatzal Orogeny isoclinal folding and axial plane deformation formed gneiss and granites. A second, Paleozoic, low-temperature episode of deformation resulted in recrystallation of some minerals. Broad arching during the Laramide Orogeny associated with low-angle faulting, compressional plutonism, and volcanism during the Oligocene (20 m.y.) also saw enormous outbursts of rhyolites and andesite tuffs, breccias, and flows. Basin and Range tectonics in Miocene time (13 m.y.) uplifted the region along its northwest axis, and subjected it to the erosion which shapes the range today. In addition, some mafic diking occurred in conjunction with faulting (Sommer, 1982).

Bedrock in the range (Figure 30) consists of interlayered Precambrian gneiss and granites with small Tertiary granite intrusions and numerous Tertiary mafic dikes. Rock units include the Casey Abbott gneiss (oldest) to the Estrella Gneiss (most abundant, forming the core of the range), to the more recent ridge forming igneous intrusives. The Estrella gneiss is a plagioclase, K-feldspar, quartz unit with granoblastic texture. Outcrops of the Estrella Gneiss are obscured on hillslopes by abundant talus (Sommer, 1982). The abundant talus is the principal sediment supply source for the alluvial fan.

The Sierra Estrella are lithologically similar to the metamorphic core complexes in Maricopa County, but lack the structural characteristics. The Estrella gneiss may represent the roots of a core complex, with the upper portions removed by erosion. The Sierra Estrella do not show the typical bulbous physiography of a core complex. Their extremely steep slopes and sharp crested peaks are indicative of their Basin and Range origin.

Depth to bedrock data for the site were collected by field observation and from a map published by the USGS (1973). The thickness of alluvium varies from zero to 400 feet. Bedrock in the channel or floodplain was not observed below the geologic apex (Figure 32). No well log data were available.

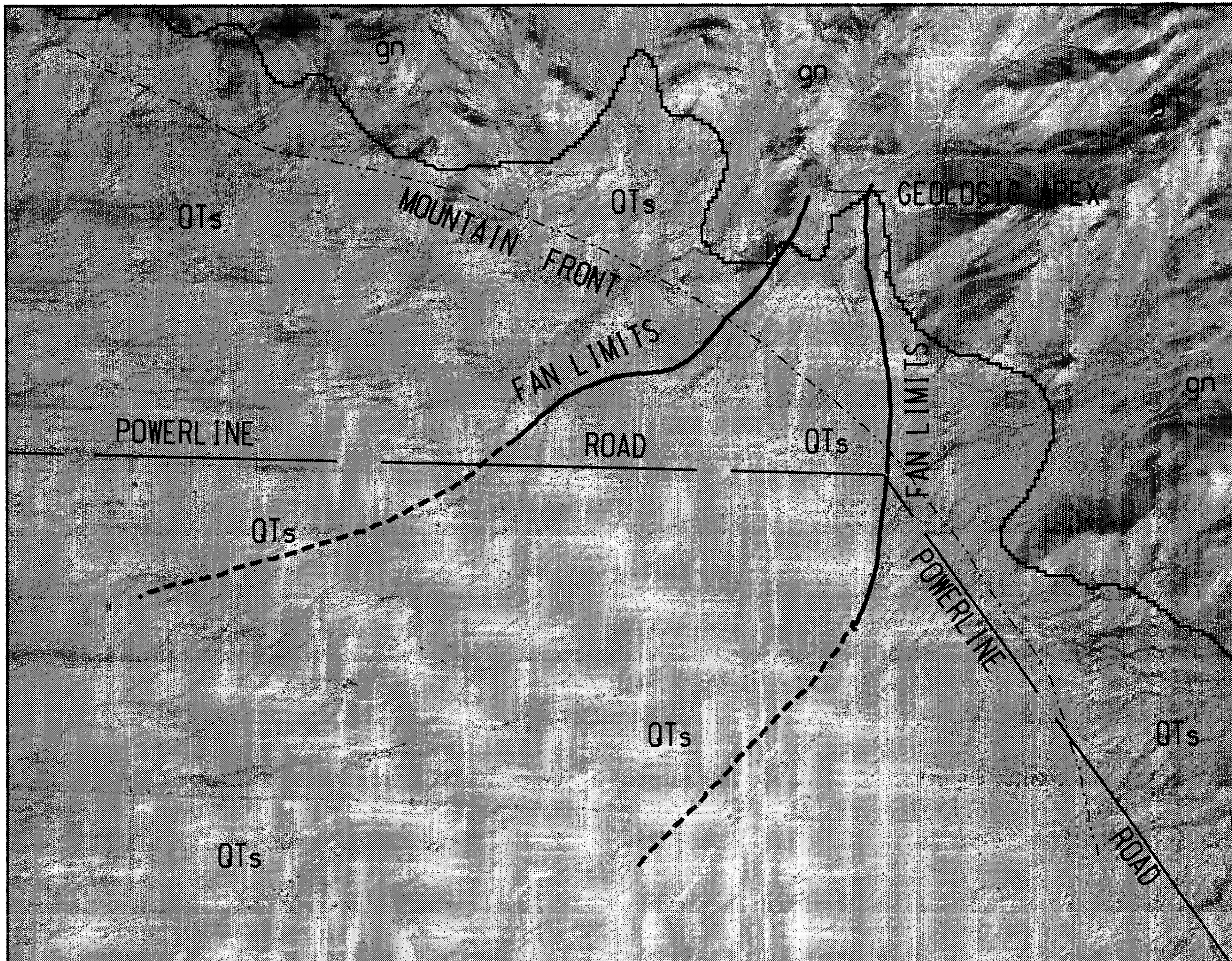
Hydrology. The Sierra Estrella site has a drainage area of 1.07 square miles at its hydrologic apex. Small watersheds like the site drainage area tend to experience peak flow during intense monsoonal rainstorms. However, no systematic data are available to substantiate this assertion for this basin.

Due to the remoteness of the Sierra Estrella site, very little flood or rainfall data are available to document its flood history. The nearest recording gauge sites are summarized in Tables 5 and 6. However, because this site responds more to localized monsoonal rainfall, the applicability of regional rainfall records for reconstructing the site's flood history is questionable.

Anecdotal evidence of flooding is available from Maricopa County road maintenance crews who maintain the SRP powerline road. According to the road crew, floods at the powerline are typically sheet floods with slight concentrations of discharge in small channels. These channels tend to change position or conveyance between storms. Flooding at the road alternates between deposition of sand and debris, and erosion from small headcuts. The road captures portions of low flows (Brundage, 1991).

No field evidence of recent intense flooding was apparent. As discussed below, the channel pattern indicates that flooding is erosional to equilibrate near to and above the apex, to slightly depositional below the apex. Field evidence indicates that sheet flooding is an important component of flow below the apex. Paleoflood data were not collected at this site.

Flood recurrence interval information provided by the FCDMC is summarized in Table 12. Flow peak rates vary from 222 cfs for the 24-hour, 2-year storm, to 1,953 cfs for the 6-hour, 100-year storm. A report provided by the FCDMC discusses more completely the derivation of the peak flow rates (FCDMC, 1991).



N

0 1500 3000 4500

SCALE 1"= 1500'

LEGEND
GEOLOGY

gn - Granite gneiss
QTs - Sand, gravel, and conglomerate

Figure 32
Sierra Estrella
Geology

Table 12 Peak Discharge Estimates (cfs), Sierra Estrella Site		
Recurrence Interval (Years)	24-Hour Rainfall	6-Hour Rainfall
	Adjusted Slope	Adjusted Slope
2	222	278
5	467	541
10	692	809
25	1,018	1,279
50	1,266	1,607
100	1,496	1,953
[1]Discharge values shown are taken directly from HEC-1 model output and do not reflect actual significant figures.		

Manning's ratings of channel sections using the hydrologic data provided by the FCDMC predict that the channel has capacity for the 100-year flood above the hydrologic apex. Below the hydrologic apex, cumulation and individual channel capacity rapidly decreases to less than the 2-year flow rate. Approximate floodplain limits are shown in Figure 33.[9] Manning's velocity ratings range near 6 feet per second above the hydrologic apex and decrease downfan to the sheet flooding area.

Paleoflood Hydrology. Paleoflood surveys of two reaches above the hydrologic apex were performed to estimate the magnitude of floods which have occurred on the fan. The upstream paleoflood reach was located in a partially bedrock controlled reach just downstream of the three-way confluence (Figure 38). The channel in this reach is a steeply sloping (0.011-0.038 ft/ft) bouldery channel with sparse vegetation on the banks. The northern bank is cut into gneissic bedrock. The southern bank is formed of carbonate cemented Pleistocene/Holocene terraced soils sequence. The topographically lower Holocene terrace rises about 11 feet above the stream bottom, and is inset into the much higher Pleistocene terrace.

Classic slackwater silt sequences are lacking in the upper reach, but several other paleostage indicators were found. Paleostage indicators in the upper reach included a silty sand unit located upstream of a sharp channel bend, a sandy terrace along the southern bank, a large prehistoric pot shard, and the early Holocene terrace which shows no signs of geologically recent flooding. The highest flood deposit, the sandy silt unit, appears to be the result of a single event. The Hohokam pot shard was found slightly embedded in flood silts at an elevation of about 3.5 feet above the channel bottom. The size and degree of preservation of the shard indicate that it probably was

[9]Floodplain limits not intended for regulatory or design purposes.

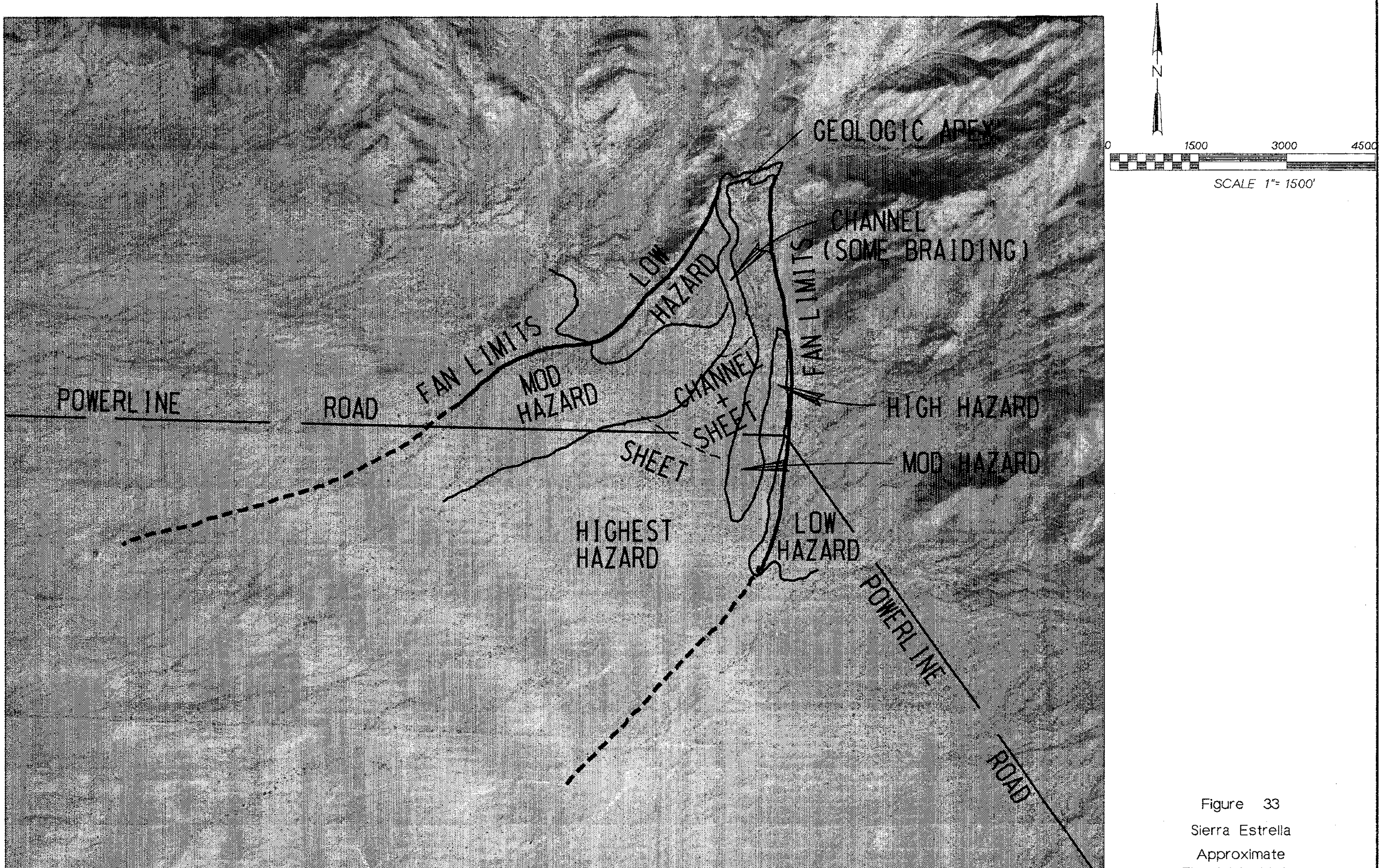


Figure 33
Sierra Estrella
Approximate
Floodplain Limits

CH2M HILL

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not transported downstream by water flow, was not buried by subsequent floods, and it was not impacted by flood debris. The sandy terrace, the topographically lowest deposit, may represent up to two floods. However, the stratigraphy in the sandy terrace is not conclusive.

The downstream paleoflood reach is located several hundred feet upstream of the hydrologic apex (Figure 38). This lower reach is a steep (0.019 ft/ft) sand and gravel bedded reach located upstream of a channel constriction. The reach is located just below the portion of the stream which experienced periodic coarse debris flows in the geologic past. The northern bank is segmented into three terraces. The lowest terrace is a relatively frequently flooded silt, sand and gravel covered surface with low, brushy vegetation. A second, topographically higher terrace supports more Palo Verde, Saguaro and other cacti, as well as some desert pavement areas. The vegetation and desert pavement probably indicate less frequent flooding. The highest terrace, of probable late Pleistocene age, shows no signs of flooding. These terraces are at about 2.5, 5, and 9 feet above the channel bottom.

Paleostage indicators found in the lower reach include flood sands and silts in a low terrace which lines the southern channel margin, a single slackwater silt unit inset into the floodplain terrace on the northern bank, and the two higher terrace surfaces. No datable material was found for any of the paleostage indicators in the lower reach.

Water surface profiles were computed for both reaches using the computer model HEC-2 (HEC, 1982). Water surface profiles were then compared to highwater and paleostage indicators to determine minimum flow rates (Figures 34 and 35). In the upper reach, HEC-2 modeling indicates that both the pot shard and the slackwater deposits were emplaced by flows of about 750-1,000 cfs. The presence of the pot shard indicates that the 1,000 cfs threshold probably has not been exceeded for at least 600 years[10]. A flood of approximately 10,000 cfs would be required to inundate the early Holocene terrace. In the lower reach, slackwater deposits record flood peaks of about 500-750 cfs. Floods of approximately 4,000 cfs and 10,000 cfs would be required to inundate the second highest and late Pleistocene terraces, respectively.

The paleoflood record does not compare well with HEC-1 modeling of the Sierra Estrella watershed. According to the HEC-1 model results, the paleofloods recorded by slackwater deposits have a minimum recurrence interval of about 10 to 25 years. The flood which emplaced the pot shard has a minimum recurrence interval of approximately 25 years. The floodplain terrace in the lower reach is inundated by flows which exceed the 25-50 year recurrence interval. The flood magnitude required to inundate the early Holocene and late Pleistocene terraces are well in excess of the 100-year flow rate.

[10] The Hohokam period of occupation ended in about 1400 A.D., about 600 years before present.

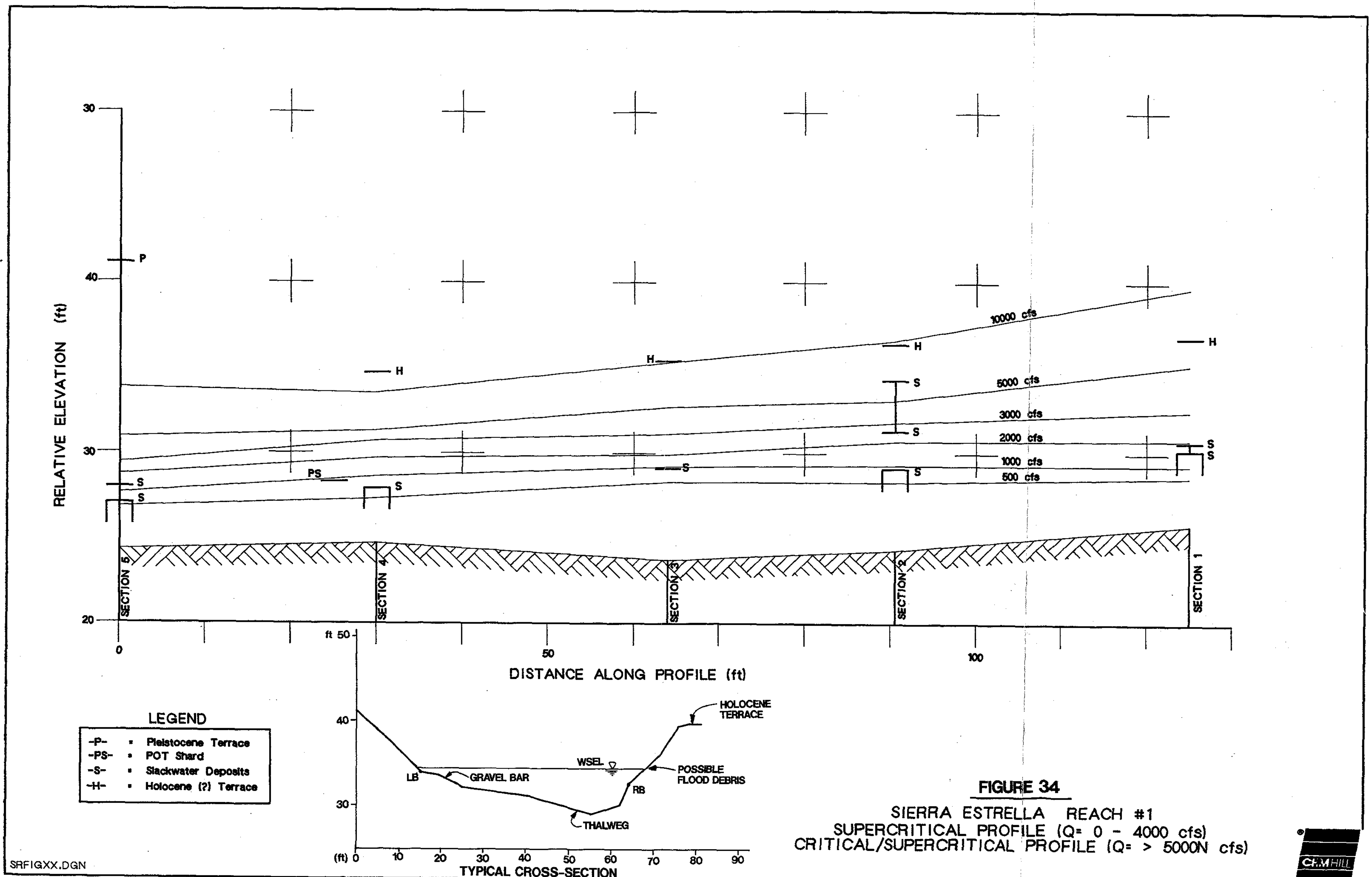
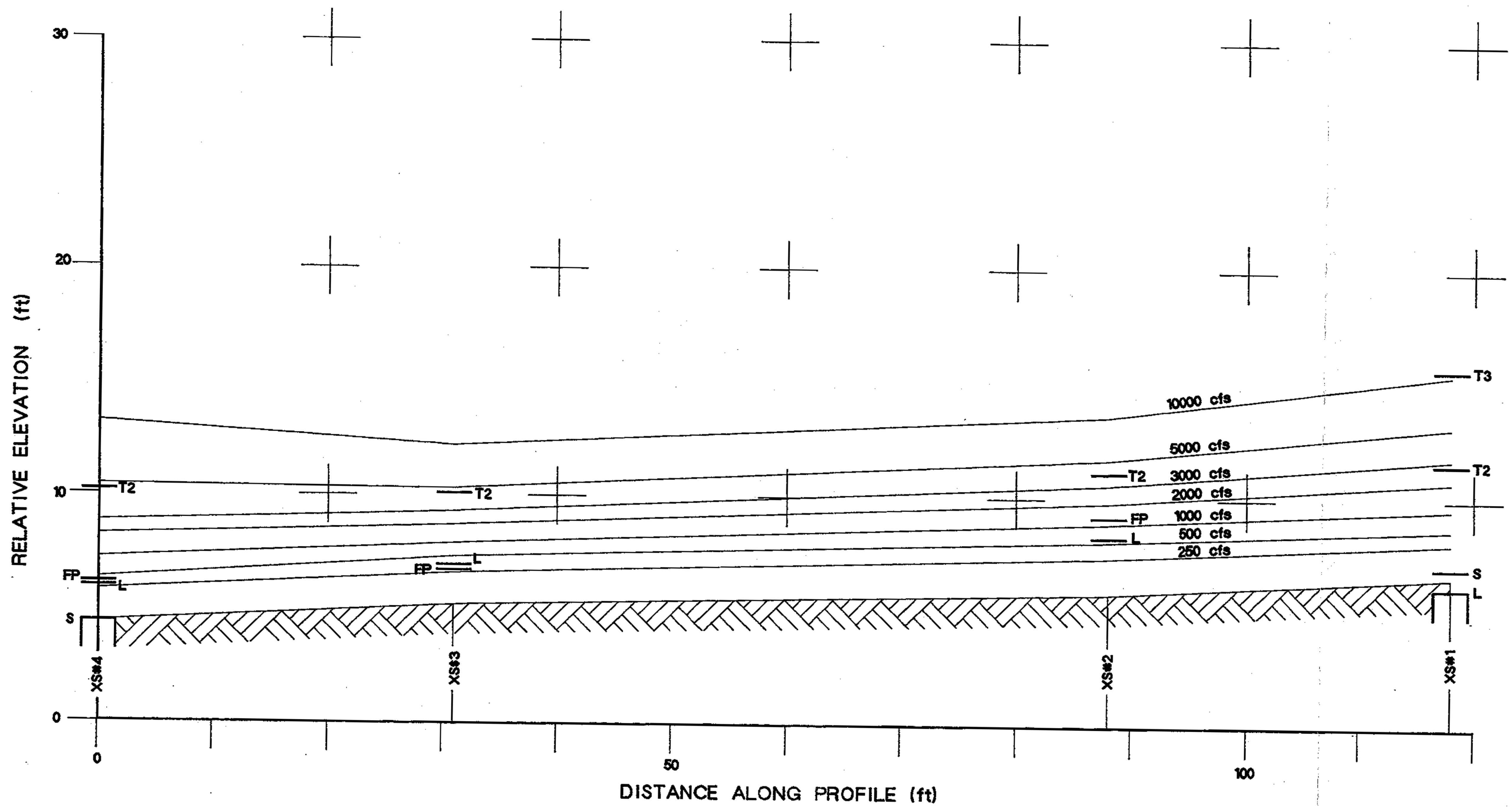


FIGURE 34

SIERRA ESTRELLA REACH #1

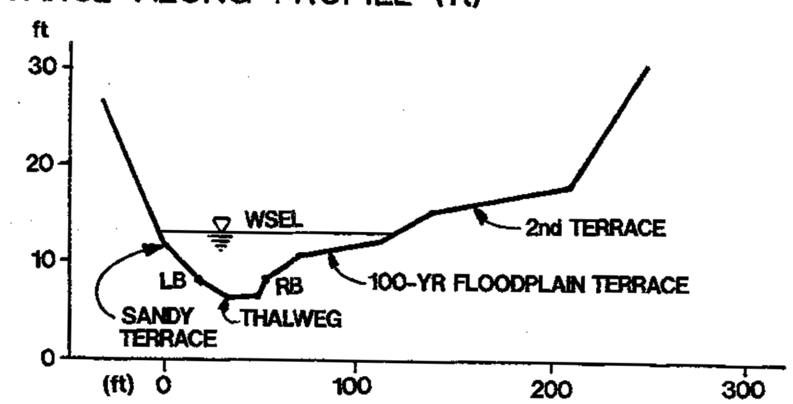
SUPERCRITICAL PROFILE (Q= 0 - 4000 cfs)

CRITICAL/SUPERCRITICAL PROFILE (Q= > 5000N cfs)



LEGEND

-L-	Vegetated Terrace at Left Bank W/ Slackwater
-S-	Slackwater Deposits
-FP-	Floodplain Terrace
-T2-	Holocene (?) Terrace W/ Saguaros, Cobbles
-T3-	Oldest Terrace W/in Canyon



TYPICAL CROSS-SECTION

FIGURE 35

SIERRA ESTRELLA REACH #2
(SUPERCRITICAL PROFILE)

SRFIGX.DGN

CH2M HILL

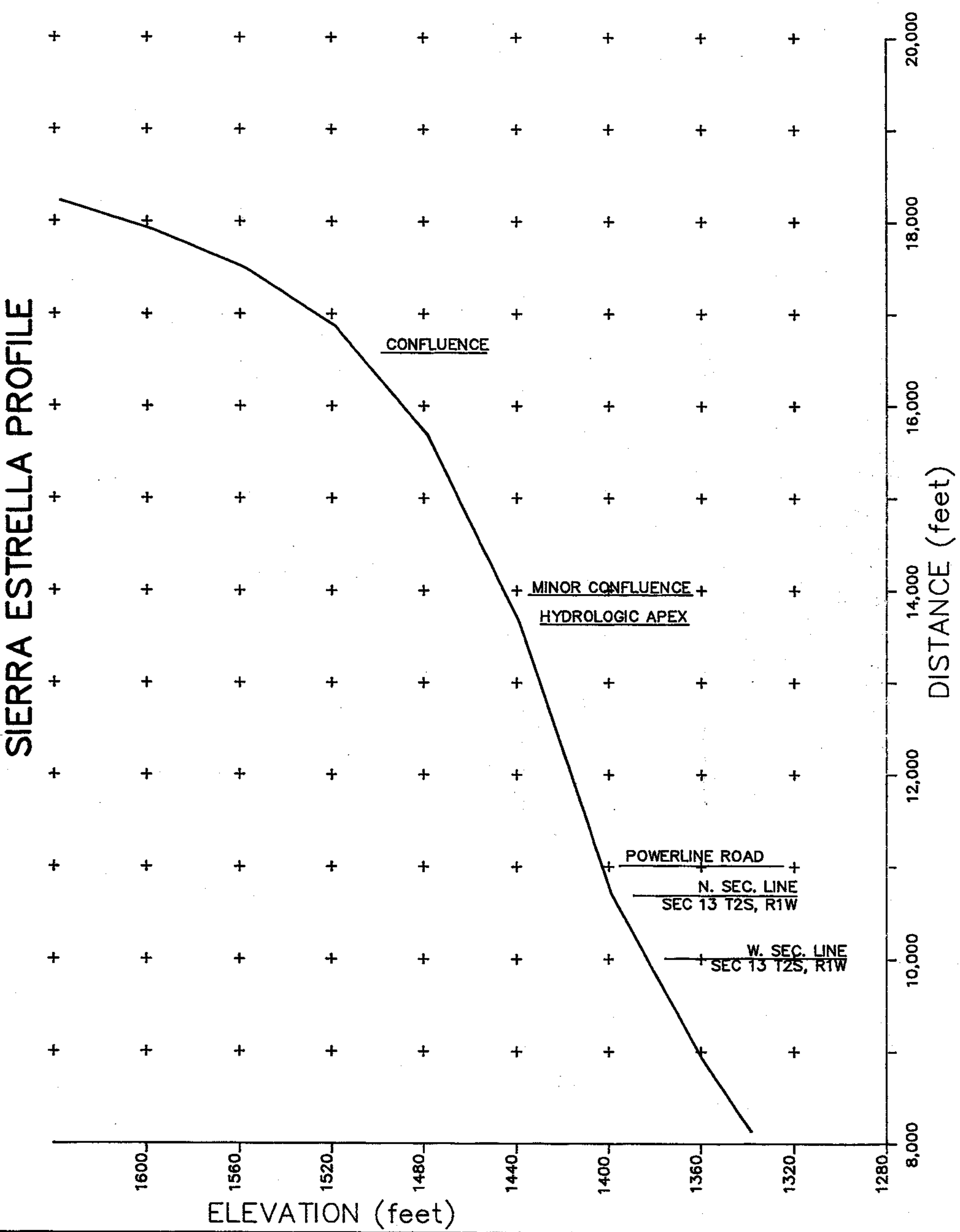
The unfavorable comparison of paleoflood HEC-2 modeling results and HEC-1 hydrologic modeling results for the watershed may be interpreted several ways. First, the magnitude of more frequent floods may be overestimated by HEC-1 modelling. The occurrence of a 600-year-old pot fragment at the 25-year flood elevation is relatively unlikely. Second, large floods simply may not have occurred in the recent geologic past on this watershed. A 100-year flood may not have occurred in the past 600 or more years. The high stability of the channel pattern (not bed elevation) during the period of photographic record supports the theory that large floods have not occurred.

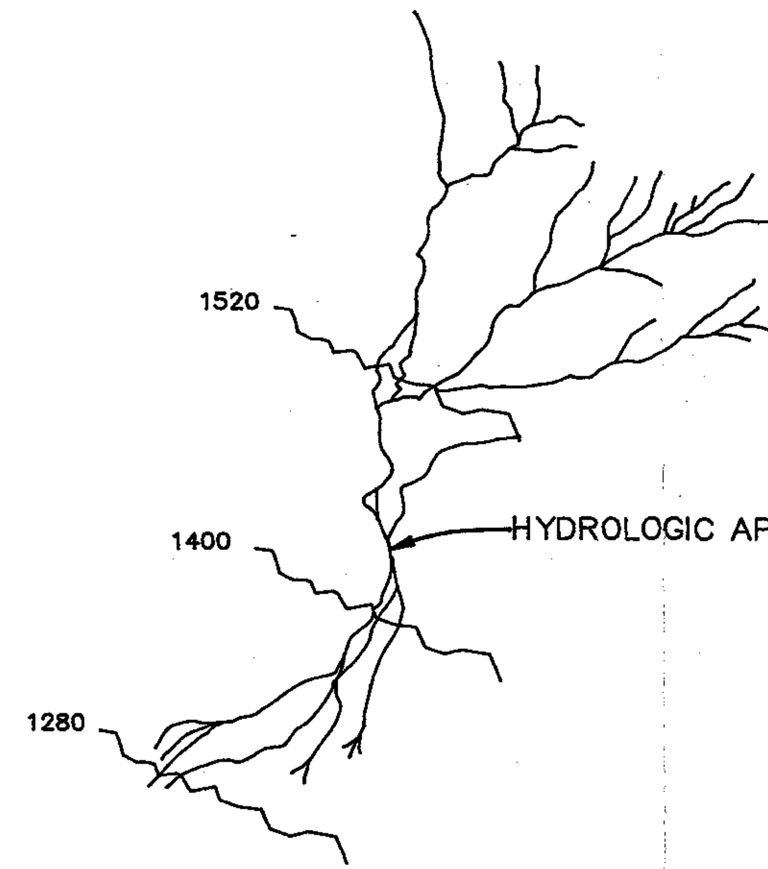
Geomorphology. The Sierra Estrella fan is an active fan located on the west side and immediately adjacent to the Sierra Estrella mountain front. The mountain front is deeply embayed, although no evidence for existence of a pediment was found. Bedrock crops out well above the apex and is not visible in the channel bed or banks. The range is tectonically inert; no signs of fault scarps or tectonic activity were found in the field. This conclusion is also supported in the geological literature (Demsey, 1989).

The primary channel above the hydrologic apex is a deeply entrenched third order stream. The slope is slightly sinuous (S=1.28) above the apex, and somewhat more straight downstream of the apex (S=1.05). Channel slope is segmented, decreasing downstream from the watershed divide through the hydrologic apex to the powerline road, and then increasing again (Figure 36). The crenulation index also increases significantly above the hydrologic apex. The drainage pattern above the apex is dendritic. Below the apex, the channel very rapidly transitions to a distributary pattern with an extensive sheet flooding component. Downstream of the SRP powerline road the dendritic pattern begins again.

The hydraulic geometry of stream channels on the alluvial fan was analyzed using field measurements. Channel geometry, including width, bank height, and flow depth as indicated by flood debris was measured every 100 feet in each channel or distributary flow path downstream of the hydrologic apex. In addition, data collection transects of the total fan widths were made every 300 to 500 feet between the geologic apex and the toe of the fan. For each transect, channel geometry, soil and vegetation characteristics, flood debris, and other geomorphic parameters were noted.

Channel geometry above the hydrologic apex reflects the change from a debris flow dominated, bedrock-controlled stream to a sand-bedded alluvial controlled channel. Channel bank elevations decrease from 15 feet high a few hundred feet upstream of the apex to less than 2 feet several hundred feet downstream of the apex. Channel geometry below the hydrologic apex is highly variable (Figure 37), reflecting the alluvial nature of the channels and frequent bifurcation and joining of individual flow braids. However, some overall trends can be discerned. Below the apex, channel depth remains essentially constant until the sheet flow reach. Channel bottom width decreases, both in individual braids and cumulative width across the entire fan. Total channelized flow area also decreases slightly downfan. The width-depth ratio shows no definite trend. In spite of this rapid transition in channel geometry, the channel pattern





CHANNEL PATTERN

CRENULATION INDEX

CONTOUR ELEV.	ALONG CONTOUR	BEGIN TO END	CREN. INDEX
1280	4110	3900	1.054
1320	4800	4500	1.067
1360	6830	5800	1.178
1400	5400	3500	1.543
1440	4510	2800	1.611
1480	7910	2900	2.728
1520	8310	2900	2.866

SINUOSITY

REACH #	IN-STREAM LENGTH	BEG-END LENGTH	SINUOSITY
1	2.488	1.95	1.276
2	1.095	1.04	1.053
3	1.244	1.18	1.054

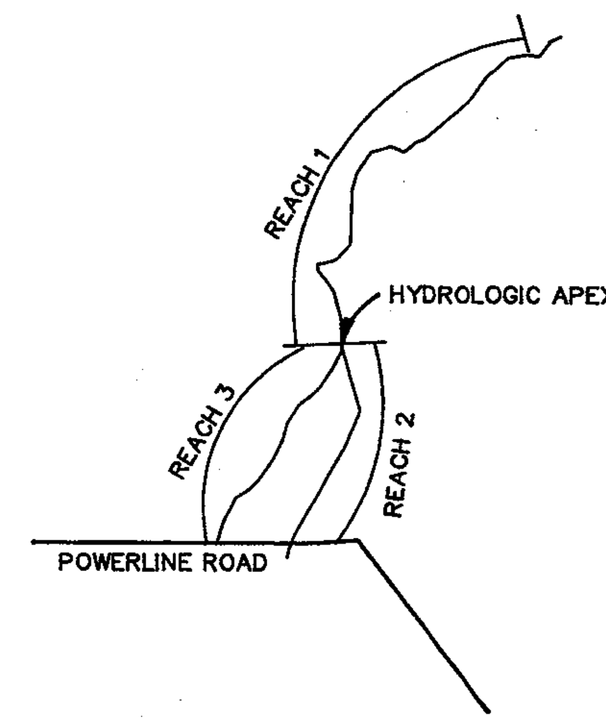


FIGURE 36

SIERRA ESTRELLA
CHANNEL PATTERN
SINUOSITY, PROFILE
& CRENULATION INDEX

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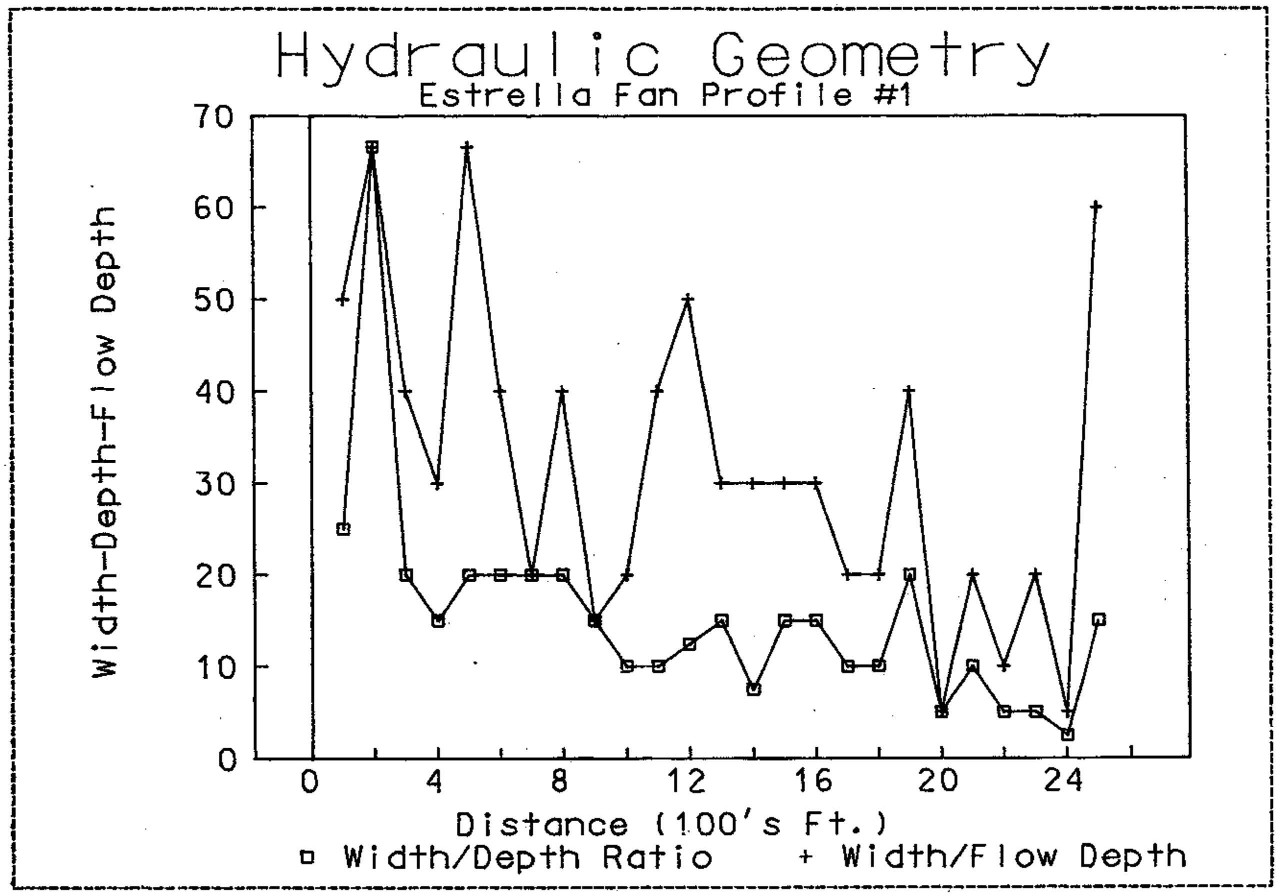

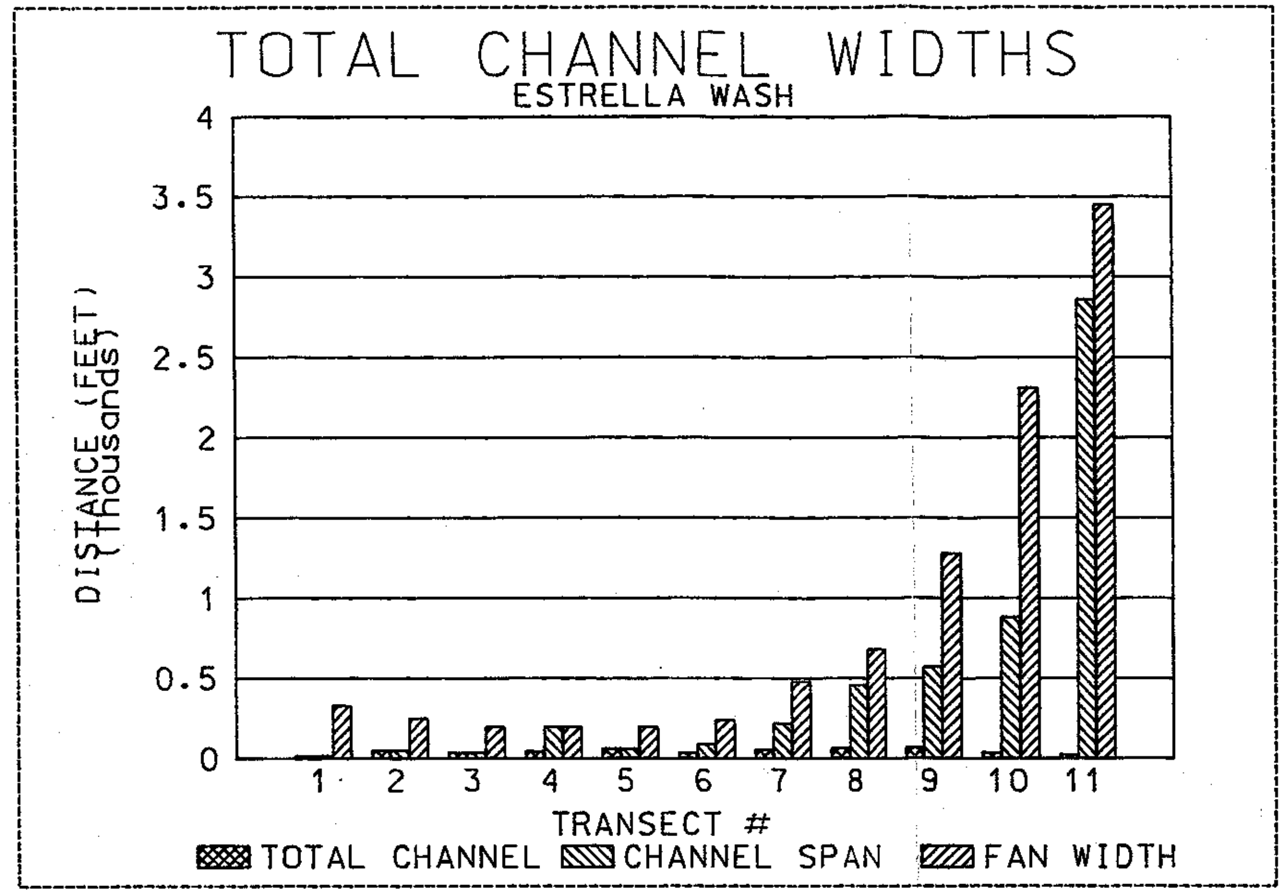

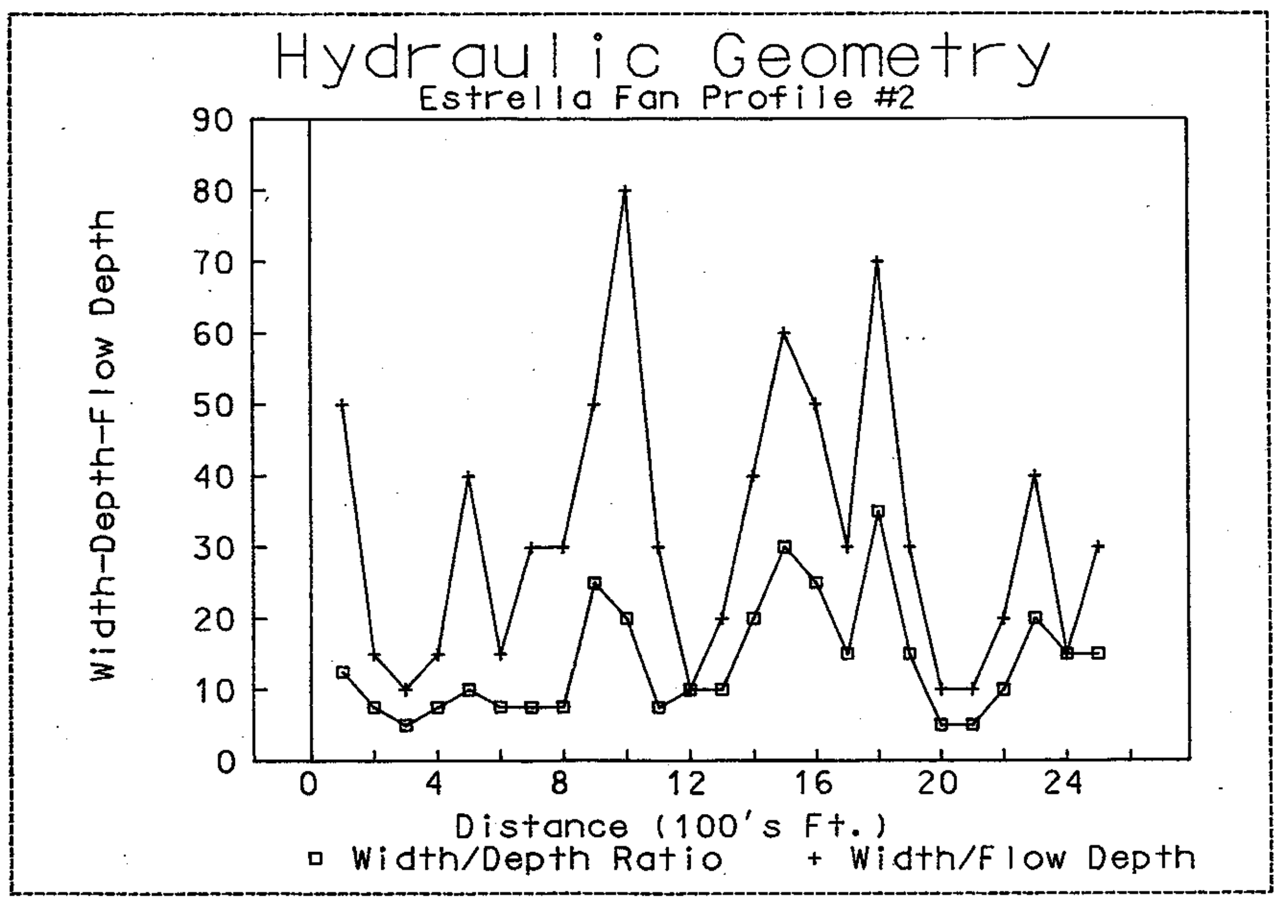

FIGURE 37

SIERRA ESTRELLA CHANNEL GEOMETRY

CH2M HILL

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at the site has been extremely stable over the period of photographic record, from 1936 to 1989 (Figure 38).

Although the Sierra Estrella site is an active alluvial fan, little evidence of channel movement or erosion was found in the field. Examination of aerial photographs from 1936, 1978, and 1989 also reveals no changes in channel location, even for the smallest braids. In addition, none of the roads traversing the lower fan area have been obscured by deposition or erosion during the past 60 years. As no evidence of recent major flooding was found, it is possible that the period of photographic record was hydrologically quiescent. It is noted that anecdotal accounts of flooding indicate that floodwaters do exploit different channels in successive events. Recent deposition of sand on heavily varnished pavement surfaces at the southern margin of the fan is evidence of progressive aggradation.

In contrast to the apparently stable reaches below the apex, the upper reaches of the primary wash are subject to damming and blockage by debris flows. Debris flow levees less than 50 years old, and probably less than 10 years old were mapped along each of the main tributaries. The runout distance for these flows is short, with the nose of the flows located above the reach of bedrock control. Bank material in the channel above the apex indicates that debris flows and coarse sediment transport was a more common occurrence during formation of the terrace surfaces. Coarse clastics in the active channel bottom grade rapidly from 1 to 4 feet diameter near the nose of the debris flows to fine gravels above the apex. Lack of soil development and fine-grained sediment in the watershed due to the rapid erosion rates relative to soil loss rates prevent the formation of significant debris flows. Presumed high infiltration rates, channel widening, slope decrease, and limited source material prevent debris flows from reaching the hydrologic apex or channels below the apex.

There are three principal geomorphic surfaces at the Sierra Estrella site (Figure 39). These parallel terraces are defined topographically adjacent to the channel, and by soil and vegetative characteristics elsewhere. Slight erosional remnants of other terraces are also visible in isolated sections of the channel upstream of the apex. The 2c/2b surface is the youngest. It includes active channel bottom deposits and the interfluves between braids. It is comprised of silts, sands, and fine gravels, with little or no soil development or carbonate formation. The 2c/2b has a distributary channel pattern, with small capacity channels. It experiences frequent flooding and active aggradation. This surface has the highest flood hazard at the site. The 2c/2b overlies or is inset into the older 2a surface.

The 2a surface is topographically higher than the 2c/2b by 4 feet to less than 1 foot where it is being slowly buried by the 2c/2b. The 2a surface may be identified by a lack of continuous defined flow paths, incipient development of desert pavement and varnish, and a slight reddening of the surface layer. Bank cuts exposing cross sections of the surface reveal a coarser surface layer of lag gravels and cobbles, with stage I

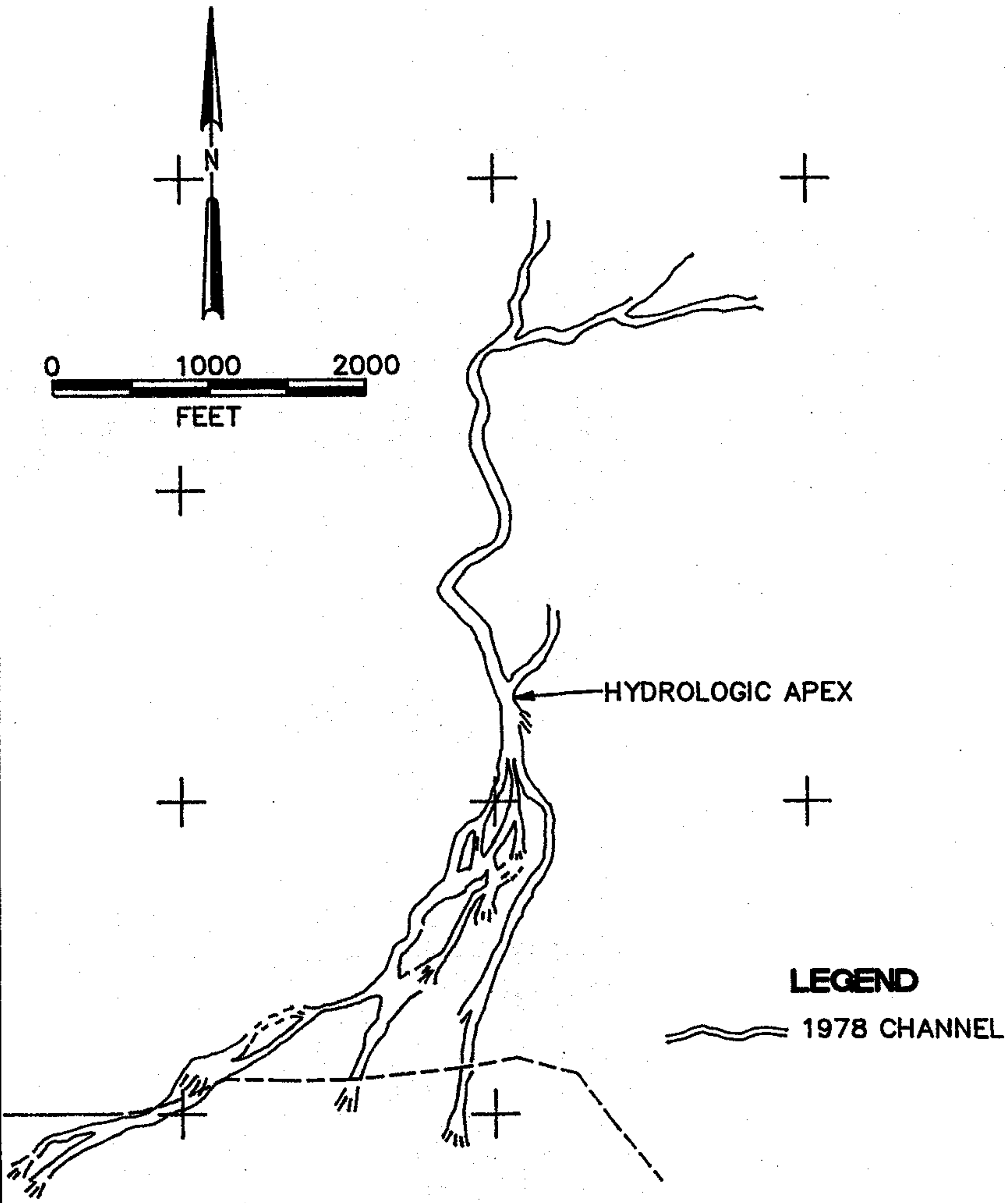
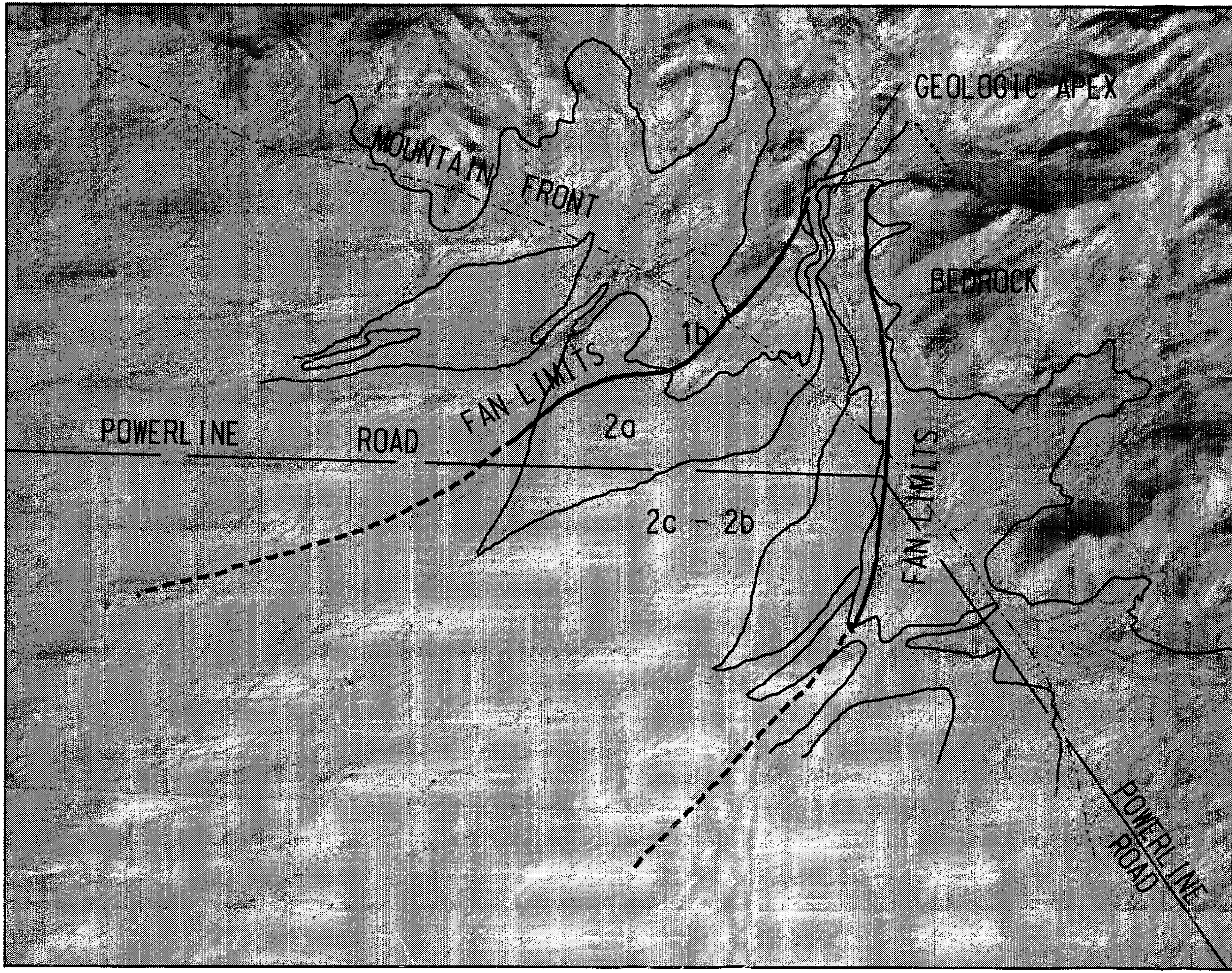


FIGURE 38

SIERRA ESTRELLA
HISTORIC CHANNEL SHIFTING
1936-1989
(NO CHANGES)

CH2M HILL



N

0 1500 3000 4500

SCALE 1"= 1500'

LEGEND

GEOMORPHOLOGY

2c - Channel fill youngest
2b - Floodplain
2a - Early Holocene
1b - Late Pleistocene
BR - Bedrock oldest

FIGURE 39

SIERRA ESTRELLA
GEOMORPHIC SURFACES

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CH2M HILL

and II carbonate development. Portions of the 2a surface may be occasionally flooded by water from the principal fan wash, but most runoff is developed from tributaries and on-fan sources. Consequently, channel development is poor, reflecting infrequent flow.

The oldest surface, tentatively called 1b, is readily distinguished from other surfaces by the degree of dissection, well-developed dendritic drainage pattern, desert varnish and pavement, and sparse vegetation. The 1b surface is topographically higher than both the 2a and 2c/2b surfaces by 5 to 10, and 20 to 30 feet, respectively. Flood hazard on this surface is low, except in the bottoms of tributaries.

Alternative Sites

Lost Dog Wash and Granite Reef were recommended as alternative data collection sites. No detailed information was collected for these sites. An explanation of site selection criteria for the two sites is provided below.

Lost Dog Wash. Lost Dog Wash drains the southern end of the McDowell Mountains in north Scottsdale. The Lost Dog alluvial fan has been the subject of several ongoing flood studies. Consequently, there is an extensive data base of geomorphic, hydrologic, topographic, and other pertinent information. It is a prime example of an urban distributary flow system which is similar in form to an active alluvial fan. However, implementation plans by private developers and the City of Scottsdale to completely channelize Lost Dog Wash would destroy gauging opportunities. Therefore, this site is recommended as an alternative site. Informal monitoring of the site by occassional field visits, periodic aerial photography, and use of the FCDMC existing ALERT network is recommended.

Granite Reef Wash. The Granite Reef site is located on the southwest side of the McDowell Mountains between the Payson Highway and the SRP cross canal. This active alluvial fan is currently undeveloped, but has some potential to be developed in the near future. There are several structures available for use in discharge and sediment gauging. However, these structures may have also altered the natural drainage processes or diverted some watersheds. Therefore, this site is recommended only as an alternative.

Discussion

Regional Trends

Generalization of data collected for this part of the study at the four instrumentation sites has revealed some regional trends in the geomorphology of alluvial fans in Maricopa County. These regional trends include vegetation growth patterns, geomorphic soil and sediment parameters, and measurable geomorphic indices. Because only four sites were analyzed, these trends should be regarded as tentative, until substantiated by further data collection on additional sites. Use of the regional trends to identify fan processes and fan type assumes that rates of soil, caliche, pavement, and varnish formation are slow processes, taking hundreds to thousands of years to form. Recently some investigators have cited unpublished data that indicates that these features may develop within less than 50 years in some environments. However, the majority of published research for arid environments indicates that these geomorphic features require hundreds to thousands of years to form.

Vegetation

Vegetative patterns are extremely useful in identifying types of alluvial fans and alluvial fan processes. In the desert, dense vegetation and trees occur only along washes. This dense vegetation outlines the drainage pattern, which can be used to distinguish fan terraces from active alluvial fans and distributary flow systems.

The fact that lines of mature trees are only found along wash banks can be used to identify fan processes. Channels not lined by mature vegetation may be newly cut. Trees found directly in the flow path with exposed roots may be used to determine bank erosion distance. In some cases, abandoned channels infilled by sediment can be identified by the remnants of dead or dying vegetation aligned sub-parallel to the principal flow direction. Conversely, apparent conveyance systems with grasses and brush growing in them and without trees on the bank may be abandoned flow paths cut off by channel movement or stream capture. Examples of these features were found on the Tiger Wash and South Mountain Park sites.

Vegetation is also indicative of other geomorphic processes. Buried trees, especially mesquite species, indicate aggradation. Degradation, lack of aggradation, and wind deflation can be seen by examining vegetation for exposed root systems or mounding around the bases of floodplain species such as creosote. The density and relative height of vegetation is indicative of the frequency and volume of runoff. Higher and denser brush communities indicate more frequent watering. Sundell (1974) reports a tendency for species to shift into the washes in dry years, and exploit the channel banks during wetter years. This tendency can be used to read the recent climatic history.

The type of vegetation reveals some information regarding the soil type. Large cacti species prefer rockier soils of the older geomorphic surfaces, and tend to avoid silty floodplains. The youngest fan areas of the Sierra Estrella and Tiger Wash sites had no large cacti; the younger surfaces on the distributary areas did. The distributary flow areas at the South Mountain Park and White Tank sites had cacti throughout the multi-channel area. Grasses grow best where velocities do not exceed 5 fps, and therefore are limited to areas of non-channelized flow (sheet flow). The densest grasses were found in abandoned channels and sheet flow areas, but not in active channels or overbanks.

Soil and Sediment Parameters

Soil characteristics are the primary geomorphic information used to distinguish types of alluvial fans in Maricopa County. However, some soil and sediment characteristics are easy to misinterpret. Cobble and boulder material in washes on distributary flow systems is most likely lag deposits left from bank erosion and headcutting, rather than debris flow remnants or recent bedload. Debris flows may be identified by continuous levees of boulders which line or cross cut existing channels, and bury vegetation. Debris flow deposits are generally not layered, with no sorting of grain sizes. Bedload deposits are imbricated and may form channel bars or islands. Erosion lag deposits are identical in composition and shape to bank material, and may still have remnant caliche coatings.

The mere presence of varnished desert pavement surface may also be misinterpreted as indicating a fan terrace. It is important to determine the stratigraphic relationship of younger material to this surface. Recent deposition on or flood inundation of older surfaces may indicate aggradation characteristic of an active alluvial fan. Topographic separation of older varnished surfaces from younger ones may be more important in identifying inactive alluvial fans and distributary flow systems.

A diagnostic indication of fan type is progressive fining of bedload in the downstream direction in conjunction with uniform deposition of fine-grained material across the fan surface. Sediment fining in the channel bed on active alluvial fans extends to the suspended or wash load grain sizes. Fining of bedload on other landforms is not as drastic as in active alluvial fan channels, with bedload never approaching wash load diameters. The Tiger Wash and Sierra Estrella active alluvial fan sites have examples of these depositional features. Active deposition on the fan leaves very uniform topography and vegetative types.

Measurable Indices

Use of measurable indices to identify fan types had mixed success. Drainage patterns may be used to distinguish inactive and active alluvial fans, but do not differentiate distributary flow systems from active alluvial fans. Channel slope increased below the hydrologic apex on both distributary flow systems, but decreased on the active alluvial fans. The topographic crenulation index increased markedly upfan on the active alluvial fan, but remained constant or oscillated on distributary flow systems.

Comparison of recent and historic channel patterns from aerial photographs also do not distinguish active alluvial fans, because channel shifts can occur on DFAs due to stream capture or headward migration of tributaries. Stream sinuosity and channel geometry are also not conclusive, with no definite trend according to fan type. The sample size of data collection sites should be increased to confirm or reject these trends.

Hjalmarson (in press) and Kemna (1990) have published more extensive data regarding identification of alluvial fan flood hazards through measurable indices. Their data base included 39 piedmont areas throughout Arizona.

Channel Avulsions

Channel avulsions are generally thought to result from sudden filling of a channel by sediment or debris flows, although real time data describing an avulsion occurrence is lacking. Therefore, the occurrence of an avulsion is inferred from apparent migration of channel location seen in episodic photography or geomorphic soil records, or simply from the presence of a channel bifurcation.

Data collection efforts for this study revealed some information regarding so-called channel avulsions on DFAs and alluvial fans. First, channels which experience migration are not necessarily aggrading. Second, the slopes of areas with apparent channel shifts are often steeper than the reach immediately upstream. This fact may be used to identify potential shifts. Third, apparently new channels often exploit previously existing smaller channels. Fourth, these so-called avulsions tend to form on the side of the fan with the steepest cross slope. Fifth, the "abandoned" (or old) channels continue to carry flow for decades after an avulsion, and are not rapidly filled with sediment. Sixth, the pace of channel avulsions is much more gradual than is tacitly assumed by the FEMA model. Photographic and geomorphic evidence, such as stable channel patterns, surficial deposits, terrace development, and soil characteristics observed on each of the study sites indicate that avulsions change the character of fan in geologic, not engineering, time. Seventh, stream capture and headward erosion of tributaries appear to be important processes in forming new channels.

As shown in the fan identification matrix (Table 1), geomorphic parameters such as vegetation, soil and sediment characteristics, and measurable indices may be used to distinguish the types of fans found in Maricopa County. Similarity of features on different fan types sometimes makes identification difficult, as seen in the case of distinguishing avulsions and stream captures. Therefore, it is recommended that a trained geomorphologist assist in fan type identification.

Implications for Instrumentation

Design of the instrumentation network will be based in part on the findings of this data collection effort. The importance of processes such as flood attenuation, rainfall distribution, channel infiltration, and sediment transport were known at the outset of the study. Data collected in Part I of the study substantiate that these processes are important on alluvial fans in Maricopa County and the southwest. Quantification of these processes appears feasible using the FCDMC's ALERT network, based on field and other information accumulated to date. Accurate gauging of these essential processes at the alluvial fan sites is not possible without adding site-specific stations to the FCDMC's existing ALERT network.

Several factors uncovered in the geomorphic analysis bear some consideration in the design of instrumentation systems. These factors include:

- **Random Channel Location.** Establishing the frequency of channel migration and avulsions is perhaps the single most important factor for applicability of the FEMA model and development of new alluvial fan modeling techniques.

- **Stream Capture.** So-called channel avulsions apparently exploit existing channels via stream capture. Design of flow gauges should consider likely capture locations, and the likelihood that currently small channels may be suddenly enlarged or may convey more runoff than their drainage area indicates.

- **Single vs. Multiple Channel Length.** Clarification of the flow pattern and distribution between single flow paths and multiple (distributary) channels must be accounted for in design of the monitoring network.

- **Headcutting.** Headcutting on distributary flow systems causes shifts in flow patterns. Stream flow gauge design should account for the probability of this process. Instrumentation of the rate of headcutting should be considered.

- **Channel Aggradation.** Aggradation in the primary channel upstream of the hydrologic apex appears to be a diagnostic feature for flow bifurcation. Gauging of this process may yield information regarding avulsions, formation of distributary flow systems, and alluvial fan evolution.

- **Flow Distribution.** The time and spatial distribution of runoff is important to the formation of new channels, abandonment of existing channels, and attenuation of peak runoff. In addition, if a relationship can be established between flow distribution and highwater marks (i.e., do peaks on parallel distributary flow paths occur at the same time?), data collection on additional sites could be accomplished without sophisticated instrumentation.

- **Self-Formed Channels.** The spatial and temporal variation in the behavior of channel geometry should be quantified.

- **Sediment Transport.** Both bedload and suspended load must be sampled to determine bulking factor, hyperconcentration, and erosion rates.

Further consideration of geomorphic variables with respect to instrumentation will be made in Part II of the study.

Implications for Application of the FEMA Model

The evidence collected for the four instrumentation sites indicates that the FEMA alluvial fan model may not be applicable to active alluvial fans or distributary flow systems in Maricopa County. Critical assumptions of the FEMA model are directly violated, even on the most active alluvial fan sites examined. These assumptions include: 1) the channel location is random, that is, flood water is no more likely to follow an existing channel as form a new channel; 2) runoff occurs in self-formed, well-defined channels, rather than as sheet flow or overbank discharge; 3) the width and depth of the self-formed channels can be described by a function of discharge at the apex; and 4) the length of the single channel reach is a function of the ratio of the canyon slope to the fan slope.

The channel at the sites studied were not randomly located during or between successive floods. Most runoff follows the pre-existing channels. Where new channels have formed within the period of photographic, historic, or gauging record, they have tended to exploit tributaries or on-fan drainages, rather than cut entirely new channels. Flood magnitudes up to the 20-year recurrence interval have been gauged within the period of record. Historic and paleoflood evidence indicates that flood magnitudes exceeding the 50-year recurrence interval have occurred within the period of photographic record. Even when apparently new channels have formed, runoff continues to flow down the original flow path in addition to the new channel. New channels were not cut in every flood, but rather were simply passed through existing washes. Floods which exceeded channel capacity were observed at each study site except Sierra Estrella. Even in geologic time, channel movement appears to favor specific areas of the fan, rather than moving randomly over the entire fan, as evidenced by the development of distinct geomorphic surfaces below the geologic apexes.

Runoff is not limited to channel flow. Evidence at each site strongly indicates that sheet flooding is a major component of flooding, even for the most frequent floods. In large floods, the majority of floodwater may be conveyed as overbank flow parallel to existing channels.

Channels at the study sites were not strictly self-forming. Bedrock and caliche provided control of channel geometry for portions of each site. The individual or cumulative channel geometry follows no consistent relationship at a single site, let alone at all four sites. Factors such as sediment load, sediment type, soil characteristics, vegetation, fan slope, and human activity directly impact channel geometry. In addition, high water marks indicate that peak discharge at the apex is significantly attenuated downfan, probably as a result of transmission losses and channel storage. Thus, the apex discharge cannot be used to estimate peak flow throughout the fan.

FEMA's channel geometry relationship predicts that the channel will stabilize at the point where a unit decrease in depth will produce a 200-fold increase in width, and that the flow depth will equal the critical depth. (Paradoxically, fan slope is not used to determine critical depth.) Slope-area ratings of channel sections above and below the apex using highwater marks indicate that flow below the apex was generally subcritical on active alluvial fans, and supercritical on distributary flow systems, particularly where channel geometry is controlled. No evidence to support FEMA's width-depth relationship was found. Field measurements of width-depth relationships summarized in Figures 9, 18, 27, and 35 directly contradict the FEMA relations.

FEMA's single channel/multiple channel length relationship is directly contradicted by physical evidence from the data collection sites as summarized in the individual site descriptions, Figures 8, 17, 26, and 34, and Table 13. First, many alluvial fans and distributary flow areas do not have canyon reaches. Therefore, the entrenched channel slope must be used as a proxy for canyon slope. However, this approach presupposes that channel entrenchment is defined by a specific recurrence interval flood; an assumption which has no physical basis. Second, slope increases below the apex on the distributary flow systems where the multiple channel reach begins, rather than decreases, as predicted by FEMA. Therefore, the FEMA method to predict the length of the multiple channel cannot be used. Third, slope on the active alluvial fans decreases slightly, but bears no relationship to the value predicted by FEMA as seen in Table 13.

Table 13
Single/Multiple Channel Relationship

Site	Length of Single Channel (feet)	
	FEMA	Measured Value
South Mountain	1,400	600
White Tank	3,700	800
Tiger Wash	10,000	40,000
Sierra Estrella	1,400	300

Part II

Part I of the Alluvial Fan Data Collection and Monitoring Study examined the processes which affect flooding on the four alluvial fan monitoring sites. Part I of the Study also described specific needs for data collection resulting from the ongoing debate regarding alluvial fan floodplain mapping. Part II of the Study recommends types of gauging equipment and monitoring procedures needed to quantify alluvial fan processes and provide the data to develop new alluvial fan floodplain models. Order-of-magnitude cost opinions for gauging equipment and maintenance of the gauging networks are also provided in Part II.

Instrumentation and Monitoring

The following paragraphs describe alluvial fan characteristics and variables to be gauged, outline the design criteria used to evaluate types of gauges, present data collection priorities, and provide a brief description of the instrumentation and monitoring equipment recommended.

Introduction

The recommended gauging and data collection plan reflects the long-term goals of the Alluvial Fan Instrumentation and Monitoring Project, as well as the ultimate intended use for the data collected. The gauging plan was developed in several steps. These steps included:

- Determination of measurable physical parameters which can be used to quantify processes likely to occur at the alluvial fan monitoring sites.
- Assessment of the parameters used in existing alluvial fan models.
- Development of feasible means to measure these parameters.

Processes important to flooding on alluvial fans were identified by examining historical, hydrologic, and geomorphic field data of alluvial fan floods as described in Part I of this report. Physical parameters identified include the duration and shape of the runoff hydrograph, sediment transport characteristics of the flood, channel scour and bank erosion, overall fan aggradation, the spatial and temporal variation of flood flow on the fan surface, the source of floodwater within the fan watershed and from on-fan watersheds, the frequency of channel migration relative to flood frequency, transmission loss on the fan surface, variation of channel geometry across the fan surface, and sheet flow and overbank flooding. Physical parameters used in existing models include topography, flood discharge rates, channel geometry, avulsion frequency, fan boundaries, and flood frequency statistical relationships.

Specific design criteria to be used for instrument selection were developed in conjunction with FCDMC staff. A wide variety of equipment types and monitoring procedures were investigated. The investigation process included consultation with gauging experts from the USGS, the Bureau of Reclamation, the USDA Agricultural Research Service in Tombstone, Arizona and Reynolds Creek, Idaho, and the University of Arizona. A literature search yielded information on state-of-the-art instrumentation which has been successfully used in arid climates in the U.S. and overseas, but has not yet been tested in the FCDMC ALERT system. Well over a hundred types of gauges and procedures were considered. The instrumentation equipment recommended represents a blend of proven, reliable technology and new applications of recently developed techniques.

The FCDMC alluvial fan networks will be the first attempt to specifically monitor alluvial fan flooding in the United States. In addition, no real-time data collection efforts exist for key elements of this project such as distribution of flood flow between branching channels, transmission loss on alluvial fans, or bank erosion and channel change. Because this type of gauging and monitoring has never been done before, and because of the unique design criteria for the project, many of the more traditional approaches to data collection could not be used. For these reasons, it is possible that modification of the recommended equipment or procedures will be required as data collection proceeds.

Key Processes

Part I of this study identified geomorphic, hydrologic, and hydraulic variables which should be quantified to be able to understand and model alluvial fan flooding. This section briefly outlines these variables and their influence on alluvial fans. In addition, the importance of specific variables for verification of the FEMA model are also discussed. The variables to be gauged and monitored found to influence or reflect alluvial fan behavior are:

- Rainfall
- Streamflow
- Sediment Transport
- Channel Scour and Deposition
- Bank Erosion
- Channel Migration/Formation of New Channels
- Fan Aggradation/Degradation
- Transmission Loss
- Weather
- Water Temperature

Rainfall

Rainfall characteristics important for the alluvial fan study are the spatial and temporal variation, and the total rainfall depth. The spatial variation of rainfall, or where the rainfall occurs within the watershed during a storm, influences sediment and water supply to the alluvial fan. Rain which falls directly on the alluvial fan, rather than the watershed above the apex, may control development of secondary drainage patterns on the fan. These secondary drainages may affect stream capture and channel migration processes. The FEMA model does not explicitly consider the affects of flooding resulting from precipitation falling directly on the fan surface.

The total rainfall depth and temporal distribution of rainfall, or the intensity of rain at specific locations, also influences water and sediment runoff rates. A threshold of rainfall depth and intensity may exist which governs the rate and form of sediment supply, particularly from mountain slopes and overland flow sources. A secondary use for rainfall data is for the calibration of FCDMC rainfall-runoff model parameters.

Streamflow

The key streamflow characteristics to be gauged are the depth, velocity, extent, flow rate, and flow hydrograph. Streamflow is the primary geomorphic input to the alluvial fan system, and is the driving force for nearly all of the processes which occur on alluvial fans. To adequately monitor alluvial fan processes, it is important to measure these streamflow characteristics at the fan apex as well as in the channels on the fan surface itself.

Streamflow characteristics may vary widely on alluvial fans. The results of Part I of this study indicate that channel size and total flow area decrease in the downstream direction at each of the monitoring sites. In addition, channelized flow at the hydrologic apex transitions first to channel and overbank flow on the upper fan, then to sheet flow, and occasionally becomes rechannelized at or below the toe of the fan. The FEMA alluvial fan model predicts that floodwater will inundate only one portion of the fan at a time. Therefore, both the temporal and spatial changes in flood flow over the entire fan surface must be monitored.

The characteristics of streamflow on and upstream of the fan influence numerous other alluvial fan processes. These processes include bank erosion (a function of stream velocity and hydrograph duration), sediment transport (a function of velocity, depth, and volume), aggradation (a function of velocity), soil formation (a function of depth and extent of flooding), and vegetative growth (a function of wetting frequency).

Sediment Transport

The sediment transport characteristics to be gauged are the spatial and temporal variation of sediment concentration and transport rates upstream and downstream of the apex over the duration of the flood hydrograph, the thresholds of movement for coarse sediment sizes, the temporal variation in sediment concentration, and the occurrence of hyperconcentrated or debris flow transport processes. Sediment transport is one of the key processes which distinguish alluvial fan flood hazards from other flood hazards. Sediment transport controls (and is the result of) aggradation, degradation, channel migration, bank erosion, channel avulsions, headcutting, channel geometry, and apex location.

The role of sediment transport in the formation and evolution of alluvial fans may be adequately understood from a geologic perspective, but is poorly understood from an engineering standpoint. Little data are available from which to determine sediment bulking factors, assess avulsion potential, delineate debris flow hazard zones, and evaluate other sediment hazards, particularly for ephemeral streams. The FEMA model does not explicitly consider the influence of sediment transport on alluvial fan flooding[9]. Rather, the FEMA model addresses some of the potential affects of sediment transport through the use of an "avulsion coefficient." Data collected for this study also may be used to calibrate sediment transport parameters on other ephemeral streams in Maricopa County.

Channel Scour and Deposition

The key channel scour and deposition characteristics to be gauged are the magnitude, extent, and location both above and below the apex of the fan, relative to the water and sediment transport rates. Channel scour and deposition control (or are the result of) sediment supply, bank stability, channel migration, avulsion, and overall fan aggradation or degradation processes on the fan. Channel scour is thought to be a function of velocity and duration of flow, sediment supply, and soil and vegetation characteristics. Because fan runoff occurs in alluvial channels, accurate streamflow gauging requires monitoring of flood scour and deposition to construct realistic rating curves.

Channel scour and deposition are geomorphic expressions of the water and sediment transport characteristics of an alluvial fan. The occurrence and scale of scour and deposition in the channels above and below the fan apex in part define whether the fan is active or inactive. In general, deposition dominates active fans and scour dominates on inactive fans. The spatial variation of scour and deposition within a single cross section on a fan channel may define the method of avulsion, channel migration, and sediment movement. In addition, quantification of scour and deposition will help refine

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[9] FEMA does require sediment transport studies on alluvial fans as part of the Letter of Map Revision process. It is unclear at this time how these sediment analyses are used to delineate floodplain boundaries.

estimates of peak discharge by allowing consideration of water transport below the post-flood bed elevation, and by providing an estimate of velocity variation within the cross section. Finally, channel scour and deposition data collected may also be used to set bank protection toe down depths, freeboard requirements, and safe set backs on non-alluvial fan channels elsewhere in Maricopa County.

Bank Erosion

The key bank erosion characteristics to be monitored are the extent and location of erosion relative to water and sediment transport rates. Bank erosion is controlled by water velocity, flow duration, soil and vegetative characteristics, and sediment transport. Bank erosion may be the mechanism for channel migration, avulsion, and other fan processes. Bank erosion, or channel width, is also one of the key parameters of the FEMA model. Accurate quantification of this parameter will be essential to developing and evaluating new models.

Bank erosion characteristics may be used to define fan type. Bank erosion may be more extreme and pervasive on active fans. On inactive fans and distributary flow systems, bank erosion is probably more localized. The data collected for this study may also be used to estimate erosion hazards on alluvial streams throughout Maricopa County.

Channel Migration/Formation of New Channels

The key channel migration characteristics to be monitored are the rate, extent, and nature of channel migration with respect to flood frequency and sediment transport. The formation of new channels during floods is the fundamental element of the FEMA model. However, no real-time or flood-specific data currently exist on alluvial fan channel migration rates or frequencies. Therefore, the data collected for this study may form the basis of analysis for future studies. The rate of channel migration is the key diagnostic characteristic which distinguishes active alluvial fans from other types of alluvial fans.

This element of the gauging effort will provide data to help resolve questions such as: Does channel migration occur as avulsion or as stream capture of existing on-fan drainages? Does channel migration/avulsion occur in every flood event on active alluvial fans or is there a threshold of sediment and/or water flow which must be exceeded? What limits the extent of channel movement within engineering time, chance or physical processes/barriers?

Fan Aggradation/Degradation

The rate and extent of overall fan aggradation outside of channel areas will be monitored during the data collection phase of the project. The rate of overall aggradation, or deposition, on the alluvial fan surface may influence the rate of channel migration, bank erosion, flow distribution, and channel geometry, as well as other fan processes. Fan aggradation or degradation is also a diagnostic characteristic for the identification of fan type. Active alluvial fans and DFAs are aggrading landforms, but active alluvial fans aggrade more rapidly (in geologic time) over a greater portion of the fan surface than DFAs.

Transmission Loss

Measurement of transmission losses lumps together two distinct components, infiltration, or loss of water through soil layers, and channel storage, or decrease in peak flow rate due to temporary storage of floodwater in the channel and overbank. Both of these hydrologic components are important and should be disaggregated if possible. Transmission losses may occur in at least two zones which strongly influence alluvial fan processes. The first zone is the alluvial reach located between the bedrock controlled canyons and the hydrologic apex. The second zone is within the channel and overbank areas on the fan surface downstream of the hydrologic apex. Because water flow provides the energy for most fan processes, any decrease in flow rate due to transmission losses may significantly impact the behavior of the fan.

The FEMA model does not currently account for transmission losses on the fan surface or in the channels above the apex. Consideration of transmission losses on fan surfaces is discussed in a recent paper by Mifflin (1991). Field evidence described in Part I of this study indicates that transmission losses totalling several thousand cubic feet per second occurred on the Tiger Wash alluvial fan in a recent flood.

Transmission loss is a highly site-specific parameter. Independent variables such as soil type, caliche formation, depth to bedrock, channel geometry, channel capacity, hydraulic roughness, and overbank area act together to control the loss rate. Therefore, attempts to extrapolate transmission loss data from this study to other sites should reflect the influence of these variables.

Weather

Weather characteristics which are important for understanding alluvial fan processes include antecedent rainfall, and evapotranspiration factors such as temperature, wind speed, and solar radiation. Regional weather characteristics are also important for establishing rainfall runoff relationships, calibrating point rainfall depths to areal distributions, and estimating sediment supply rates. Weather parameters to be gauged include air temperature, wind speed, and solar radiation. Other weather parameters such as storm tracking, relative rain intensity, soil moisture, and regional characteristics should also be monitored and recorded for specific storms. These regional weather data sources will shorten response time for manual monitoring procedures, and will supplement and help evaluate real-time data.

Water Temperature

The fluctuation of water temperature during flooding will be gauged. Water temperature affects sediment transport rates. A decrease in water temperature generally increases bedload transport and decreases suspended load transport. Because of the influence of sediment transport on alluvial fan processes, water temperature, which directly influences sediment transport, should be measured at least at one point on the fan, preferably at the apex. Water temperature also affects the performance of pressure transducer streamflow gauges.

Data Collection Priorities

Quantification of the alluvial fan flooding variables described in the preceding section is needed to develop and evaluate accurate new models and understand alluvial fan flooding. This section describes the relative priority of gauging these alluvial fan parameters. The prioritization scheme reflects the project goals. The prioritization scheme may be used to develop different project cost levels by successively eliminating lower priority instrumentation types until a given budget level is achieved.

Topography (1st Priority). Topographic mapping, in conjunction with detailed post-flood field investigations, can be used to estimate most of the other key alluvial fan variables described earlier. For instance, using detailed topography, peak flow rates can be estimated from flood debris elevations and Mannings' rating of channel sections. Changes in channel location, new channel formation, and bed or fan elevation also can be measured by resurvey or by comparison with new mapping. Detailed topography also provides a failsafe backup to more temperamental electronic gauging systems. Therefore, detailed accurate topography of the alluvial fan surface which covers the full extent of potentially flooded surfaces, including portions of the channel above the apex is the most essential element of the gauging and monitoring network.

Reliance on topographic mapping alone requires commitment to extensive field work after each flood and does not provide information regarding the rate of change during floods. That is, the results of fan flooding can be measured, but the process and cause may remain unknown. In addition, the level of accuracy possible from use of only topographic mapping may not be sufficient to support the development of new models. Therefore, other use of other gauging equipment is highly recommended.

Streamflow (2nd Priority). Because the primary goal of the study is to understand how flooding occurs on the types of alluvial fans found in Maricopa County, installation of streamflow gauges is the second priority for the gauging networks. Of the streamflow gauges proposed, gauges at the apexes are the highest priority. Streamflow gauges located above the apex are of lower priority. If full instrumentation of certain sites is delayed, a stream gauge should be placed at the hydrologic apex in the interim.

Channel Migration (3rd Priority). Monitoring of channel migration and new channel formation is the third priority for the project. The rate and frequency of changes in channel position define the type of flood hazards which distinguish different types of alluvial fans, as well as distinguish alluvial fan flood hazards from riverine flood hazards.

Rainfall (4th Priority). Rainfall gauging is the next priority for gauging. Since rainfall precedes runoff, real-time rain gauging provides flood warning and allows lead time for field crews to be in position to observe alluvial fan flood flows. At minimum, two rain gauges should be placed on a fan to distinguish on-fan storms from watershed storms.

Transmission Loss (5th Priority). Transmission loss gauging is the next priority for instrumentation. Reduction of peak runoff rates on alluvial fans can be significant, sometimes resulting in complete dissipation of a flood wave as it crosses the surface of the fan. Since flood flow controls most of the other alluvial fan processes, the rate of transmission loss profoundly affects how those processes occur.

Sediment Transport (6th Priority). Sediment transport gauging is the next priority for the instrumentation phase of the project. The role of sediment movement in channel migration, avulsion, and scour processes may be extremely important for defining fan flood hazards. In addition, measurement of sediment bulking will provide data to help estimate water discharge rates. Sediment discharge measurements also have important applications unrelated to the specific goals of this project.

Scour and Deposition (7th Priority). Channel scour and deposition measurement is important for accurate calibration of water discharge estimates and for monitoring of channel change and avulsions. Therefore, installation of scour gauges is the next priority for the instrumentation phase.

Weather (8th Priority). Weather and water temperature instrumentation is the next priority for the proposed instrumentation. Although ranked low in priority, these gauging and monitoring systems will provide valuable information needed for the long-term operation of the networks. Storm tracking, general weather data, and soil moisture data to be gathered using NEXRAD, NOWrad, and infrared remote sensing are important for appropriate interpretation of the other data collection and for providing adequate lead time for flood response.

Design Criteria

General design criteria were established by which to evaluate specific types of instrumentation. The instrumentation recommended demonstrated the following characteristics:

- Reliability
- Low Liability
- Cost-effectiveness
- Resistance to Vandalism
- Unobtrusiveness
- Geomorphic Passivity
- Automated Operation

Reliability

The recommended instrumentation network will give preference to proven technology that has been successfully field tested in an environment similar to the alluvial fan monitoring sites. Gauges installed on the alluvial fan sites can be expected to experience: (1) temperature fluctuations from 10° to 130° F, (2) dry streambed conditions more than 90% of the time, (3) dusty atmospheric conditions, (4) streamflow with high dissolved solid concentrations, (5) high velocity flow resulting in coarse sediment transport and high suspended sediment concentrations, (6) flash floods with times to peak of less than one hour, and (7) long-term and short-term changes in channel geometry. The recommended gauges must have a proven record of success under these types of conditions.

Reliability of the network will be enhanced through the use of parallel, or backup, instrumentation systems wherever feasible. For instance, streamflow data will be collected primarily by pressure transducer gauges. However, crest stage gauges will also be installed to help calibrate pressure transducers and provide backup estimates of peak stages if the transducers fail. Field survey of highwater marks will provide a third level of backup for peak flow estimates. The crest stage gauges can provide the information for slope-area measurements of peak flow. Other backup systems are described in detail elsewhere in this report.

Finally, use of on-site data loggers will be used in addition to, or in place of, telemetry units to prevent transmission failures from aborting data collection during a flood. Key parts of the networks will remain telemetered to provide early flood warning and real-time monitoring. The telemetry units recommended have the capability to continue to collect and store up to 32k bytes of data in the event of a transmission failure.

Low Liability

The presence and operation of the instrumentation system must not create unnecessary liability exposure for the FCDMC or for the property owner. Gauges which could be an attractive nuisance, or creates significant hazards for hikers, horse riders, off-road vehicles, or livestock will be avoided. In short, it should not be easy to trip over, fall off, or crash into the gauges.

Cost Effectiveness

The design of the instrumentation system will attempt to balance cost-effectiveness with the other design criteria and project goals. System design attempted to achieve a level of accuracy appropriate for the study goals and the budget. Varying levels of cost may be obtained by phasing the instrumentation installation or by eliminating types of instrumentation according to the prioritization scheme outlined elsewhere in this report.

Resistance to Vandalism/Unobtrusiveness

The recommended gauging system will attempt to minimize the potential for vandalism by using unobtrusive equipment which blends in with the natural environment. Equipment will be encased or sealed where possible using established techniques. The presence of the instrumentation should not attract attention or hinder existing or future uses of the property on which it is installed.

Geomorphic Passivity

The presence of the instrumentation on the alluvial fan must not significantly alter the overall natural hydrologic, hydraulic, or geomorphic process[10]. That is, gauging equipment cannot restrict the stream's ability to adjust bed, bank, or floodplain geometry in a manner that could significantly affect the behavior of the alluvial fan.

Automated Operation

Because of the remote location of the alluvial fan data collection sites, and because floods may not occur during normal working hours, the instrumentation systems should be designed to function without direct manual input. The systems will be designed to allow manual measurements where appropriate. However, preference is given to automatic data collection which is transmitted to a central data base via telemetry, or is collected manually after a flood.

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[10] This discussion recognizes the applicability of the Heisenberg Principle, that the act of observation changes the system in some manner.

Recommended Instrumentation

Given the instrumentation design guidelines and the processes to be gauged and monitored, the following instrumentation plan is recommended for each key process. Lists of gauging and monitoring equipment considered and recommended are shown on Tables 14 and 15. Descriptions of instrumentation plans for each of the four study sites are provided in the next section of this report.

Rainfall

Three types of rainfall gauges are used in the FCDMC ALERT and volunteer network, telemetric tipping bucket gauges, weighing recorders, and manual "clear view" depth gauges. Tipping buckets and clear views are recommended for precipitation measurement at the alluvial fan sites.

The tipping bucket rain gauge is the standard ALERT instrument used for measuring rainfall rate and volume. Rain enters the gauge through a large upper funnel and passes through debris filtering screens (Figure 40). A small low funnel directs the water into one of two tipping buckets inside the gauge. The bucket tips when a specified volume of water has been collected. As the bucket tips, it causes a switch closure, and brings a second bucket into position under the funnel ready to repeat the cycle. When the measure bucket tips, the collected water drains out through discharge ports in the side of the gauge. The switch closure sends an electronic signal which can then be sent to a data logger or to a central data base via telemetry.

Clear view gauges are manual reading gauges made of transparent material. Typically, they are attached to a vertical support which does not obstruct rain falling into the gauge. Clear view gauges are read and emptied manually after each rainfall or at specific time intervals during a storm.

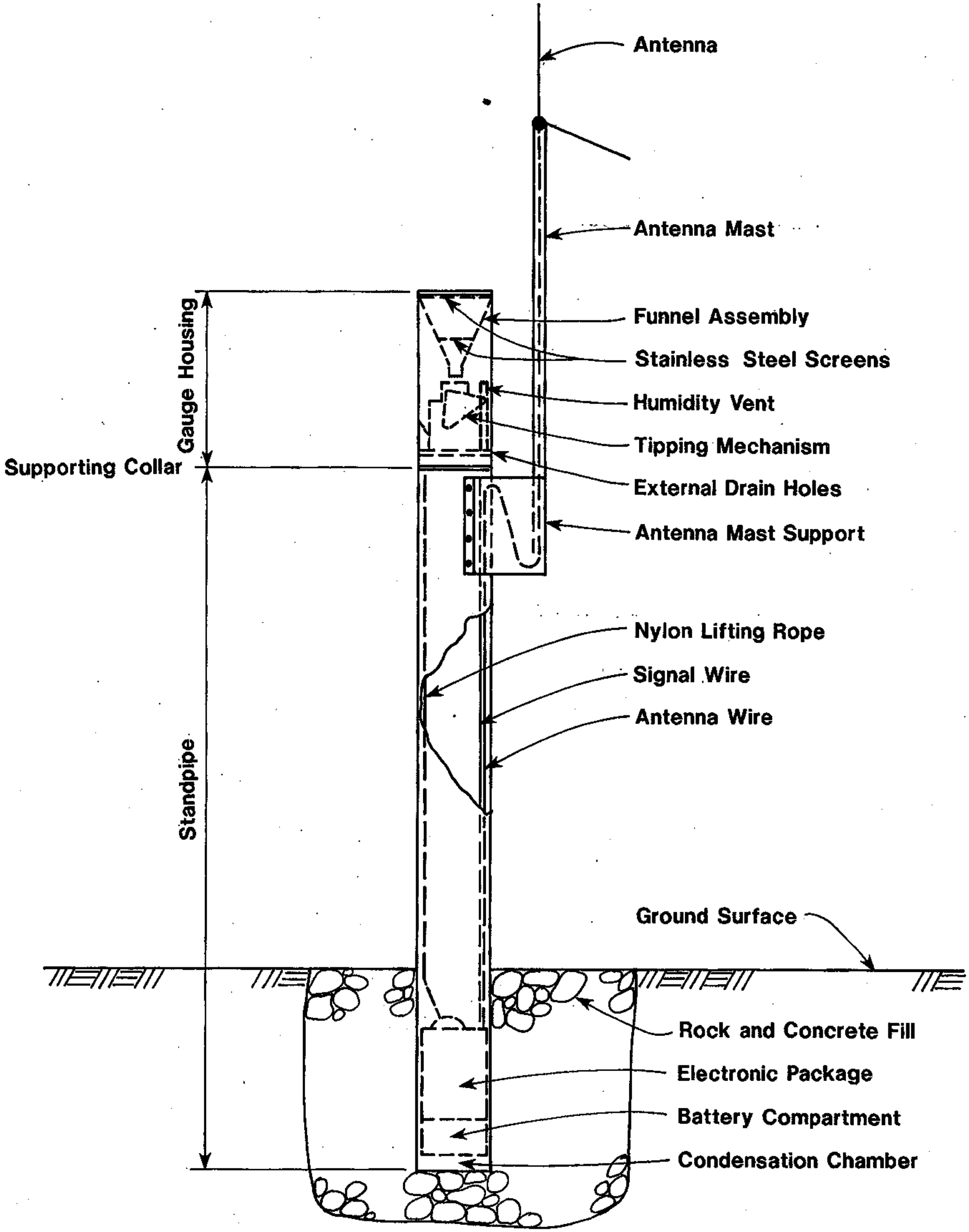
Tipping bucket and clear view gauges have been successfully used by the FCDMC and throughout the world for several years in a wide variety of applications. They meet all of the design objectives described earlier as well or better than other types of rainfall gauges investigated. Telemetered tipping bucket gauges should be used where line of site to repeater stations is available. Tipping buckets with data loggers are recommended where line of sight is not available. Clear view gauges are recommended at sites with easy access to provide supplemental rainfall depths in areas between tipping bucket gauges.

Tipping bucket precipitation gauges should be protected with Nipher-type shields to improve rain catch efficiency. Where the use of rain shields is not feasible, the rain catch measured should be adjusted using the graph shown in Figure 41.

Table 14
Summary of Instrumentation Types Investigated

Rainfall Tipping Buckets with Nipher Shields Clear Views with Oil Film NEXRAD Radar (Doplar) Weighing Buckets Float Buckets Remote Sensing/Satellite Data	**Streamflow** Pressure Transducers Float Sensors Crest Stage Cork Recorders Flume Control Section Weir Control Section Drop Box Weirs Shaft Encoders Ultrasonic (Acoustic) Sensors Optical Sensors Electromagnetic Sensors Tracer Dilution (Dyes, Salts) Laser Doppler Anemometer
Sediment Drop Box Bedload Trap Painted Boulders (d50 < trap inlet) Turbidimeter U.S. U-59 Suspended Sediment Sampler Indirect from PT/Float Comparison Nuclear Radiation Ultrasound Scattering Luminescent Bedload Tracking Acoustic Bedload Sensors Suspended Sediment Capacitance Manual Measuring Equipment U.S. DH-50 Suspended Sediment Sampler (Recommended) U.S. BMH-60 Hand Line Bed Material Sampler (Recommended)	**Transmission Loss** Streamflow Instrumentation In-line Piezometers Dual-Ring Infiltrometer Tests Soil Testing Geophysical Logging Hydrologic Modeling
Scour/Deposition Vertical Scour Chains Horizontal Scour Chains Scour "Doughnuts" Surveyed Transects Digital Elevation Model/GIS Software	**Bank Erosion** Surveyed Transects Aerial Photography Digital Elevation Model/GIS Software Satellite Imagery Aerial False Color Imagery Airborn Laser Profiler
Channel Migration Aerial Photography Digital Elevation Model/GIS Software Satellite Imagery Aerial False Color Imagery Airborn Laser Profiler	**Fan Aggradation** Surveyed Transect Digital Elevation Model/GIS Software
Weather ALERT Weather Station NEXRAD Radar (Doplar) Submersible Water Temperature Probe	

Table 15 Summary of Instrumentation Types Recommended	
Rainfall Tipping Buckets with Nipher Shields Clear Views with Oil Film NEXRAD Radar (Doplar) NOWrad Radar	**Streamflow** Pressure Transducers Float Sensors Crest Stage Recorders Infrared Remote Sensing (Optional)
Sediment Drop Box Bedload Trap Painted Boulders (d50 < trap inlet) Turbidimeter U.S. U-59 Suspended Sediment Sampler Indirect from PT/Float Comparison U.S. DH-59 Susp. Sed. Sampler U.S. BMH-60 Bed Material Sampler	**Transmission Loss** Streamflow Instrumentation (PT & Float) Piezometers Wells Dual-Ring Infiltrometer Tests Soil Testing Geophysical Logging Hydrologic Modeling
Scour/Deposition Vertical Scour Chains Horizontal Scour Chains Scour Collars Surveyed Transects Digital Elevation Model/GIS Software Infrared Remote Sensing	**Bank Erosion** Surveyed Transects Aerial Photography Digital Elevation Model/GIS Software
Channel Migration Aerial Photography Digital Terrain Model/GIS Software	**Fan Aggradation** Surveyed Transect Digital Terrain Model/GIS Software
Weather ALERT Weather Station NOWrad Radar NEXRAD Radar (Doplar) Submersible Water Temperature Probe	



Note: Antenna Not Used with Data Logger.

Figure 40

Precipitation Gauge Tipping Bucket Assembly

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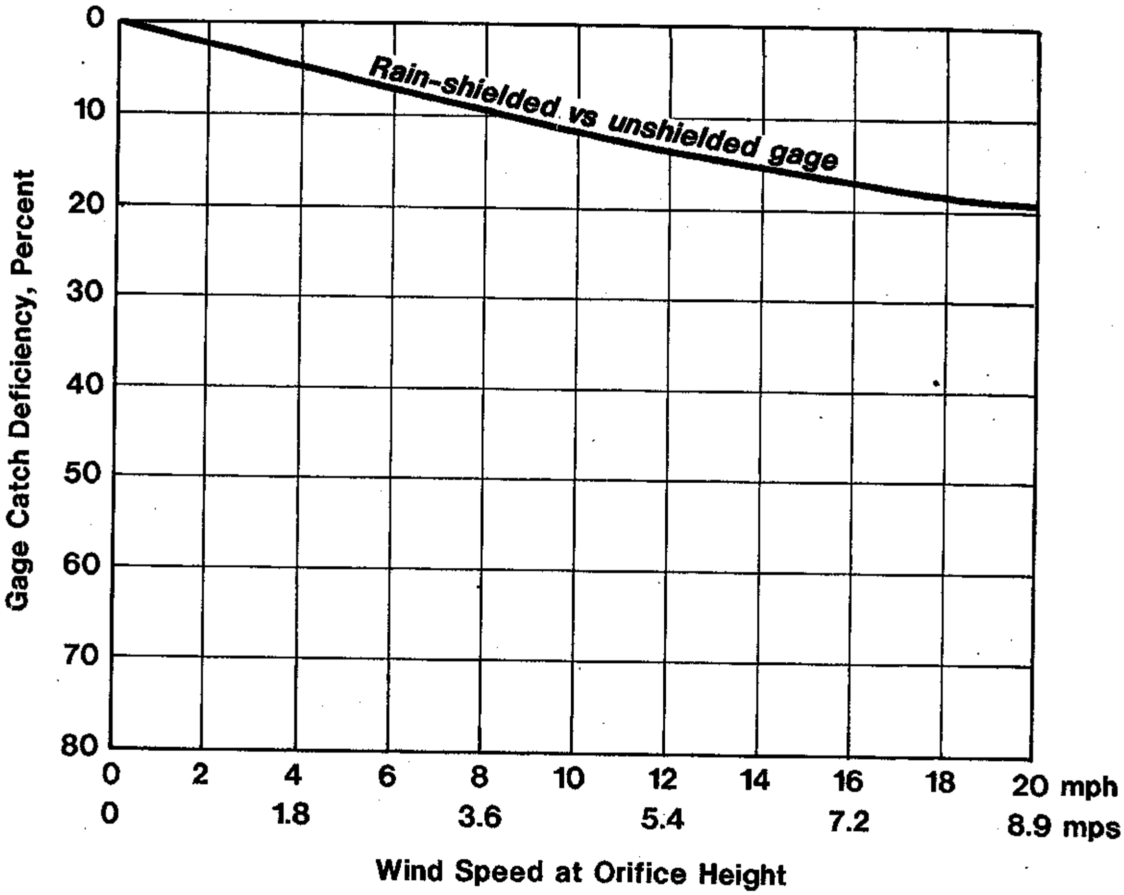


Figure 41

Unshielded Precipitation Gauge Catch Efficiency

Other types of rainfall monitoring equipment investigated, but not recommended, include drum recorder weighing and float gauges, and remote sensing. Drum recorders cannot provide real-time data directly input into a computer data base. Instead, rainfall records are printed on drums that are manually collected, interpreted, and entered into a data base. This process often results in a time lag of months to years before data become available. Weighing and float gauges must store the rainfall catch, and must be serviced more frequently to prevent overtopping, or error from evaporation losses. Rainfall measurement by remote sensing using radar or satellite data is expensive and has not yet obtained the resolution required to accurately monitor small watersheds.

Streamflow

The FCDMC ALERT network and FCDMC cooperative gauging efforts use several types of instruments to gauge streamflow depending on site characteristics and the intended use for the data. The instrumentation methods include manual and automated devices, and use velocity- and stage-based techniques. For the alluvial fan data collection study a combination of stage-based gauges are recommended. The recommended instrumentation includes telemetered pressure transducers and float sensors, and non-recording crest stage gauges.

Pressure transducers (PT) measure the pressure of the floodwater and sediment mixture exerted on a sensor submersed at a known elevation in the stream (Figure 42). The PT makes periodic instantaneous pressure readings which are translated into electronic signals and transmitted to a computer data base. After correction for temperature, pressure readings can be translated into stage. Stage is then related to discharge through a rating curve for the gauging reach.

PT gauges are proven technology, reliable if properly installed and maintained, vandal-resistant, unobtrusive, and inexpensive, and have low liability. The long-term accuracy of PT has been questioned by many investigators. PT have successfully provided an acceptable level of accuracy for other gauging applications in Maricopa County and other communities in the southwest when properly maintained. Where greater gauging accuracy is required for this study, float sensors are recommended to supplement PT measurements.

Float sensors also translate stage into discharge (Figure 43). However, float sensors measure water surface elevation rather than depth. Float gauges consist of a float device attached to a chain or tape. The float assembly is installed in a stilling well designed to minimize the affect of water surface fluctuations, or wind. As the float rises, electronic signals representing water surface elevation are sent to a computer data base. Water surface elevation may then be related to discharge through a rating curve for the gauging reach.

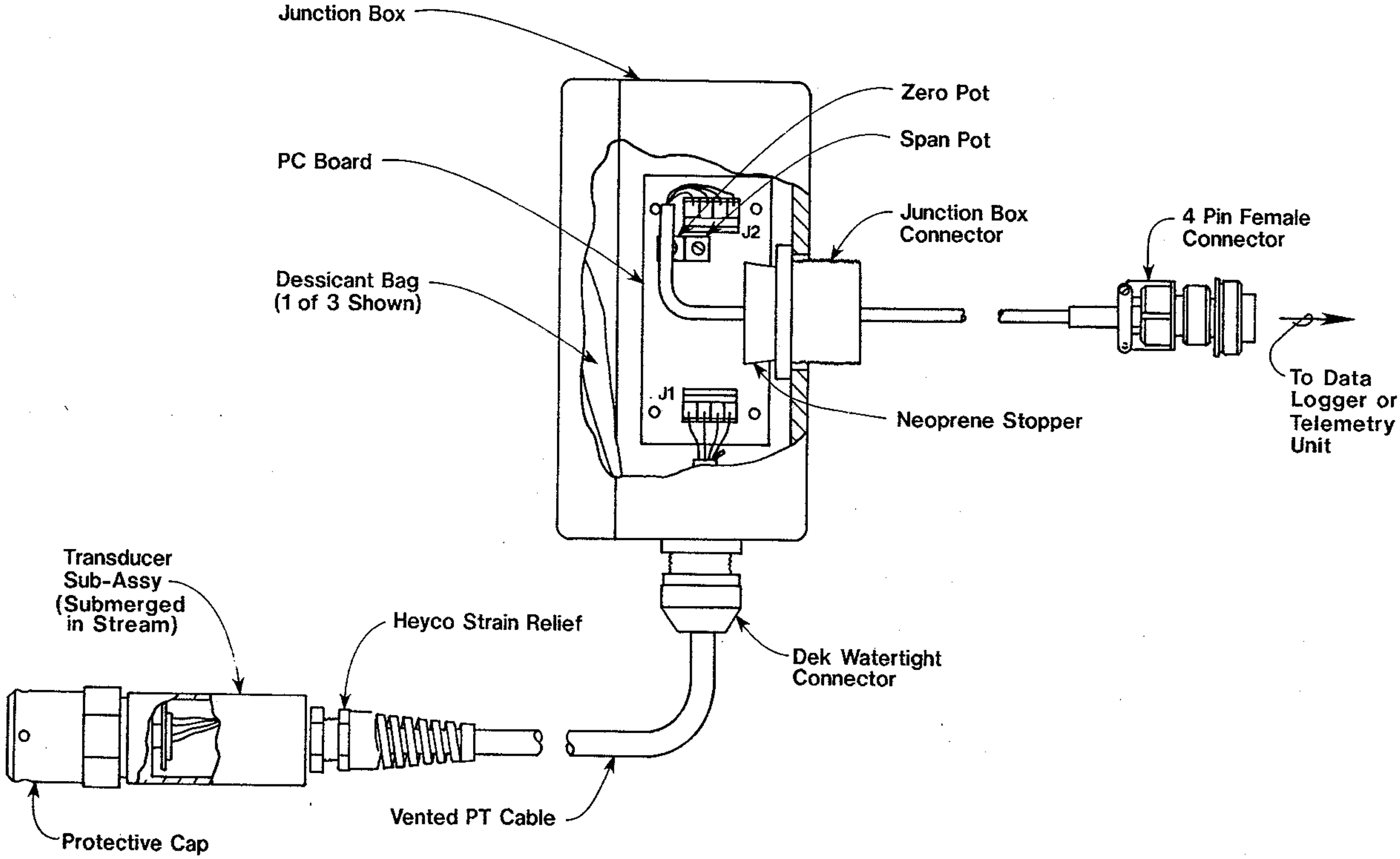


Figure 42

Pressure Transducer Unit

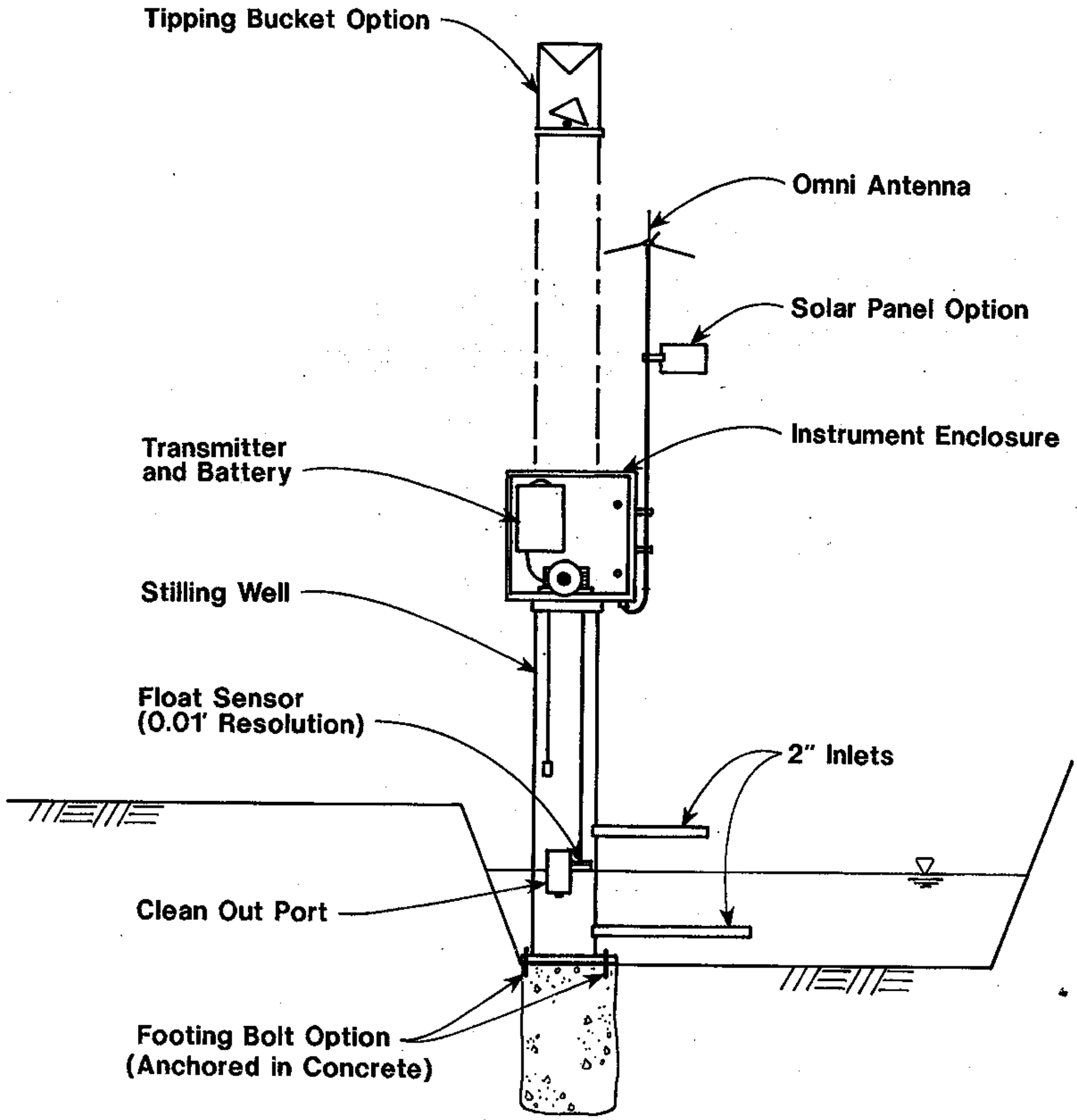


Figure 43

Float Gauge Installation

Float gauges have been successfully used in arid regions for many years. Float sensors have the reputation of being more accurate than PT gauges, and are very reliable. Because a stilling well must be constructed in the stream, float gauges tend to be more obtrusive, more susceptible to vandalism, and more expensive than PT gauges. The stilling wells have a tendency to fill with silt, reducing the accuracy of measurement on the descending limb of the flood. Float sensors are recommended where greater accuracy is required, such as in transmission loss monitoring reaches. PT and crest stage gauges will be used with the float gauges to provide backup data. Both PT and float sensors are geomorphically passive.

Crest stage gauges normally consist of a wooden stake inside a vertically mounted metal pipe, an intake device, and a reservoir of granulated cork (Figures 44 and 45). The cork floats on the water surface inside the pipe as floodwater enters through the pipe intake, and the cork adheres to the board. After a flood, the board is removed and the peak stage of the flood is estimated from the maximum elevation of the cork on the board. Two types of crest stage gauges are recommended for this study. First, longer crest stage gauges will be used for streamflow measurement in the channels above the apex. Shorter crest stage gauges will be installed in transects across the fan surface below the apex to measure overbank and sheet flooding depths.

Crest stage gauges are extremely reliable gauges if properly installed and maintained. They are very inexpensive, durable, unobtrusive, resistant to vandalism, relatively accurate, and geomorphically passive, and have low liability. Because they are manually read, they must be serviced after each flood, or data from smaller floods may be erased by later, larger events.

Three combinations of the recommended streamflow instrumentation types are recommended for three applications at the fan sites. Streamflow gauging in well defined streams above and below the hydrologic apexes will be performed by PT and crest stage gauges (Figure 45). The PT should be sited using the criteria outlined later in this report. An array of crest stage gauges, two upstream and two downstream of the PT should be installed at the ends of the PT rating reach. Another crest stage gauge should be installed on the bank opposite the PT or float gauge. The crest stage gauges will be used to check the PT peak stage measurements and to provide an energy slope. In the transmission loss reaches, PT and crest stage gauges will be supplemented by float gauges. Transmission loss instrumentation is described below.

Short crest stage gauges will be used to measure peak stages in poorly defined channels and sheet flow areas on the fan surface. These shorter crest stage gauges should be located at uniform intervals in transects extending across the width of the fan. The crest stage gauge transects will help determine where flooding occurs on the fan, but will not provide temporal flow characteristics. For this reason, at least two PT gauges are recommended for installation along the more prominent channels on the fan surface below the hydrologic apex to help define the timing of runoff on portions the fan surface.

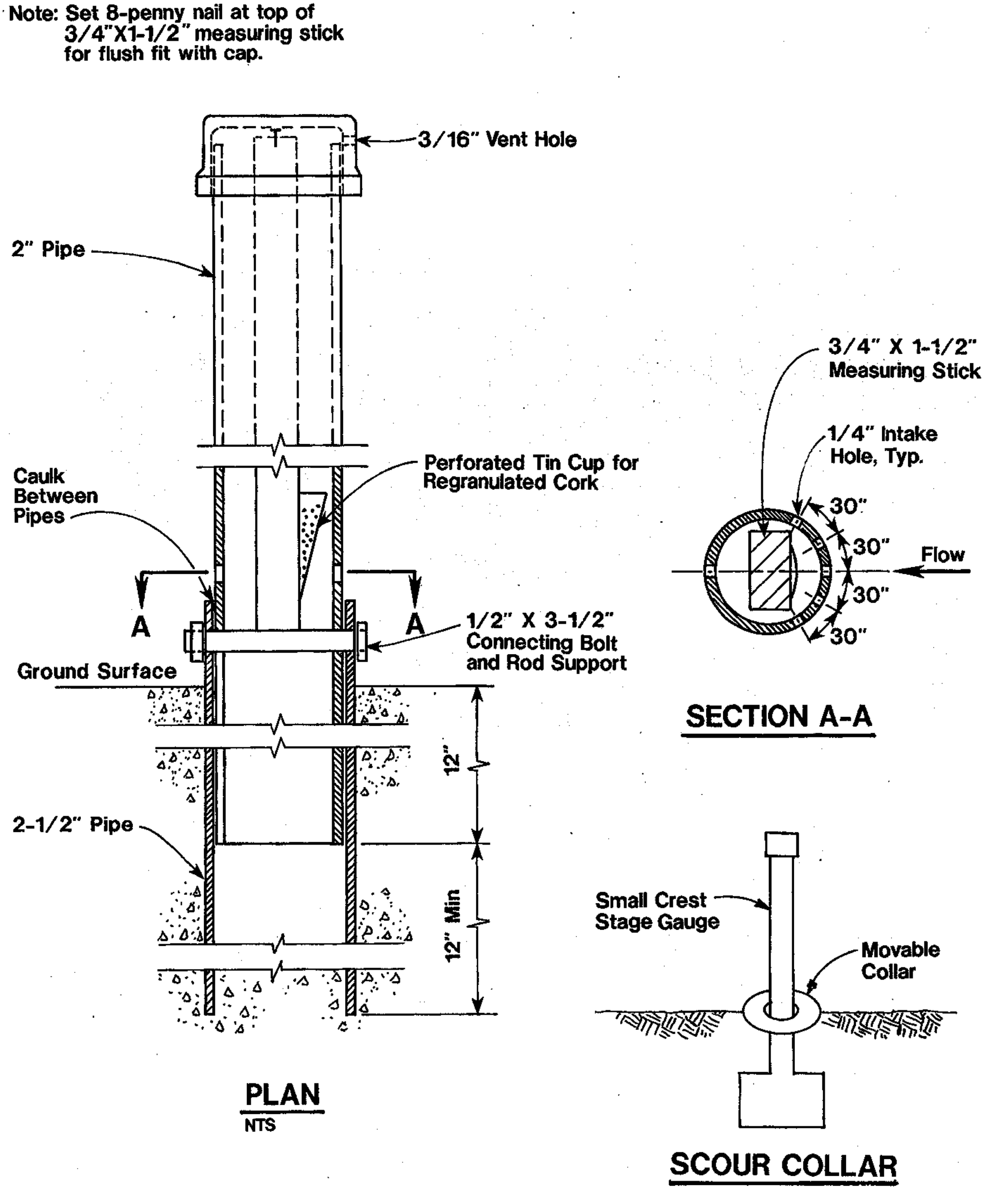
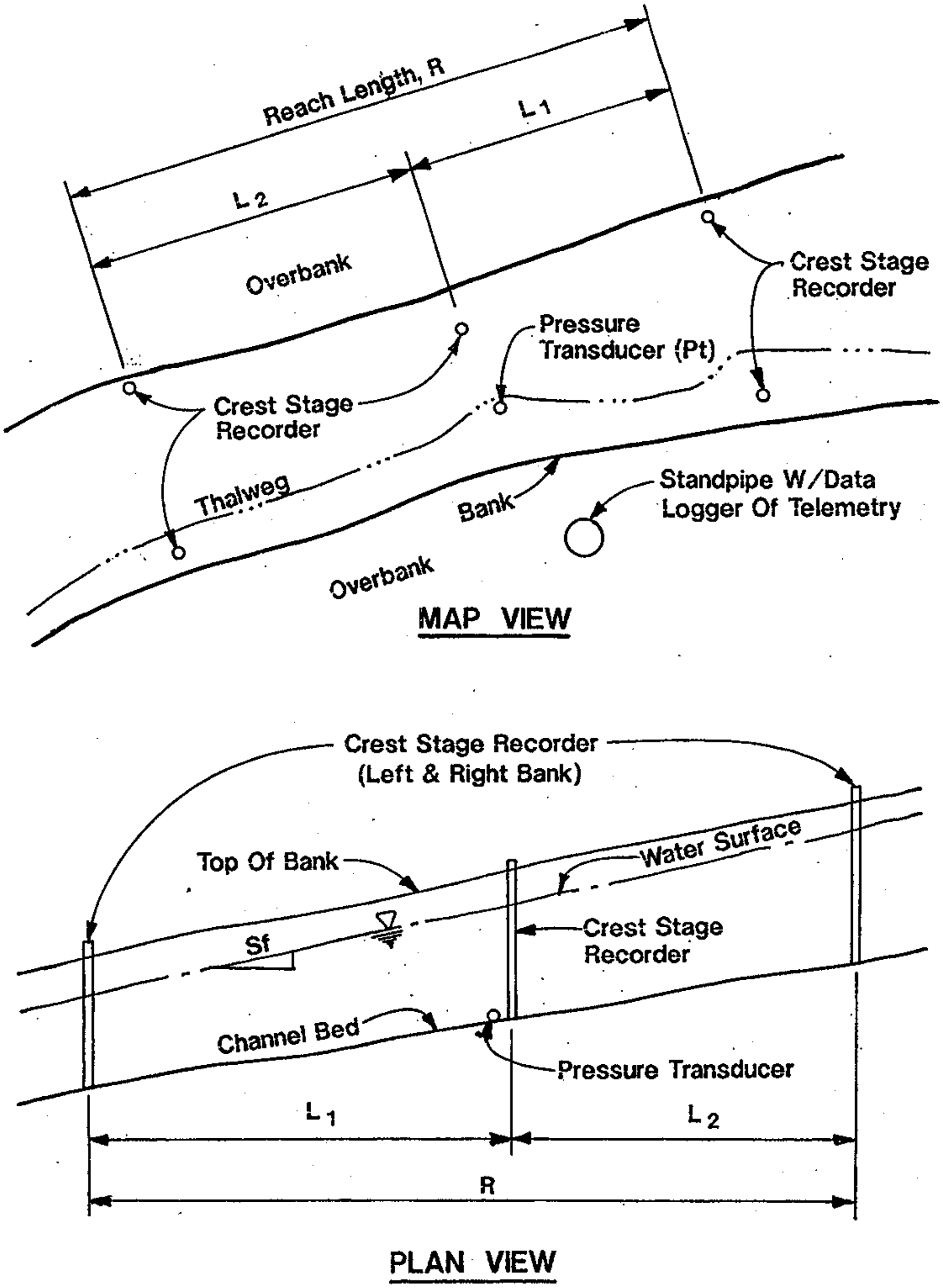


Figure 44

Standard Crest Stage Recorder Installation



Notes:

$L_1 - L_2$ = Distance Of Straight Channel ≅ 5 x Width Of Channel At Pressure Transducer Guage

R = Reach Length ≅ (Minimum) 75 x Channel Depth At Pressure And R > 1/Sf

Sf = Water Surface Slope

Figure 45

Typical Stream/Guage Installation

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Most of the proposed streamflow gauging sites do not have bedrock control. In order to reduce potential scatter in stage-discharge conversions due to shifting control, sediment transport, channel scour and deposition, and bank erosion will also be gauged and monitored at the streamflow gauging reaches.

In addition to more traditional gauging methods described above, Digital Terrain Models (DTM) will be prepared in electronic formats to assist in reconstruction of flood events. DTMs are electronic files containing 3-dimensional coordinates for a grid of points over the mapped area. These models may be used in the future with discharge data for the development and application of 2- and 3-dimensional hydraulic computational models.

Several other approaches to stage measurement were considered, but do not meet the design criteria for this project. First, construction of flumes or weirs could eliminate uncertainties in channel geometry, and provide more accurate discharge estimates, but would create excessive liability, would disturb natural processes of channel change, might not withstand flood forces, and would certainly exceed the project budget. Scour holes which would form downstream of flumes in alluvial channels would present a hazard to recreational traffic in the washes. The size of flume needed for some fan streams would match some of the largest flow measurement flumes ever built. Finally, permission to construct and maintain the flumes would be difficult to obtain since none of the sites are located on property owned by the FCDMC.

Second, manual collection of discharge data may be possible at some of the study sites, but has several important limitations. Manual velocity measurements describe only one part of the hydrograph. Given the likelihood of flash flood conditions, it is improbable that a crew could adequately describe a velocity transect of the channel before the flow rate significantly changed. Unless the flood lasted longer than one hour, it is unlikely a crew could reach a site in time to measure the peak discharge. Given the probable velocities and sediment loads, safe measurement of a large flood would probably require a gondola system. Finally, manual collection of data is not practical in sheet and overbank flow areas.

Dilution-based measurement techniques, such as dye or salt injection are appropriate for steady flow conditions where only a single flow rate is of interest. Also, the high dissolved solid content and suspended sediment transport loads of the study site streams would render dilution techniques ineffective even if a single flow rate were desired.

Automatic measuring techniques investigated, but not recommended, included velocity measuring devices such as acoustic, optical, and metered vanes. Measurement of velocity by in-stream flow meters which could reliably withstand the site water and sediment flow conditions without altering the geomorphology have not yet been developed. The cost, liability, and obtrusiveness of such structures would not meet the established design criteria. Out-of-stream velocity measuring devices such as optical and acoustic sensors do not meet design criteria of proven reliability, cost effectiveness, and resistance to vandalism. Ultrasonic devices have not been adequately field tested in an Arizona environment.

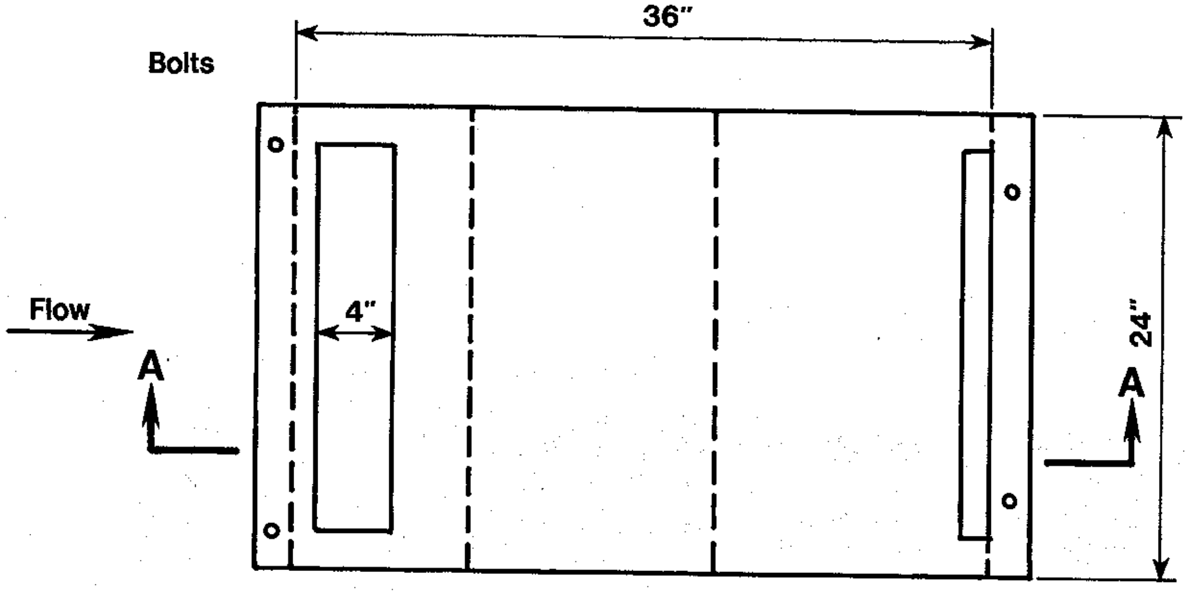
Sediment Transport

The FCDMC currently does not have sediment samplers in its ALERT network. However, a new FCDMC water quality monitoring program developed by the USGS will use manual samplers and an automated pump sampler to measure the suspended load component of the total load. For this study, drop box bedload traps and painted marker boulders are recommended to gauge bedload movement. In addition, turbidimeters, U.S. U-59D suspended sediment samplers, and indirect measurements from PT/float sensor comparisons are recommended to gauge suspended sediment transport. If manual samples are desired to calibrate automated sample measurements, a U.S. DH-59 suspended sediment sampler and a U.S. BMH-60 hand line bed material sampler may be used, although in-stream manual sampling is not recommended.

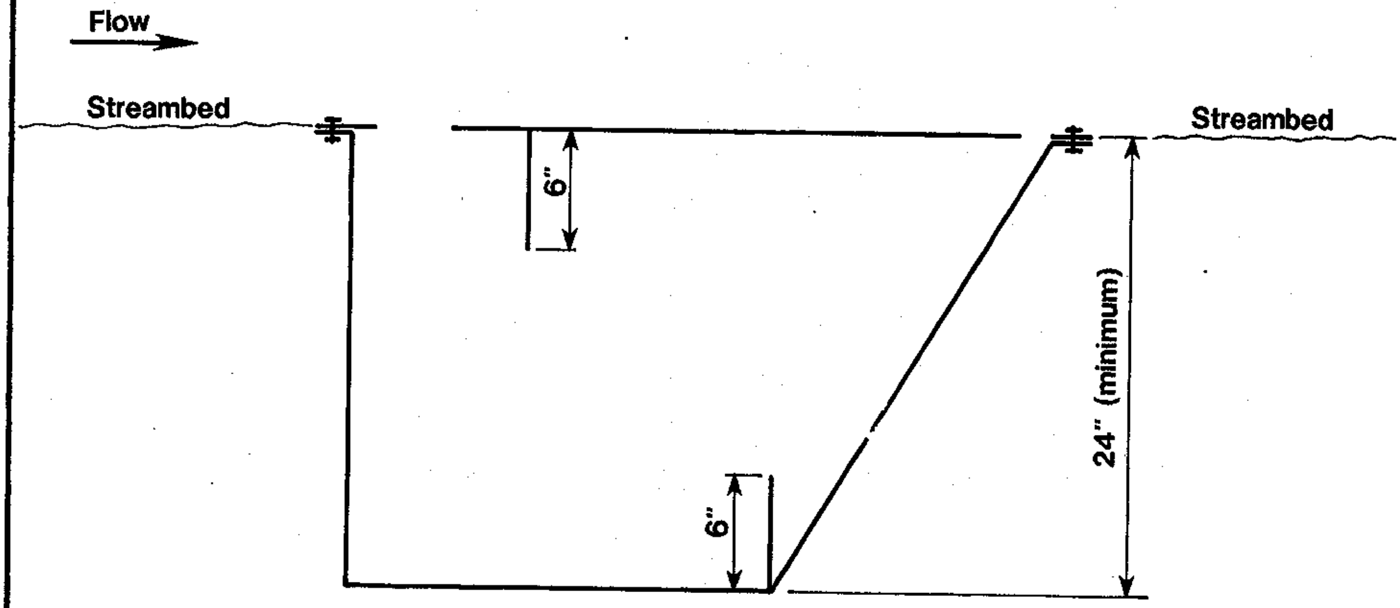
The technology of sediment sampling on high gradient alluvial ephemeral streams is not as advanced as the technology of streamflow or rainfall sampling. Given the design guidelines for the project the range of acceptable sampling equipment is limited. Therefore, sediment transport measurements will be supplemented by post-flood measurements of scour, bank erosion, fan aggradation, and indirect sediment transport estimates to enhance accuracy. Backup sampling systems will also be used to allow cross checking of data, and to protect against system failure.

Automated bedload sampling will be conducted with a drop box bedload sampler. The conceptual design of the drop box sampler (Figure 46) is based on discussions with the USGS, Bureau of Reclamation, and project staff. The drop box trap is installed flush with the bed elevation in a relatively stable reach with minimal expected scour. Water and sediment enter the box during flooding through an inlet at the upstream end. Water and suspended sediment escape through a narrow outlet at the downstream end, leaving the bed sediment behind. A baffle at the top and bottom of the box drive water and sediment deeper into the box and trap sediment at the bottom. A removable top will allow the box to be emptied and trapped material measured after each flood. Some adjustment of the box may be required if the bed elevation changes substantially.

Bed sediment larger than the drop box inlet will be monitored by painting boulders in the sampling reach. The loss of marked boulders and inflow of new boulders will be used to determine the maximum bedload diameter. In cases where painted boulders are retrieved, the distance of transport downstream may be used to determine velocity and stream power variation on the fan. Studies of boulder transport using painted rocks indicate that a 30 percent retrieval rate may be expected.



PLAN
1" = 1'-0"



SECTION A-A

Notes:

1. Box sides may be tapered to facilitate removal from stream
2. Box may be sealed proportionally larger depending on of bed material and expected flow duration.

Figure 46

Drop Box Bedload Sampler

The backup bedload sampling system relies on the scour measurement system, described elsewhere in this section. Sieve analysis of material deposited above the scour chains may be used to supplement size distribution measurements of bed material from the drop box. The rate of bed load movement will be inferred from automatic and real-time suspended load measurements made using a turbidimeter.

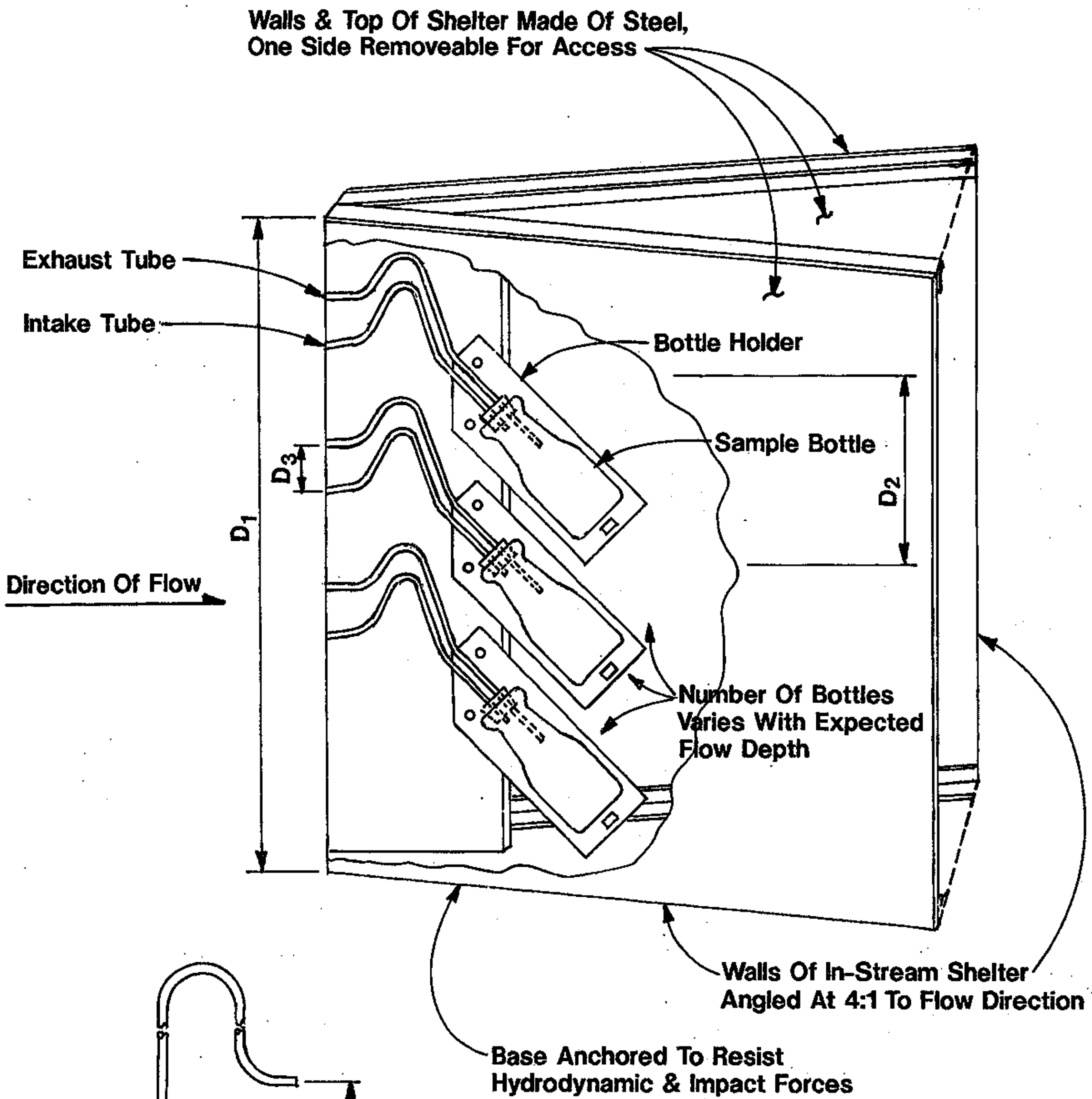
A U.S. U-59D sampler is recommended for reliable, automatic time-integrated suspended sediment measurements for specific flow depths. The U.S. U-59D (Figure 47) consists of a series of sampling bottles that operate on the siphon principle, mounted on a support structure. The support structure also provides protection from vandalism. Sediment collected in the bottles is analyzed after each flood. The bottle intake tubes should be sized to accept coarse sand grain sizes.

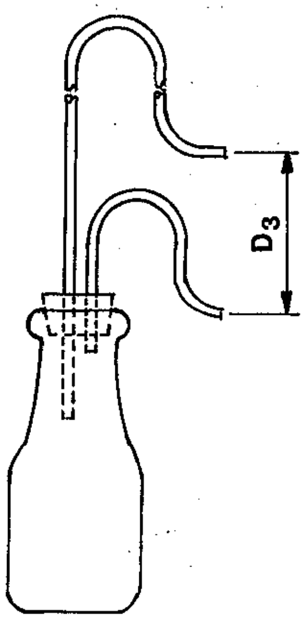
The U.S. U-59D has several limitations. The U.S. U-59D tends to sample only the water surface layer on the rising limb of the hydrograph, and its inlets are sometimes susceptible to clogging by floating debris. The intake and exhaust tube spacing should be set to accommodate site specific velocity conditions. However, the U.S. U-59D is not dependent on a power supply, and has been successfully tested in numerous field applications.

A turbidimeter is recommended for real-time and backup suspended sediment measurement (Figure 48). The turbidimeter, or turbidity sensor, measures suspended sediment through the principle of light transmission. The turbidity sensor is placed at fixed elevation in the stream. Data are provided on a real-time basis and can be transmitted through telemetry to a base station or recorded on a data logger at the site. Turbidimeters are relatively cost effective, unobtrusive, passive, low-liability devices, but can be more vulnerable to damage if improperly installed and maintained.

Indirect methods are recommended as a third method of estimating suspended sediment load. Where both pressure transducer and float sensors are used, the difference in depth readings can be related to additional pressure on the transducer due to the sediment in the water. This indirect technique has not previously been tried, and may require calibration. Therefore, some experimentation with field data will be necessary before the results are used for modeling purposes.

Manual sampling of sediment is not recommended due to the risk to field personnel caused by hazardous velocities and sediment transport. However, if manual samples are required to calibrate automatic sampler data a depth-integrating U.S. DH-59 suspended sediment sampler (Figure 49), and a U.S. BMH-60 hand line bed material sampler (Figure 50) may be used. The U.S. DH-59 and the U.S. BMH-60 are lightweight samplers designed for use in moderate velocities and depths. Therefore, actual data collection should be limited to lower recurrence interval flows. Manual sampling of suspended or bedload flow in more extreme velocities and depth would require construction of a crane, hoist, or cableway, and use of heavier samplers such as a U.S. D-74 for suspended sediment and a U.S. BM-54 for bed material. It is not recommended that field personnel attempt to sample by wading in floodwaters.





HORIZONTAL INTAKE

Notes:

D_1 = Height Of Sampling Housing = Maximum Expected Flow Depth

D_2 = Spacing Between Sample Bottles, Varies 0.5 - 1.0 Ft.

D_3 = Intake/Exhaust Spacing Varies With Expected Velocity & Depth

Figure 47

US-U59D Suspended Sediment Sampler

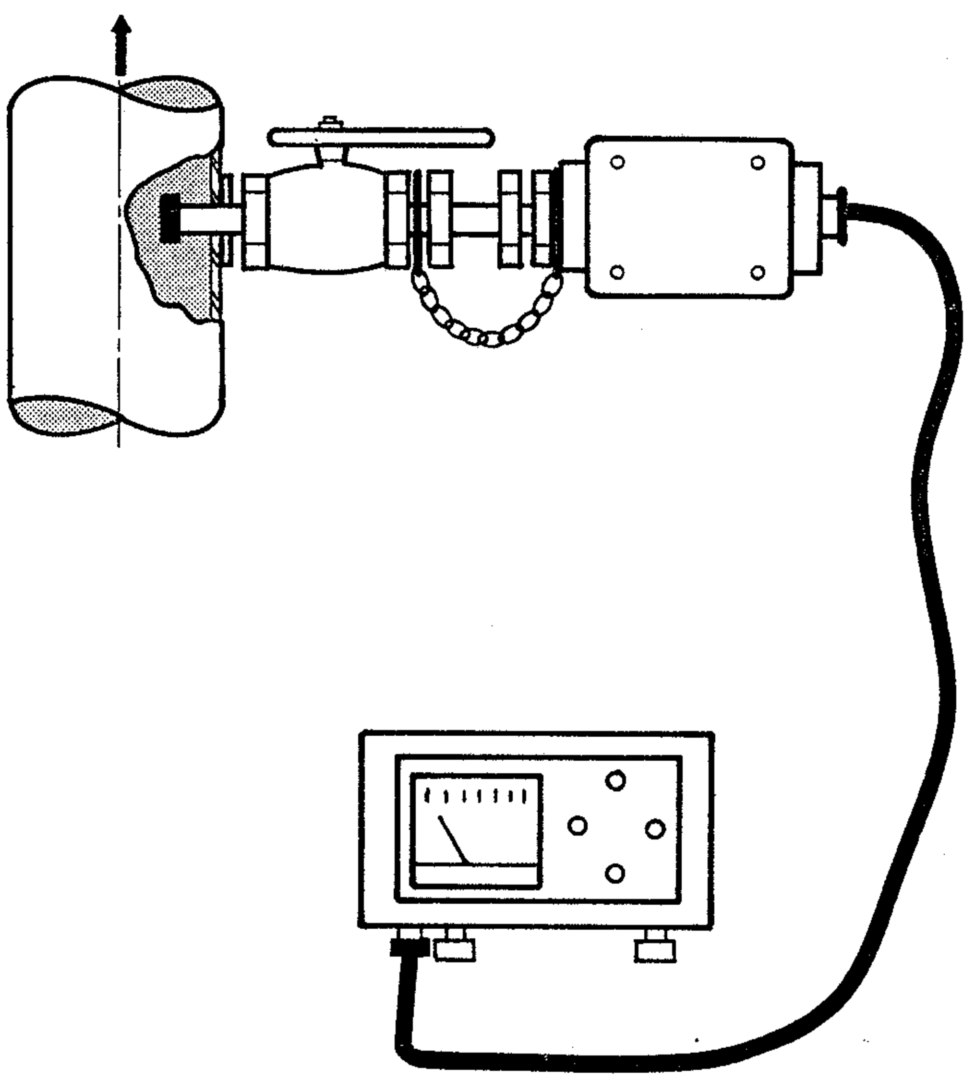


Figure 48

Typical Turbidimeter Application

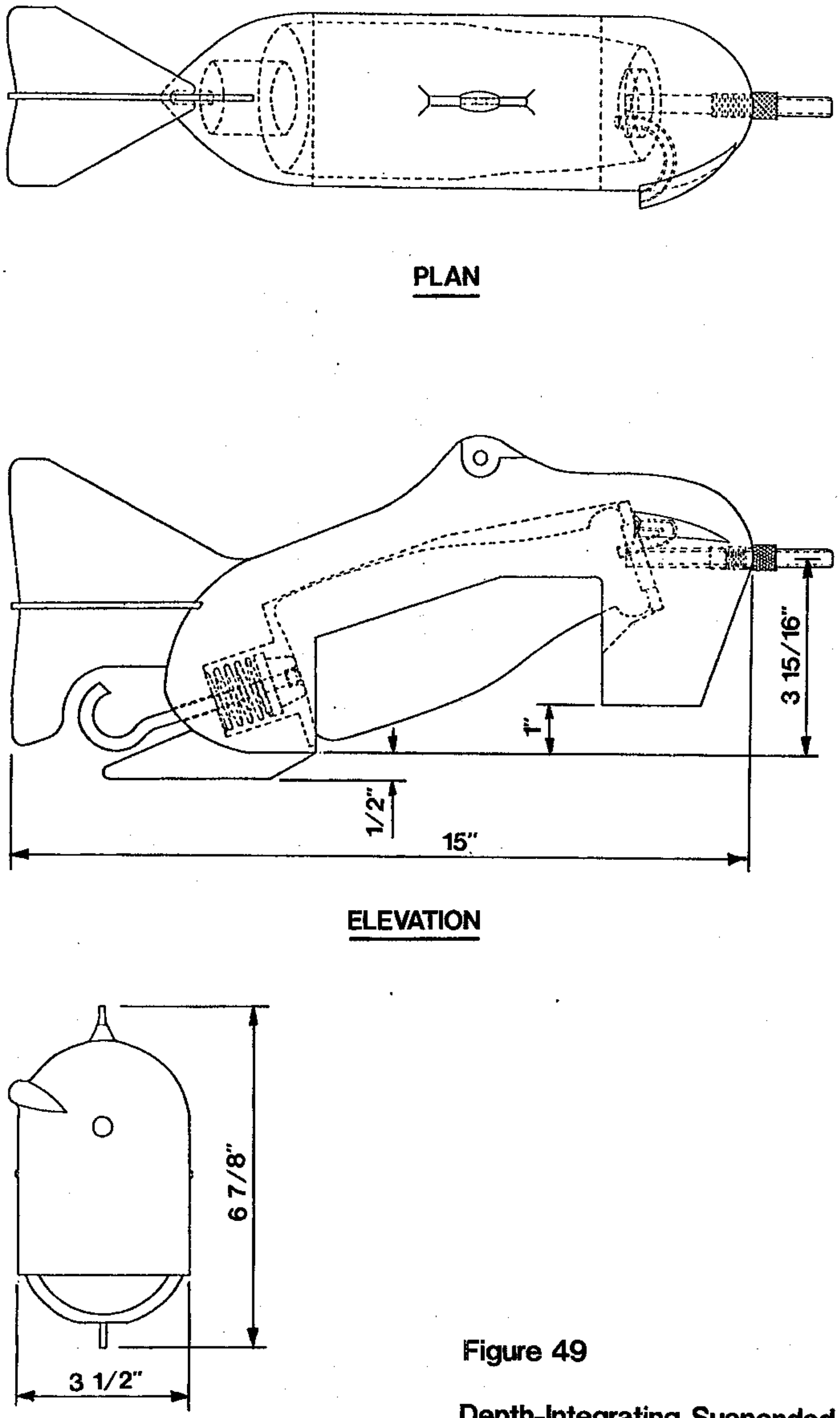
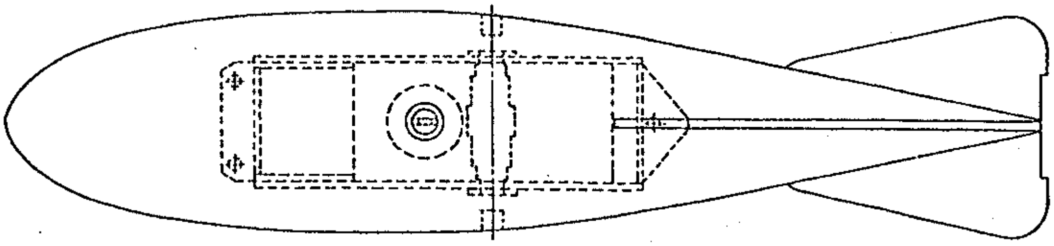


Figure 49

Depth-Integrating Suspended-Sediment Hand-Line Sampler, US DH-59



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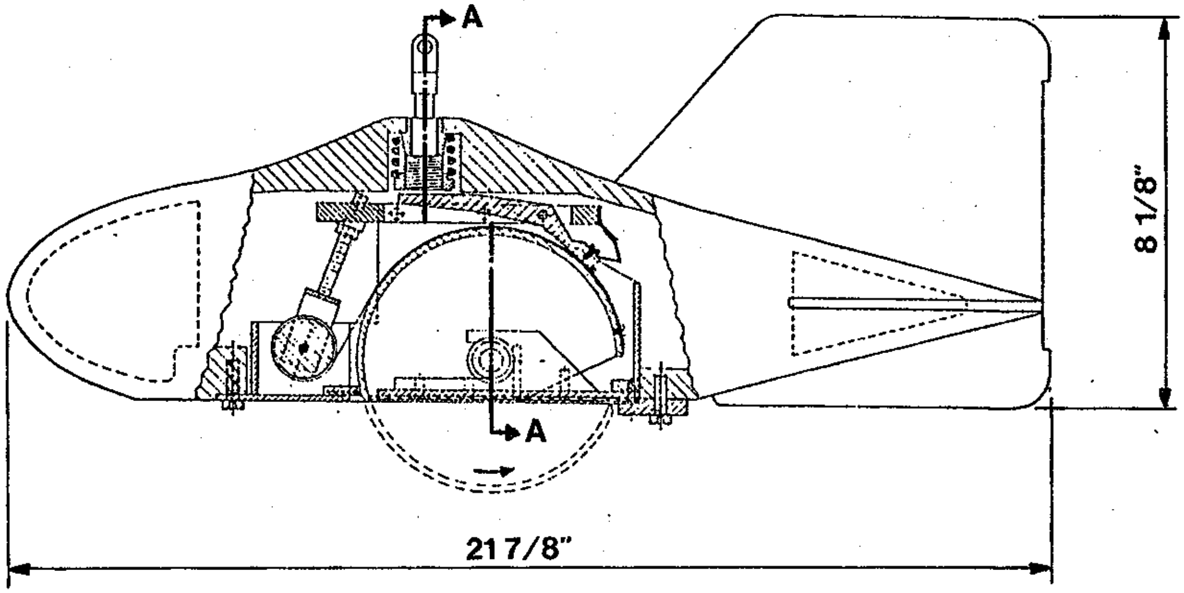
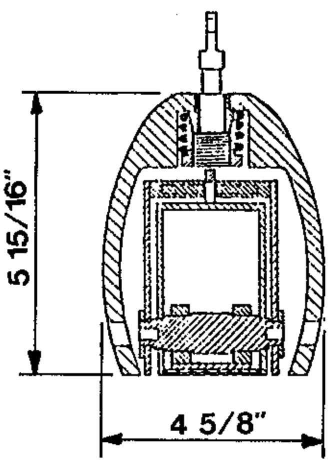


ELEVATION



SECTION A - A

Figure 50

Hand-Line Bed-Material Sampler, US BMH-60

A final source of readily available sediment transport data are road maintenance logs and deposition upstream of man-made constrictions. Field inspection of material deposited on road crossings by field crews may be used as an indicator of bedload. Material deposited at man-made constrictions such as the Tiger Wash Detention Basin and the future South Mountain Parkway (Outer Loop) should be estimated using periodic surveys, GIS sensing methods, or remote sensing as described below.

Sediment deposition may be monitored using detailed survey transects, periodic DTM comparisons using GIS software, and near infrared remote sensing from LandSat imagery. These techniques are described elsewhere in this report.

Numerous alternate sampling techniques were investigated, but were not recommended for measuring sediment transport. These techniques included automated sampling methods which require construction of flumes, weirs, or cableways. These gauges require extensive construction, are expensive, may alter natural geomorphic processes, create unacceptable liability, and are susceptible to flood damage. Most flume-type automated samplers require direct electrical power and are used on very small streams. Pumping and acoustic samplers were also investigated. Pumping samplers, because they have a single inlet, have a tendency to clog. They are also expensive and are prone to failure when battery powered. Acoustic sensors have not been extensively field tested in ephemeral streams. What little data exists indicates that these sensors are somewhat fragile, and may not function in high sediment concentrations. They are also expensive and may be more vulnerable to vandalism.

Water Temperature

The FCDMC currently has no water temperature sensors in its gauging network. The accuracy of pressure transducer and sediment transport measurements is directly dependent on water temperature. Therefore, a water temperature probe should be installed in at least one location at each site, preferably at a point where pressure transducer streamflow gauges are used.

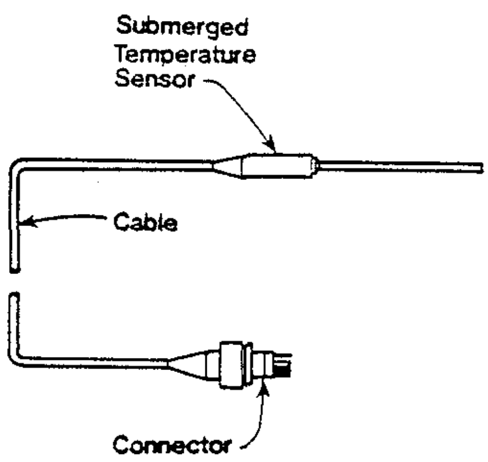


Figure 51 Temperature Sensor

The recommended temperature sensor consists of a linear thermistor contained in a stainless steel sheath (Figure 51). Real-time temperature readings may be transmitted via telemetry or stored in a data logger. The temperature sensor is compatible with the FCDMC ALERT system, and is approved by the USGS.

Channel Scour and Deposition

The FCDMC currently does not monitor scour and deposition in natural channels. Three manual techniques are recommended to measure channel scour and deposition. The recommended manual techniques for scour include scour chains and collars, surveyed channel sections, and detailed topographic mapping. Deposition will be monitored using surveyed transects. Cost-effective, reliable automated scour/deposition gauging systems have not yet been developed.

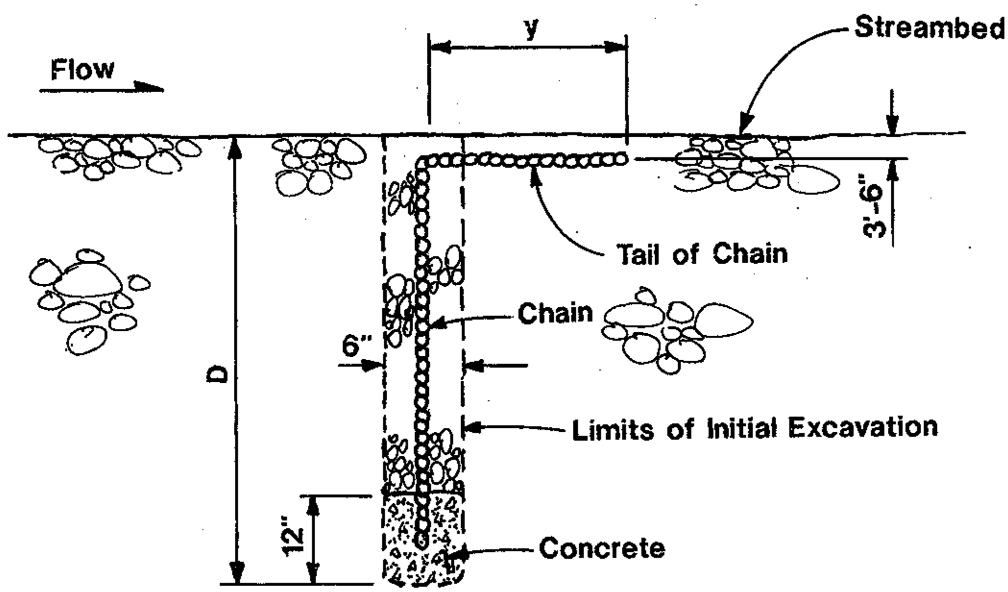
Scour chains have been successfully used in a wide variety of stream environments. The typical scour chain application consists of a chain segment anchored below the expected scour depth and buried upright in the native channel soil (Figure 52). As scour removes the channel bed material and exposes the chain, the chain collapses and lies on the scoured channel bottom. Deposition may later bury the collapsed portion of the chain. After a flood, the chain is uncovered to reveal the elevation of scour (the maximum elevation of the vertical portion of the chain). From this elevation the depth of scour can be computed.

For this project, a horizontal scour chain application is also recommended. For this application, a heavy gauge chain is buried at a very shallow depth across the width of the channel (Figure 53). During a flood the slack chain drops to the scour depth at each point across the channel. After a flood the chain is uncovered, and its elevation surveyed. In this way, maximum scour across the entire channel can be known.

Scour collars are heavy rings which slide down a vertical shaft as the supporting soil is scoured away. Scour collars will be mounted on the smaller crest stage gauges used in the transects across the fan surface. In this way, a single crest stage gauge can be used to simultaneously collect flow and scour information.

The scour information will be used to assess the accuracy of the streamflow measurements based on pre-flood channel geometry, and to adjust rating curves. The vertical scour chain application is recommended for most scour locations below the hydrologic apex. The horizontal scour chain is recommended for the transmission loss reaches above the fan apexes, near or in the sediment sampling reaches.

On the fan surface, channel location and channel geometry may be more uncertain than upstream of the apexes. Therefore, use of scour chains is not practical because floodwater may not flow in pre-flood channels. Therefore, it is recommended that permanently monumented transects be surveyed at key points in the channel and on the fan surface. Key points include reaches where stream gauges are installed, gauge



<u>Procedure</u>

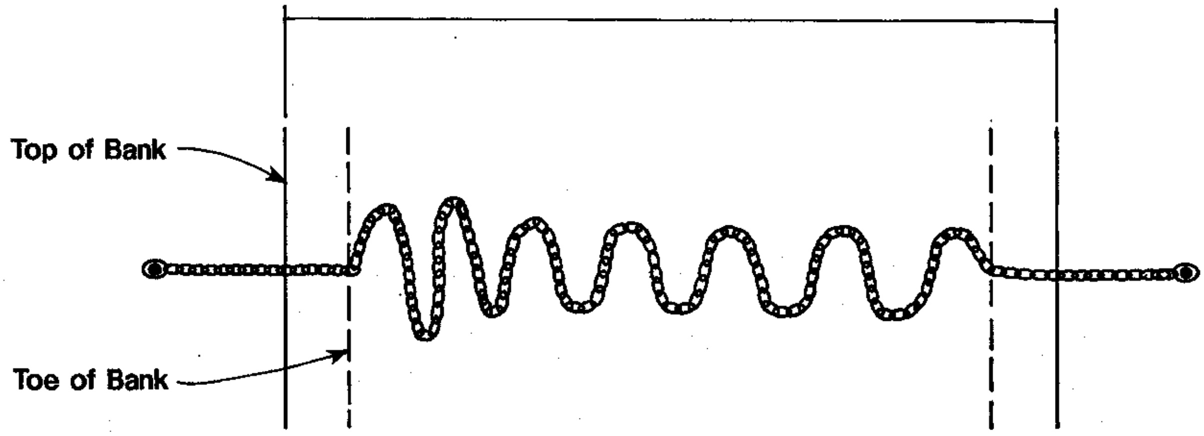
1. Auger 6" Hole
2. Set Chain
3. Fill Lowest 12" w/Concrete
4. Fill Hole w/Compacted Channel Material

<u>Notes</u>:

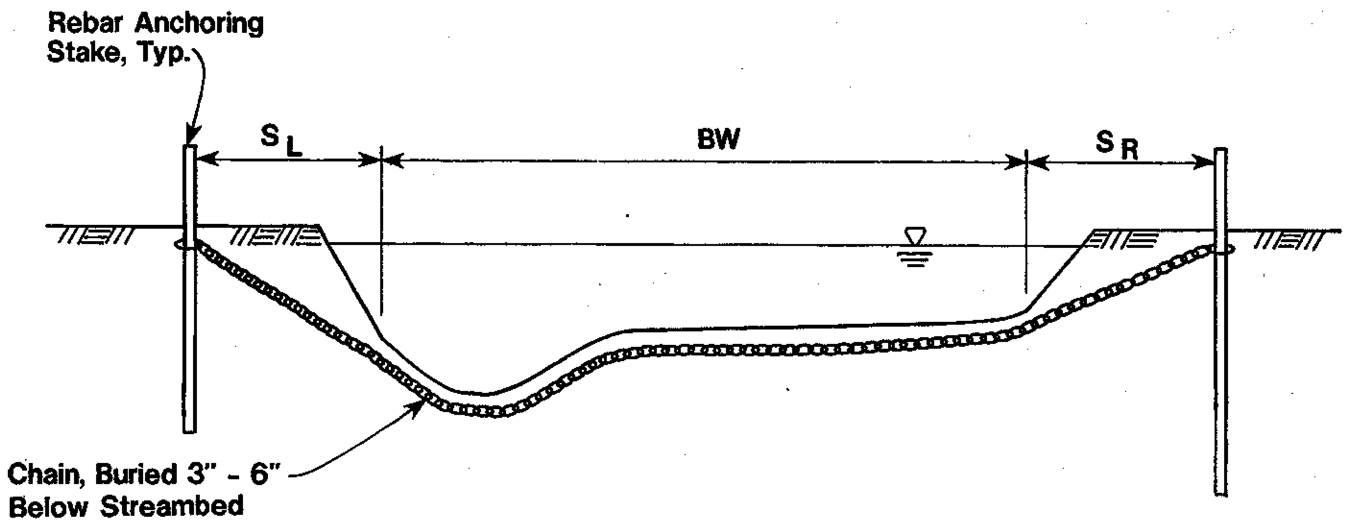
d_s = Depth of Scour
D = $1.5d_s + 1'$ or 4' Minimum Depth of Auger Hole
y = Lowest of 100-Year Flow Depth, or Bank Height

Figure 52

Vertical Scour Chain



PLAN



CROSS-SECTION

Notes:

1 Length of Chain = 2.0 BW + 1.5 (S_L + S_R)

S_L = Left Setback from Channel Bottom

S_R = Right Setback from Channel Bottom

BW = Width of Channel Bottom

2 Place More Of Chain Slack In Deepest Part Of Channel Bed

3 Drive Rebar To Refusal Or 2x Channel Depth

Figure 53

Horizontal Scour Chain

transects on the fan surface, and points where soil testing trenches were excavated. Elevation points should be measured at 2-foot intervals in existing channels and at all grade breaks on the interfluve areas. After significant floods or when channel changes are observed, transects can be resurveyed to determine net changes in bank erosion and channel geometry.

Detailed topography should be periodically updated to estimate net channel changes. This approach is more appropriate where a lower level of detail is needed. As the updated topography is provided, specific transects can be evaluated for change using GIS or Microstation engineering software.

Real-time, automatic scour gauges are currently being developed for the National Transportation Safety Board by E.V. Richardson of Colorado State University (Richardson, 1991). These scour gauges have spring-loaded sensors which extend away from a pile driven into the streambed. The sensors emit a signal as they are moved by flowing water after initial exposure by scour. Dr. Richardson has indicated that it may be possible to use one of the alluvial fan sites as a beta test site for the new scour gauge.

Bank Erosion

The FCDMC currently does not monitor bank erosion as part of the gauging network. Manual and remote techniques are recommended to gauge bank erosion. The recommended manual technique uses surveyed transects as described for channel scour and deposition above. Remote techniques include comparison of dated aerial photography and comparison of detailed site topography. No automated bank erosion instrumentation currently exists.

Transects of channel and fan areas will be monumented and surveyed as described elsewhere. These surveyed transects can be updated periodically or after significant floods to determine the extent of bank erosion. Transects should be surveyed in likely bank erosion areas, such as the outside of bends or where bed elevation changes are expected, as well as in "typical" channel reaches without these characteristics.

Comparison of periodic aerial photography is the simplest and best way to identify areas of significant bank erosion. Combined with topographic information, the extent and volume of bank soil material removed can be estimated. Use of GIS system technology will radically simplify bank erosion distance and volume computation. Periodic photography should be produced in constant scales and /or be digitized into an electronic data format such as Intergraph to facilitate comparison. Characteristics identifiable from the photographs can be coded as attributes in a GIS database coverage for future comparison and analysis.

Channel Migration/Formation of New Channels

The FCDMC currently does not monitor channel migration or the formation of new channels. No gauging instrumentation currently exists to monitor these types of changes. Therefore, comparison of periodic dated aerial photography and field surveys are recommended to monitor channel migration and formation of new channels.

Post-flood channel location may be compared with pre-flood photography to determine if the location of channels has shifted. Field checking of suspected channel avulsion should be made to confirm photographic evidence, and investigate potential human causes.

Streamflow data for the fan surface from the transects of crest stage gauges will be used to determine if floodwater shifted to a non-channelized portion of the fan, but did not form a new channel. In this way, areas where no channels formed but significant flow was conveyed can also be monitored.

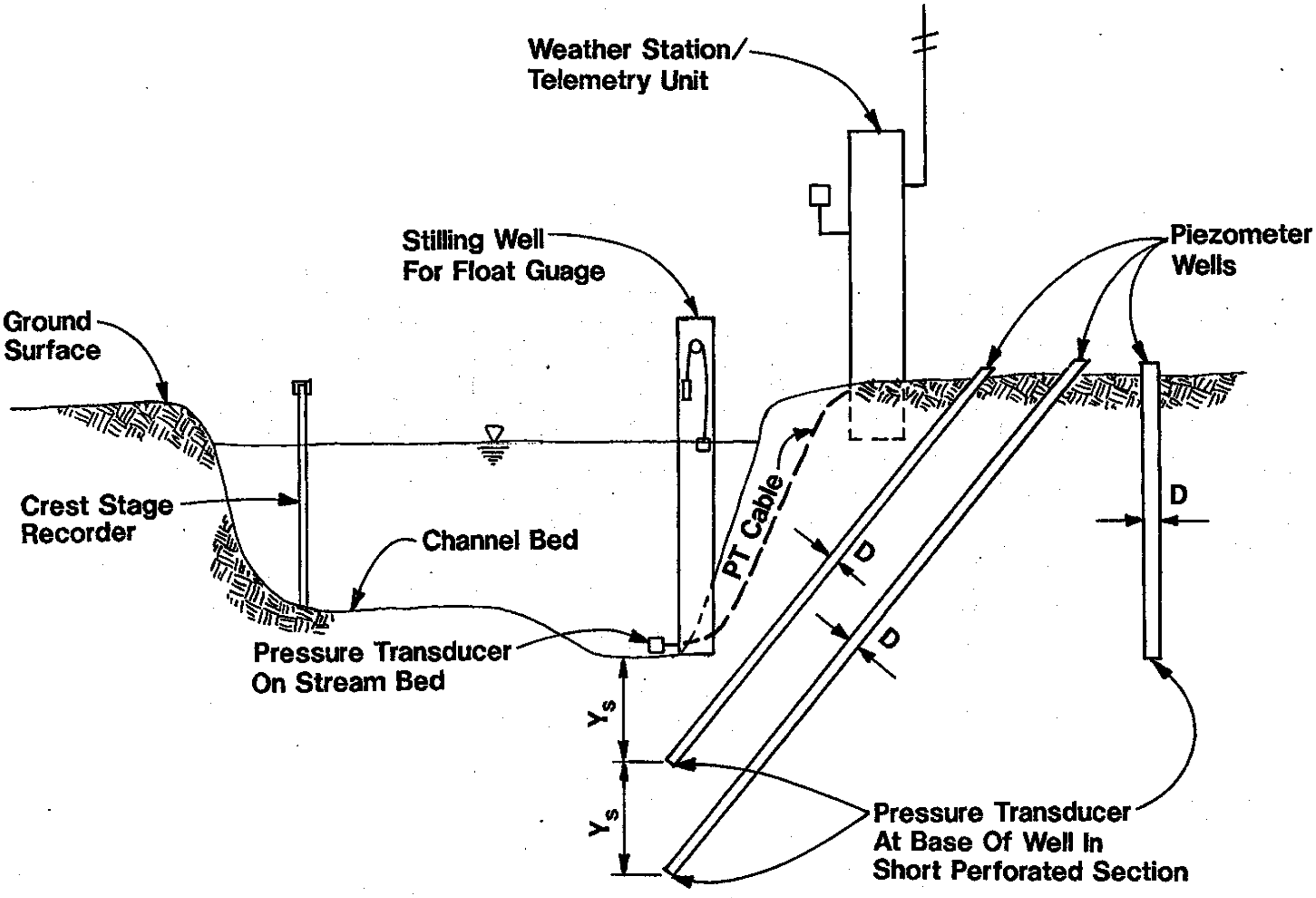
Fan Aggradation

Overall fan aggradation can be quantified using survey transects and GIS format DTM topographic information described earlier. Periodic or event based comparison of the entire fan or select areas can be made to determine if the rate of aggradation is significant (measurable) within engineering time.

Transmission Loss

The FCDMC currently has no gauges which specifically monitor transmission losses. Transmission loss measurement consists of two components, infiltration of streamflow into the soil substrate, and temporary storage of floodwater in channels and on the floodplain. Separate types of instrumentation will be required to disaggregate the two forms of losses. A combination of streamflow and infiltration sensors are recommended to gauge transmission losses (Figure 54) in the channelized reaches above the hydrologic apex at the Tiger Wash site, and on the fan surface at the White Tank Mountain site.

The streamflow component of the recommended gauging plan will use pressure transducers, float sensors, and crest stage gauges to determine discharge rates at each end of the transmission loss reach. These types of gauges are described elsewhere in this report. The number of total gauges required for the sites will be reduced if gauges recommended for the hydrologic apex are used as the downstream end of the transmission loss reach. Measured streamflow data should be combined with detailed topographic data for the channel and floodplain and used to calibrate hydrologic routing using computer models such as HEC-1.



Notes:

Y_s = Expected 100-Year Scour Depth

D = 2", Well Diameter

Figure 54

Infiltration Monitoring Station

CH2M HILL

The infiltration component of transmission loss will be estimated using buried peizometers. Piezometer installation (Figures 55 and 56) will consist of pressure transducer sensors placed in grouted 2-inch diameter wells with a short perforated section. The pressure transducers installed in the well bottoms function like the streamflow pressure transducers. As streamflow infiltrates into the streambed, water enters the well through the perforation. The pressure transducers transmit depth of well water readings to a data logger housed in a standpipe. The timing of water depth readings may be used to determine the rate and depth of infiltration.

Three wells should be drilled at each infiltration station (Figure 54). Two wells will measure vertical infiltration beneath the channel thalweg, and one well will measure lateral infiltration toward the overbank. The sub-channel wells should be augered from the overbank area at an angle of up to 60 degrees from vertical. This will place the sensors directly below the channel thalweg, one at the maximum expected depth of scour, and the other at twice the scour depth. Alternatively, if the alluvial substrate is not uniform, the sensors should be placed at the boundaries of soil units. The wells will be capped in housing with a locking steel cover. A soil moisture probe may be added above the lateral infiltration well to ensure that the water depth measured is not derived from rainfall infiltration from the overbank surface.

Supplemental infiltration data will be provided through the use of infiltration tests and geophysical logging. Saturated channel infiltration rates may be determined using double ring infiltrometer testing at uniform distances throughout the transmission loss reach. Geophysical logging of the channel bottom should be completed to determine the depth to bedrock and feasibility of transmission loss measurement, prior to installation of gauging equipment.

Measurement of the infiltration component of transmission loss is new technology. The gauging system recommended in this report has not yet been field tested for this application, though is well known in groundwater monitoring. Other components of the recommended system have been successfully used in the field. However, because the transmission loss gauging system is the first of its kind, some modification or alteration may be required as specific field conditions are encountered.

Weather

The FCDMC ALERT network currently has several complete weather stations, and is linked to the National Weather Service (NWS) Surveillance Radar (WSR-74). The existing weather stations measure rainfall, temperature, humidity, wind speed and direction, and atmospheric pressure (Figure 57). The recommended weather data collection program consists of two parts. A full weather station is recommended for each site to provide real-time complete weather information and assist in providing lead time for flood observation.

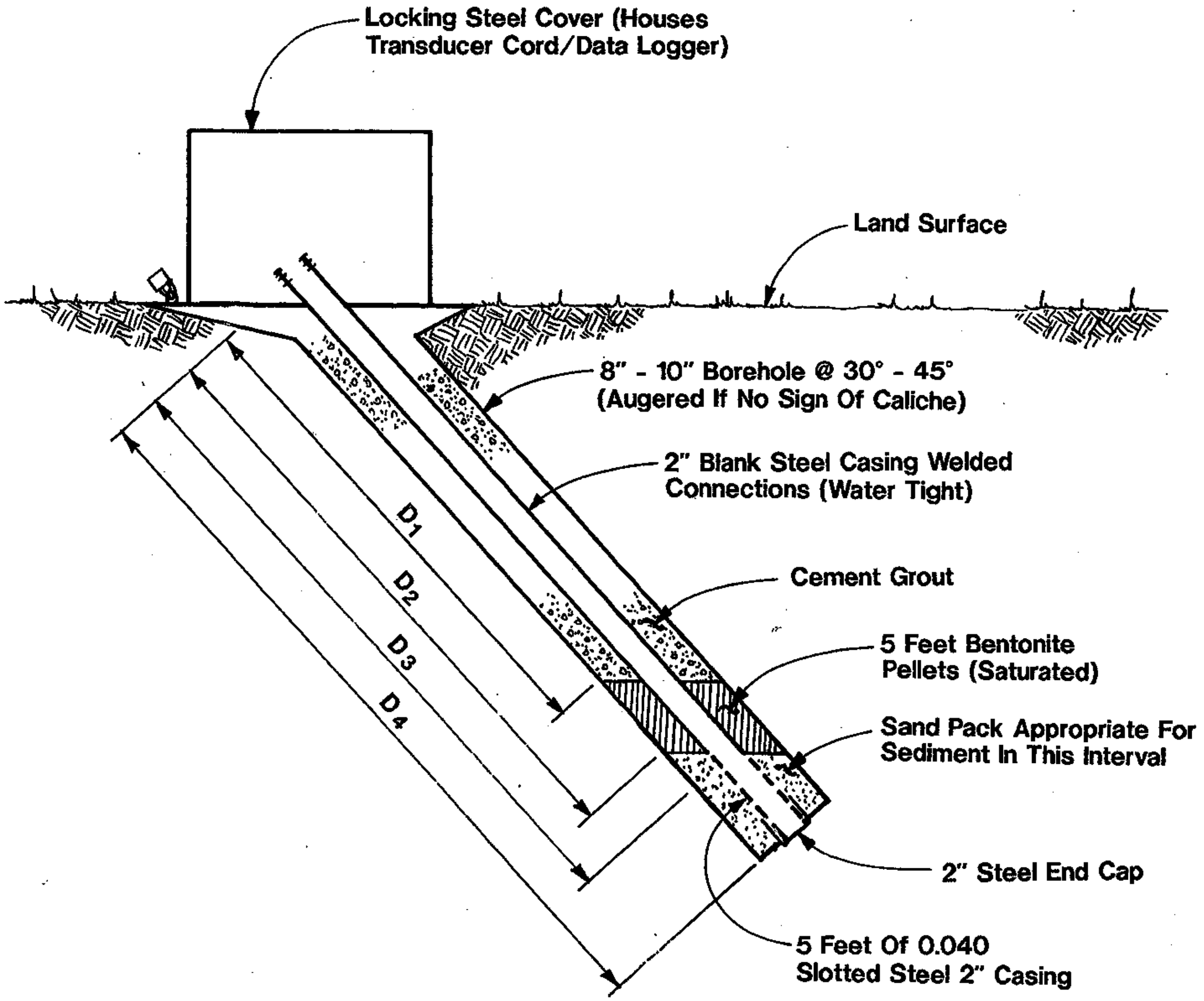


Figure 55

Concept Design For Angled Piezometer Well

CH2M HILL

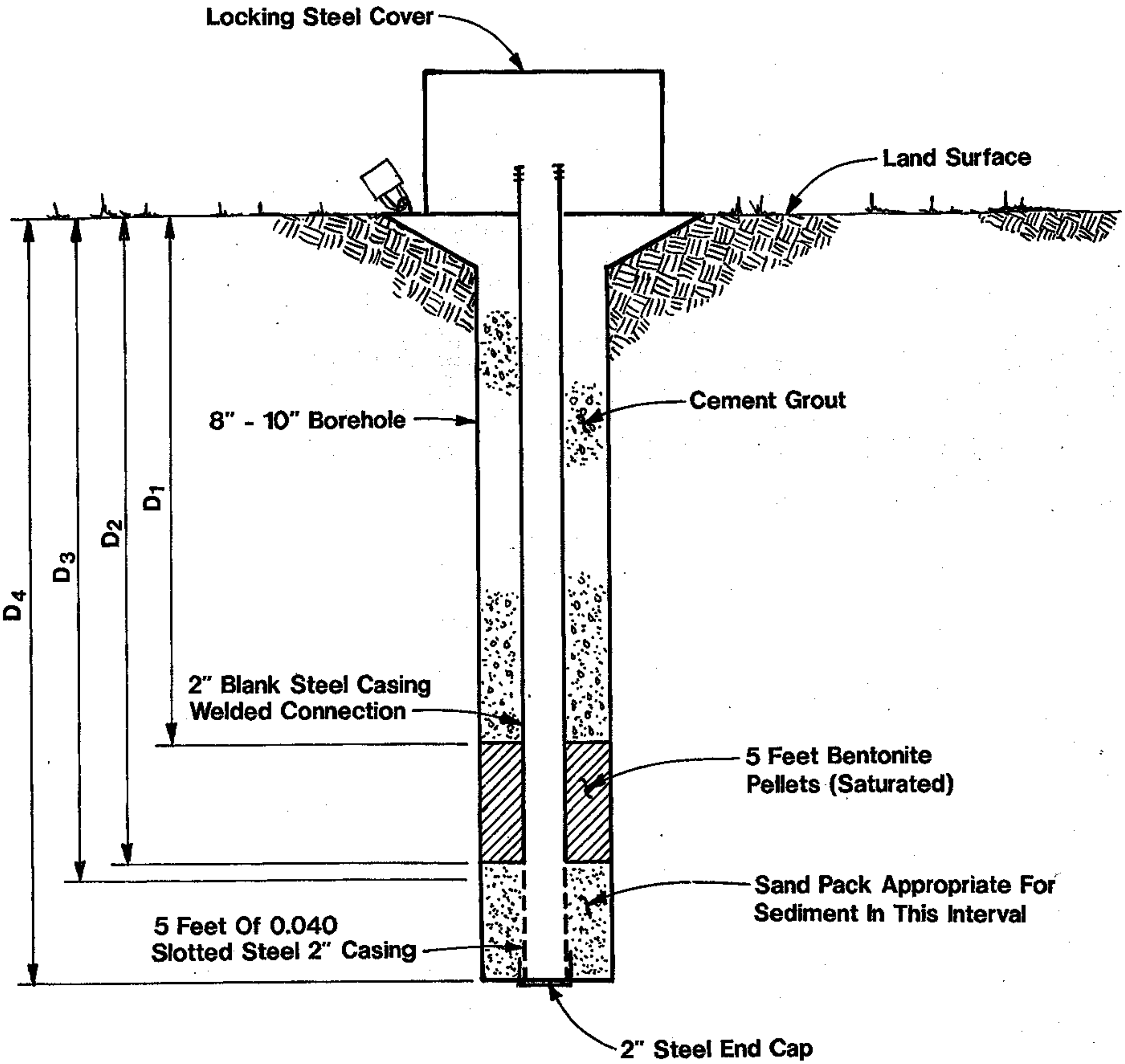


Figure 56

Concept Design For
Vertical Piezometer Well

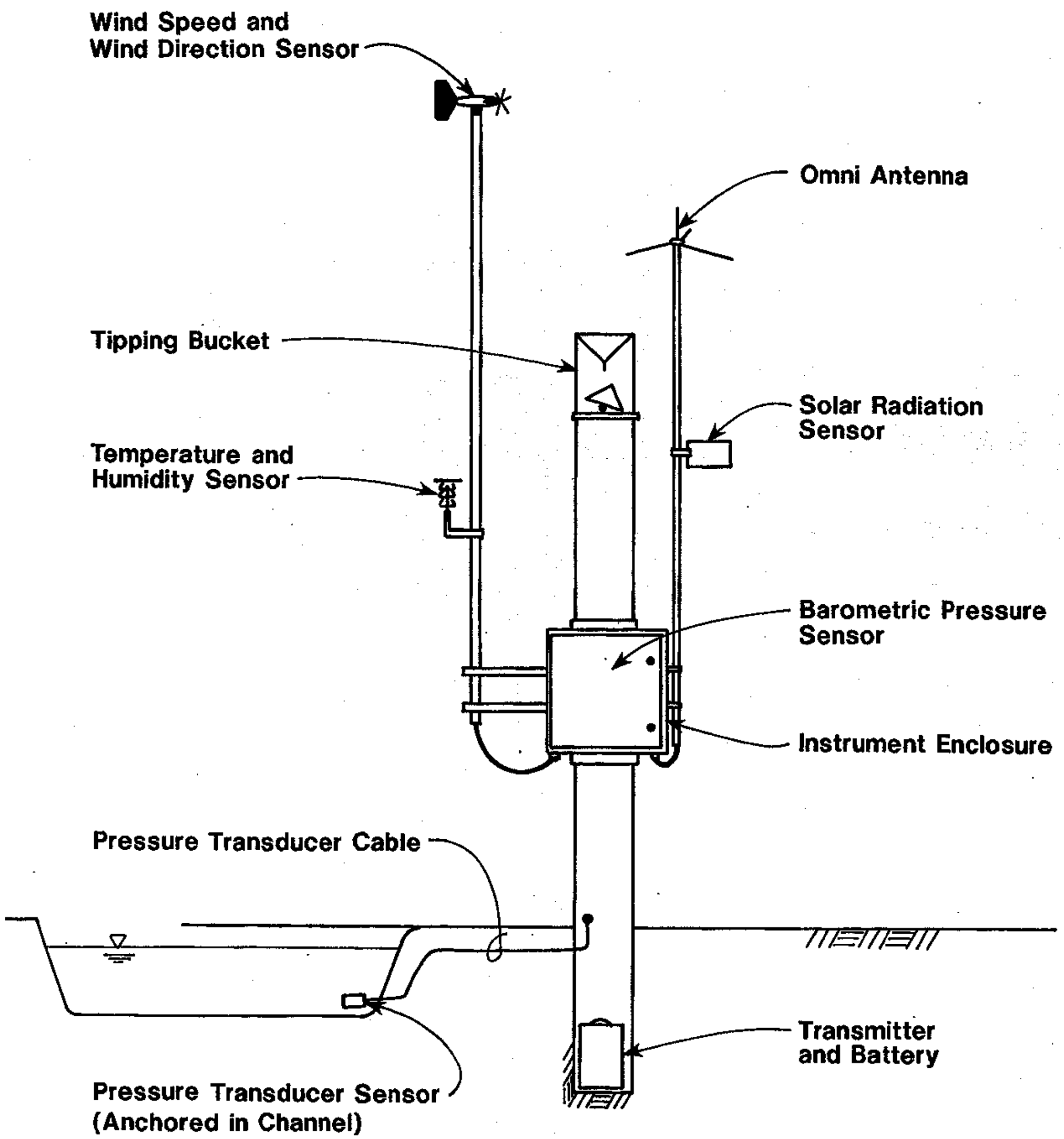


Figure 57

ALERT Weather Station

Includes Tipping Bucket & Pressure Transducer

Next-Generation Doppler radar (NEXRAD) is a new technology radar system being developed by NWS for implementation in the 1990's. This technology will significantly improve flash flood detection and prediction and eliminate several of the limitations constraining conventional radar. NWS plans call for installation of NEXRAD in Phoenix in early 1994, however there is some question concerning the ability of NWS to meet this schedule. An alternative to the NWS NEXRAD radar system which is currently available is NOWrad from WSI, a private vendor. NOWrad is a composite radar imagery product. By compositing images from more than one radar installation, radar images of the monitoring site which are currently in radar shadows can be tracked by the FCDMC.

Weather data will serve at least two purposes in the monitoring study. The weather information may be used after an event to reconstruct rainfall-runoff relationships, such as soil moisture losses and evapotranspiration losses, or describe antecedent conditions in the channel such as bank saturation or vegetative stability. VCR recordings of incremental radar trackings can be used to reconstruct storm tracking within the watershed, correlate measured rain gauge catches with radar intensities, and replace data from a failed rain gauge.

Radar based data used in conjunction with ALERT data will be the primary tool for making decisions about mobilization of field crews. Video records of the radar images will be used to augment the field and gauge data after storm events for determining storm tracking and areal distribution of rainfall. Data obtained from the radar images may be interfaced with a GIS database using such techniques as stepped-gain contour tracing, or grid overlay methods.

Remote Sensing Monitoring

Opportunities to use remote sensing to monitor alluvial fan flooding were fully explored. In current practice, remote sensing means detection and measurement of the intensity of some portion of the electromagnetic spectrum that is either emitted or reflected. For this project, remote sensing may be most applicable to measuring those parameters which do not lend themselves to more direct means. Measurement of soil moisture offers information on the spatial distribution of overbank or sheet flooding, or the deposition of transported sediment.

Remote sensing techniques investigated included visible spectrum, near-infrared, thermal radiation, microwaves, ground penetrating radar (GPR). The current state of the art and cost of remote sensing technology limits the potential application of remote sensing to this project. However, cooperative efforts with ARS, the University of Arizona, and other researchers should be pursued. Specifically, post-flood flights using the ARS thermal channel scanner and transects mapped using GPR, may yield valuable information to both ARS and the District, and may be funded by outside sources. In addition, obtaining and archiving pre- and post-flood Landsat photos in both visible and near-IR when available is recommended.

Monitoring Plan

Introduction

The instrumentation plan described in the previous section includes recommendations for a variety of equipment and techniques that are currently used by the FCDMC. These are referred to herein as "standard." Several of the recommendations, however, present either new methodologies, atypical uses of existing technologies, or gauge types which may be unfamiliar to the FCDMC. These are referred to as "non-standard." The purpose of this section is to describe the installation, operation, and monitoring procedures that make up the alluvial fan monitoring plans. The monitoring plans are intended to provide a methodology for evaluating the quality and applicability of the data gathered so that modifications to the instrumentation program can be made as needed to satisfy the long-term goals of the program.

Objectives

The objectives of this section are as follows:

- Describe the surveying, photogrammetric, manual, and other indirect and direct methods of data collection.

- Summarize installation, maintenance, and operating requirements for the recommended instrumentation.

- Describe a recommended monitoring plan for each fan system.

Limitations

The recommendations found in this section are based on the information described in previous sections, manufacturer's data, and the recommendations and past experience of the FCDMC, CH2M HILL staff, and other users of these types of equipment. Where adaptations of non-standard devices and techniques are recommended for this project, assumptions regarding performance and applicability have been made that will be confirmed or modified as data are collected. The detail and accuracy of the cost opinions and staffing plans is intended to provide general planning level information only.

Instrumentation

The instrumentation plan presented in a previous section recommended measurement devices and techniques that included both standard and non-standard gauging and monitoring equipment. The following section presents recommended siting and installation guidelines, standard operating procedures, maintenance, and monitoring requirements for the successful implementation of the instrumentation plan.

Standard Equipment

The instruments described in this section are currently used by the FCDMC and the operating procedures are well understood by FCDMC staff, therefore detailed procedures for their operations and maintenance are not reiterated. General siting and installation guidelines are summarized below for the following equipment:

- Precipitation and Weather
  - Tipping Bucket Gauges
  - Clear View Gauges
  - ALERT Weather Stations

- Streamflow
  - Pressure Transducer Sensors
  - Float Gauges

- Data Collection Electronics
  - Telemetry
  - Data Loggers

Siting and Installation

General and project specific guidelines to be used when siting precipitation, streamflow, and weather gauges are outlined in the following paragraphs. All gauges should be periodically photographed and marked with a permanent reference point.

Precipitation and Weather. The precipitation and weather gauges recommended are tipping bucket and clear view rain gauges, ALERT weather stations, and water temperature sensors.

Precipitation. The following design guidelines should be used in siting and installing rain gauges:

- Niper or Wyoming shields are recommended for rain gauges exposed to wind. Where shields are not used, and where rain gauges are not protected by vegetation, the reported rain catch should be adjusted to account for wind velocity at the inlet (Figure 41). Wind shields should not be used if they will attract attention to the gauge and increase the potential for vandalism. Gauges may be sited in openings in stands of bushes or trees to protect them from excessive wind.

- The distance from isolated obstructions such as bushes, trees, or man-made devices should be 4 times the height of the obstruction above the gauge.

- Rain gauges generally should not be sited on steep slopes, in narrow canyons, or next to cliffs.

- As a guide, an equal number of ridgetop, slope, and valley rain gauge sites should be used at each monitoring site.

- The density of rain gauges in a watershed should be based on the topographic characteristics of the watershed, the size of the watershed relative to estimated likely storm diameter, coverage of key subwatersheds, the ability to track storm movement, and access.

- Oil may be placed in clear view gauges (and the depth of oil noted) to prevent evaporation between the end of the rainstorm and the time the gauge is read.

Weather Station. The following design guidelines should be used in siting and installing ALERT weather stations:

- Weather stations should be located at the hydrologic apex for each monitoring site.

- The weather station should be located clear of obstructions.

Water Temperature. The following design guidelines should be used for installation of water temperature gauges:

- Temperature probes should be located where they have minimal risk of being buried by flood deposition.

- Temperature probes should be located where they have minimal risk of being damaged by hydrodynamic forces or sediment impact.

- If stilling wells are used, the temperature probe may be placed in the stilling well only if in-stream installation is not feasible, and floodwater directly enters the stilling well.

Streamflow. Two types of standard streamflow gauges are recommended, float sensors, and pressure transducers (PT). Siting and installations requirements for both types of streamflow sensors are similar, although float gauges have several additional requirements.

Gauging Reaches. The following general design criteria should be used in siting streamflow gauging reaches to determine peak flows by indirect methods. The gauging reach should:

- Be accessible for maintenance.
- Promote deposition and preservation of highwater marks.
- Be relatively straight, especially upstream of the gauge. (Rule of thumb: the gauging reach should be straight a distance of five channel widths upstream of the gauge, and a distance of two channel widths downstream of the gauge.)
- Be long enough so that the change in water surface elevation is greater than the potential error resulting from alternate interpretations of the highwater mark profile. (Rule of thumb: the reach length should be 75 times the mean channel depth, and the fall through the reach should be greater than the velocity head.)
- Have a relatively simple trapezoidal channel geometry and uniform slope.
- Have minimal overflow sections.
- Contract rather than expand, where possible.
- Sited in relatively stable channel reaches with minimal expected scour or deposition, where possible.
- Have no more than 15 percent of the flow with velocity less than 0.5 foot per second.
- Detailed cross sections should be surveyed perpendicular to the principle flow direction at regular intervals throughout the reach.

Float Gauges. Stage recording gauges should:

- Have sufficient height to accommodate the entire range of expected stages.
- Have a sufficient number of intakes at various stages to account for potential silt clogging and to ensure that the water level in the well will not lag behind stream stage.
- Have intakes correctly oriented to the flow direction.
- Have intakes small enough to damp out waves and surges.

- Be sized to allow easy maintenance.

- Be located as close to the thalweg as feasible without risking flood damage.

- Have a surveyed reference elevation or bench mark.

- Contain clean-out doors to easily remove silt.

Data Collection Electronics. Data collected at the gauging stations will be transmitted electronically via radio or microwave telemetry, or will be stored on site in data loggers. Solar panels should be used where feasible to extend battery life and decrease the need for frequent maintenance.

Telemetry. Real-time monitoring telemetry units will be used at the weather stations located at the hydrologic apexes of the fan sites and at several of the precipitation stations as illustrated in Figures 58 to 61. Sufficient output ports should be used to account for each weather variable, streamflow, precipitation, turbidimeter, and piezometer readings, where applicable.

Data Loggers. Data loggers will be installed at all electronic gauges not equipped with telemetry. Because temperatures of 120 F may damage memory, data loggers should be installed underground to minimize overheating.

Operating and Maintenance Procedures

The existing operating and maintenance procedures for standard FCDMC gauging equipment such as precipitation, streamflow, and weather stations are appropriate for the purposes of this study. Additional quality control and data archiving procedures are described in a later section.

Electronic Sensors. All electronic sensors including tipping buckets, pressure transducers, float sensor, weather sensors, and water temperature sensors should be checked and recalibrated periodically. Pressure transducers, in particular, have a tendency to drift.

Data Loggers. The following operating and maintenance procedures should be used for data loggers:

- Data loggers should be protected against excessive heat by being housed underground, in weather-proof enclosures. Excessive heat may cause battery leakage and corrosion of the electronics mother board. The recorders must be kept below 120 degrees Fahrenheit.

- Maintenance of batteries follows the same schedule as telemetry units.

- Information should be downloaded from data loggers according to the storage capacity and frequency of sensor input. Data loggers recommended for this study have 32k RAM, capable of storing about 110 days of data from two analog inputs set at 10 minute intervals. As the frequency or number of sensor readings increases, the frequency of service also increases.

Non-Standard Equipment

Several types of equipment and procedures are recommended which may not be familiar to FCDMC staff. For these, recommended installation, maintenance, and standard operating procedures are summarized below. These gauges types include:

- Streamflow
  - Crest Stage Recorders—Full Size
  - Crest Stage Recorders—Small

- Sediment Gauges
  - U.S. U-59D Suspended Sediment Sampler
  - Turbidimeter
  - Drop Box Bed Load Trap
  - Painted Boulders
  - Manual Samplers
    - U.S. DH-59
    - U.S. BHM-60

- Scour Gauges
  - Vertical Chains
  - Horizontal Chains
  - Scour Collars

- Peizometer Wells

Siting and Installation

General and project specific guidelines to be used when siting non-standard streamflow, sediment, scour, and transmission loss gauges are outlined in the following paragraphs. All gauges should be periodically photographed and marked with a permanent reference point.

Streamflow. Non-standard streamflow gauges recommended include full-size and small crest stage recorders. Full-size crest stage recorders have been recommended for augmenting the recording PT and float instruments in several locations. Small crest stage recorders will be used in regular intervals to record flow through transects located on the fans surfaces. Small crest stage gauges may be constructed of PVC pipe. The siting and installation are similar for both types of crest stage gauges. Crest stage gauges should:

- Have a surveyed reference elevation recorded in a permanent log book for the site.
- Be located away from channel obstructions such as large boulders or vegetation.
- Be located both upstream and downstream of real-time streamflow sensors as shown in Figures 44 and 45.
- Be located outside of the thalweg to minimize flood damage and obtrusiveness.
- Have sufficient height to cover the range of expected flows. Gauges located in transects on the fan surfaces can be smaller due to lower expected flood depths.
- Be suffiently anchored to resist hydrodynamic and flood impact forces.
- Be located on opposite left and right banks upstream and downstream of real-time gauges such that a line drawn between the gauges will intersect the flow at a right angle.

Sediment Gauges. Sediment gauge types recommended include turbidimeters, US-U59D suspended sediment samplers, bedload drop box samplers, and painted boulders. General siting guidelines for all types of sediment gauges include reaches:

- Which are immediately adjacent to a recording streamflow gauging stations.
- Where minimal backwater conditions exist.
- Where confluences or difluences create complex lateral hydraulic variations.
- Which are relatively straight, according to the criteria outlined for streamflow gauges.
- Where high turbulence creates high suspended sediment transport rates.

Turbidimeters. The following guidelines should be used in siting and installing turbidimeters to measure real-time sediment concentration. Turbidimeters should be:

- Installed to minimize damage of the in-stream sensor, but maximize exposure to effective flow.

- Installed with guidelines and restrictions similar to pressure transducer sensors.

US-U59D. The following guidelines should be used in siting and installing US-U59D to measure depth-integrated suspended sediment concentration. US-U59D suspended sediment samplers should be:

- Installed so that the samplers intakes exceed the stage of expected flows.

- Oriented so that the intakes are pointed directly into the expected flow direction.

- Placed far enough into the channel to avoid slackwater and reach an average velocity zone.

- Anchored in concrete below the expected scour depth to prevent movement during flow.

- Sized to reflect expected velocities and suspended sediment loads. The intake diameter and spacing may be varied to optimize sediment collection according to instructions given in (USGS, 1961; 1972).

- Marked with a permanent reference point or bench mark.

Drop Box Bedload Traps. The following guidelines should be used in siting and installing drop box bedload traps to measure time-integrated bedload sediment size distribution. The drop box bedload traps should be:

- Installed with a bottom depth set below the expected depth of scour.

- Located in the thalweg.

- Installed in reaches with minimal long-term degradation.

- Installed with the inlet elevation set slightly below bed elevation.

- Installed with the inlet oriented perpendicular to the expected flow direction.

- Located far enough from the channel banks to avoid sedimentation from bank sloughing.

- Marked with a surveyed reference point or bench mark.

Painted Boulders. The following guidelines should be used in siting painted boulders used to measure coarse sediment transport:

- Painted boulders should be used at each sediment sampling station. A sediment sampling station included a turbidimeter, U.S. U-59D, and a bedload drop box.

- Boulders with a median diameter larger than the width of the inlet of the drop box bedload sampler (4 inches) should be numbered with durable, high visibility paint. Four sides of each boulder should be marked with arrows indicating its resting position.

- At least 5 boulders in each range of 10 sediment size gradation, from 4 inches to the maximum diameter present in the channel should be marked and numbered.

- Boulders from both upstream and downstream of the other sediment samplers should be marked and returned to their natural resting place in the channel.

- Boulders from both the thalweg and channel margins should be used.

- The painted boulder reach should be photographed and fully described in a permanent field log.

Scour Gauges. Three types of gauges are recommended to monitor channel and overbank scour: vertical and horizontal scour chains to measure channel scour, and scour collars for measuring overbank scour within the on-fan transects.

Scour Chains. Horizontal and vertical scour chains should be sited and installed using the following guidelines:

- Vertical scour chains should be buried and anchored below the maximum expected depth of scour. General expected scour depths can be estimated using standard procedures outlined in various engineering manuals[11].

- Stratified soil material excavated to install the vertical scour chains should be replaced to match native layering and compaction.

[11] For example, E.L. Pemberton, and J.M. Lara, *Computing Degradation and Local Scour* 1984. Bureau of Reclamation, Denver, Colorado. A copy of this manual was provided to the FCDMC by separate transmittal.

- Horizontal scour chains should be buried 3 to 6 inches below the existing channel bed with enough slack in the chain to reach maximum expected depth of scour at any given point.

- The position of scour chains and surveyed transects should be monumented and referenced from a point well outside the expected erosion area. The elevation of the bed above the scour chains should also be surveyed. Photographic and text descriptions of the locations should be used.

Scour Collars. The following guidelines should be used for siting and installation of scour collars to measure overbank and channel scour within the fan transects.

- Surveyed transects should be positioned to determine scour, bank erosion, channel migration, and fan aggradation as described below.

- Scour collars should be mounted on small crest stage recorders in the fan transects with reference to a surveyed elevation.

- The scour anchor should be heavy enough to resist flotation.

Transmission Loss. Transmission losses will be measured using accurate float gauge streamflow measurements, as well as pressure transducer and crest stage gauges, and infiltration data collected from piezometers.

Gauging Reaches. The transmission loss gauging reaches should be sited according to the following criteria:

- No significant tributaries should enter the reach.

- No flow should escape the reach by surface processes.

- Reaches should be as long as possible to maximize attenuation and infiltration.

- Geophysical testing of the transmission loss reach should be conducted to test the depth of caliche or bedrock. If impervious caliche or bedrock is encountered near the surface which would prevent infiltration, alternative transmission loss reaches should be considered.

- Dual-ring infiltrometer testing of the transmission loss reach should be completed in conjunction with well installation to provide baseline data with points for calibration.

Streamflow Gauges. Streamflow gauges used for monitoring transmission losses should be installed according to the design criteria outlined previously.

Piezometer Wells. Piezometers placed in wells located directly below the thalweg will be used to measure the infiltration component of transmission loss. The piezometers consist of pressure transducers placed in a perforated section of the well. Siting of the piezometer wells should follow these guidelines:

- Well heads should be located in the overbank area closest to the thalweg.
- Subchannel piezometer wells may be drilled at an angle up to about 60 degrees using an auger drilling rig.
- Wells should be drilled so that the bottom of the well is directly beneath the thalweg (or as close as possible, given field conditions).
- Well bottoms under the thalweg should be placed at the expected 100-year scour depth and at twice that depth, or at recognizable subsurface soil boundaries.
- The vertical piezometer well located in the overbank should be located a distance from the nearest channel bank equal to the width of the channel. The bottom elevation of the vertical well should equal the elevation of the scour depth in the thalweg.
- The wells should be sealed to prevent rainwater or occasional overbank flooding from entering the well.
- Wells may need to be permitted by the Arizona Department of Water Resources.
- If significant cobble layers are present in the substrate, the wells cannot be drilled by augering. Another drilling method must be used.

Standard Operating Procedures

This section describes standard operating procedures for non-standard gauges. Standard operating procedures detail the procedures that should be followed to collect data from the gauges after a flood.

Streamflow

Crest Stage Gauges. The crest stage gauge was developed to measure the maximum instantaneous stage attained during a single storm event. It must be recharged after each event or information from the smaller events will be lost. For this reason, care must be taken to ensure the peak reading represents the desired event. Crest stage gauges will be used to calibrate pressure transducer stage measurements and to provide a reliable back-up method of flow measurement. Operation of small and full-size crest stage gauges is identical.

Procedures for reading and recharging the crest stage gauges are as follows:

1. Photograph the gauge and the adjacent stream reach.

2. Check for damage that could have altered the surveyed reference point. Check also to make sure the gauge has not been tilted by erosion or by debris impact. Note any changes in the gauge log.

3. Record the date, time, site name, observer's name, the weather conditions and streamflow conditions. Weather data may be used to determine if highwater marks on the outside of the pipe may have been washed off.

4. Locate highwater marks on crest stage gauge or adjacent channel banks[12]. If marks are readily available, determine their elevations relative to the surveyed reference point on the gauge.

5. Remove the top cap of the galvanized pipe and carefully remove the staff located inside the pipe. Extreme care must be used during this procedure to ensure the cork located on the staff is not disturbed.

6. Measure and record the distance from the bottom of the staff to the top of the residual cork deposited on the staff. Using a pencil, mark on the staff the high water mark and the date.

7. Recharge the crest stage gauge for future use by rinsing the inside of the pipe to flush residual cork to the bottom of the pipe. Clean the staff and refill the cork reservoir located at the bottom of the staff.

8. Replace the staff and secure the top cap.

Sediment Gauges

Turbidimeter. A turbidimeter is an optical sensor placed directly in the stream which takes instantaneous measurements of sediment concentration. The sensor performs similarly to a pressure transducer. Analog readings from the turbidimeter will be transmitted via telemetry to the data archiver.

The following procedures are recommended for collecting sediment transport data from the turbidimeter:

[12] Chalk may be rubbed on the outside of the crest stage gauge as a secondary indicator of water level.

1. Print hard copies of telemetry readings prior to collection of samples from US-U59D samplers for comparison.

2. Compare total sediment concentration from US-U59D samples after lab analyses to determine relative accuracy of turbidity readings.

U.S. U-59 Suspended Sediment Sampler. The US-U59D sampler operates on the siphon principle, and is used to automatically collect suspended sediment samples from flashy, intermittent streams at remote or inaccessible sites which are visited by personnel at infrequent intervals.

The operating procedures for collecting data from the US-U59D suspended sediment sampler are:

1. Photograph the sampler and the surrounding stream reach.

2. Check the sampler for damage that could have altered the surveyed reference point. Check for tilting of the sampler. Document damage in the gauge log book.

3. Check all bottles for samples and compare to crest stage gauge readings and highwater marks. Check for blockage of intake and exhaust tubes. Document problems in the log.

4. Remove and replace bottles that collected samples. Record sampling time, date, personnel, and weather conditions and label sample bottles. Labels should include the following:

    - Site name and location
    - Date of installation of bottle
    - Vertical position number of bottle
    - Estimated storm date for collection
    - The removal date and time

5. Samples should be analyzed for total sediment concentration and percent sand/silt/clay composition. Hydrometer analysis will probably be required for fine grained material.

Drop Box Bedload Trap. The drop box bedload trap relies on gravity to trap bedload material in a steel box installed below the streambed elevation of the thalweg. The bedload sampler is used for automatic collection of bed material size distribution data on streams where flow conditions and access limit direct or real-time sampling.

The following procedures are recommended for collecting bedload samples from the drop box sampler:

1. Photograph the drop box and surrounding streambed. Record channel conditions at the box, such as the size of cobbles resting on the inlet.

2. Remove the cover and photograph the material in the box before disturbing the sample.

3. Measure the depth to material in the box (as shown) to allow computations of the volume of material captured. Measure from the top center of each side of the box to the top of the material and record:

Measuring Point-Top of Center of	Distance from Top of Box to Top of Material (feet)
Upstream side	0.5
Left side (looking downstream)	0.3
Downstream side	0.2 (0.5)=0.1
Right side	0.3

Note: Measure the distance on the downstream side along the pline of the downstream side of the box. Then multiply distance by 0.5 to obtain vertical distance.

4. Remove and photograph all material from the drop box and place it on a tarpaulin.

5. Determine the intermediate diameter of the 100 largest particles. The average diameter may be measured with calipers and recorded. Record the measurements as shown below.

Particle No.	Largest Diameter centimeters	Smallest Diameter centimeters	Average Diameter centimeters
1	9	6.5	7.8
2	9	6	7.5
3	8.5	5.5	7.0
4	-	-	6.5
5	9.5	7.5	8.5
.	.	.	.
.	.	.	.
.	.	.	.
98	8	4.5	6.2
99	-	-	7.5
100	7	6	6.5

6. Photograph the 100 particles measured as a group. Use a metric ruler in the photograph for scale.

7. Select a typical shovel-full of the smallest material on the tarpaulin and place it in a sample bag. Label the bag with location, date, time, name of observer.

8. Record the photographs in the log book, the sequence in which they were taken, and the number of each photograph on the roll.

9. Distribute the remaining sediment sample evenly in the streambed downstream of the drop box.

10. Replace the cover on the drop box making certain the larger slot is on the upstream end of the box.

11. Perform sieve analysis on the sediment sample at a licensed lab.

Painted Boulders. Painted boulders are used to determine the maximum sediment size in transport in the streamflow and sediment gauging reach. Sediment sizes too large to be collected in the bedload trap can be monitored by periodic inspection. The size and number of boulders removed and brought into the reach during a flood indicate maximum transport capacity.

Flood response procedures for painted boulders include the following:

1. Photograph the boulder reach including all visible boulders. Use the same camera angles and viewpoints as used in the baseline analysis.

2. Count the number of painted boulders remaining in the reach.

3. Compare pre-flood photography of the painted boulder reach to determine if marked boulders have been buried by flood deposition, or if markings have been removed by erosion.

4. Make a brief reconnaissance of the reach to determine if boulders have been transported only a slight distance downstream.

5. Record the number of size range of boulders lost from the reach in a permanent log. Note conditions which may prevent exact determination of the boulder count, or other unusual conditions.

6. Re-mark new boulders brought into the reach to replace the number of boulders lost from the reach. Boulders should be renumbered sequentially from the last pre-flood number used in case lost boulders are later found. Photograph the new boulder alignment using established viewpoints.

Manual Sediment Samplers. Manual sediment sampling is probably feasible only at the South Mountain Park site due to access and travel time constraints. Extreme caution should be used before field personnel attempt to enter a flowing stream. Hoists or cranes are recommended over wading. Sampling should never be performed without trained emergency personnel.

General manual sampling procedures include the following:

- Avoid upstream obstructions.

- If there is material left in the bottle after the initial sample, the stream vertical may be integrated a second, or even a third time, each being additive to the same sample bottle. If additional integrated runs are made, make certain the bottle does not become full.

- Remove the bottle from the sampler and label.

U.S. DH-59 Suspended Sediment Sampler. The following procedures should be followed for manual sampling when conditions permit:

1. Securely seal a clean bottle for each sample within the body of the sampler using the spring-loaded arm.

2. Sampler can be suspended from a flexible line and raised and lowered by hand.

3. Raise and lower the sampler at a uniform rate between the water surface and the bottom of the stream. On contacting the streambed, the direction of travel is instantly reversed and the sampler raised at the same or some other uniform rate.

4. The sampler continues to take its sample throughout the period of submergence and must be removed from the stream before the bottle has completely filled. This ensures that the bottle contains sediment from throughout the entire trip, from when the bottle first entered the water until it was removed.

5. Rinse inside of sampler body.

6. Label the sample, including the:

    - Stream name
    - Location of cross section
    - Stream depth covered by sample
    - Date
    - Time
    - Personnel's initials
    - Stage of stream

7. Transport the sample to a licensed lab for total solids or hydrometer analysis.

US BMH-60 Bedload Sampler. The following procedures are applicable for manual sampling with the US BMH-60.

1. The sampler can be suspended from a flexible line and raised and lowered by hand. Upon contact with the streambed the sampler bucket penetrates the streambed and collects a sample of the bed material.

2. Rinse the bucket after removing sample.

3. Label the sampler including:

    - Stream name
    - Location of cross section
    - Stream depth covered by sample
    - Date
    - Time
    - Personnel's initials
    - Stage of stream

4. Transport the sampler to a licensed lab for sieve analysis.

Scour Gauges

Vertical Scour Chains. Vertical scour chains measure maximum event scour at a point by collapsing as bed material is scoured away, removing support for the anchored chain.

The following procedures should be used to collect scour data from vertical scour chains:

1. Real-time stage measurements should be compared to the rating curve for the station to determine if channel velocities approached erosive velocities.

2. Field conditions should be compared to pre-flood photographs to corroborate rating curve estimates of erosive velocities.

3. If it appears scour has occurred, initiate the remaining procedures. If not, photograph the reach and record conclusions in the site log book.

4. Survey the bed elevations at chain location.

5. Excavate the bed material to uncover the horizontal portion (tail) of the chain. Remove the tail from the hole.

6. Survey the elevation of the bottom of the hole.

7. Fill in the excavation with lightly compacted bed material up to 3" to 6" below streambed surface.

8. Survey the bottom of this trench.

9. Place the tail of chain in the trench in the downstream direction.

10. Fill the trench to surrounding bed elevation, covering the chain.

11. Photograph the reach and record measurements in the log book.

Horizontal Scour Chains. Horizontal scour chains measure maximum event scour for an entire cross section by collapsing as bed material is scoured away, removing support for the anchored chain.

The following procedures should be used to collect scour data from horizontal scour chains:

1. Real-time stage measurements should be compared to the rating curve for the station to determine if channel velocities approached erosive velocities.

2. Field conditions should be compared to pre-flood photographs to corroborate rating curve estimates of erosive velocities.

3. If it appears scour has occurred, initiate the remaining procedures. If not, photograph the reach and record conclusions in the site log book.

4. Survey the channel bottom between monumented anchors at each end of the horizontal chain.

5. Remove the bed material over the chain to uncover chain.

6. Bring the chain up to the surface.

7. Survey bottom of the trench (the scoured chain elevation).

8. Fill in the trench with lightly compacted bed material up to 3" to 6" below streambed surface.

9. Survey the bottom of the new trench.

10. Lay the chain in the new trench.

11. Cover up the chain.

12. Photograph the reach and record measurements in the site log.

Scour Collars. Scour collars are discs mounted on the small crest stage gauges which move vertical in response to scour around the base of the crest stage gauges. Any movement in the scour collars should be noted in the field book when checking the cork elevation on the staff in the crest stage gauges. Scour collars will only be used in the fan transects.

Transmission Loss

Piezometer Wells. Measurement of the infiltration component of transmission loss is new technology. The piezometer gauging system recommended in this report has not yet been field-tested for this application, though it is well known in groundwater monitoring. Other components of the recommended system have been successfully used in the field. However, because the transmission loss gauging system is the first of its kind, some modification of standard operating procedures may be required as specific field conditions are encountered.

Piezometers measure the pressure of a column of water in the base of the well. As channel infiltration supplies water to the perforated well bottom, water will collect and trigger the pressure transducer. The rate of infiltration with respect to depth and to the timing of the flood wave can be measured in this way.

Data collection from flood response for the piezometer wells includes the following:

1. Download data from data loggers.

2. Examine collected data according to the data collection quality control plan.

3. Data should be archived in conjunction with streamflow measurements for the transmission loss reach.

4. Record information and actions taken, along with site name, date, time, etc.

Maintenance Requirements

Maintenance means labor performed on gauges intended to keep the gauging system in working order, excluding flood response. Maintenance items may include:

- Inspection between flood events
- Repair of damage from vandalism or natural forces
- Recalibration of sensors

All of the non-standard gauges not connected to telemetry or data loggers will require biannual inspection to ensure that they have not been damaged by animals, vandals, or other forces. Inspection should take place immediately prior to the flood seasons. Instrumentation which uses telemetry or data loggers can be inspected as part of routine electronic servicing.

Streamflow

Crest Stage Gauges. Scheduled maintenance activities:

1. Check all parts for function. Specifically, the staff and cork reservoir should be in good condition.

2. Check intakes for blockage.

Sediment Gauges

Turbidimeter. Scheduled maintenance activities:

1. Clean optics every 3-6 months.

2. Recalibrate sensor.

U.S. U-59D Suspended Sediment Sampler. Scheduled maintenance activities:

1. Check all parts for function. Specifically, the tubing and bottles should be in good condition.

2. Check intakes for blockage or bending.

3. Check the orientation to ensure that the intake nozzles are still pointing directly into the flow path.

4. Check condition of nozzle, seals, and tension in spring of the arm that secures the bottle.

Drop Box Bedload Trap. Scheduled maintenance activities:

1. Check trap for aeolian and miscellaneous debris.

2. Clear intake.

Painted Boulders. Scheduled maintenance activities:

1. Inspect for conformity with previous boulder counts and boulder position.

2. Photograph the painted boulder reach.

Manual Sediment Samplers. Scheduled maintenance activities include:

1. Check moving parts for easy movement.

2. Check seals and trap locking mechanism.

Transmission Loss

Peizometer Wells. Periodic maintenance of piezometer wells includes biannual:

1. Inspect the water-tight well cap.

2. Recalibrate the pressure transducer. An electronic moisture sensor (electronic sensor) may extend to the base of the well to determine the depth, if any, of water in the well. The pressure transducer may then be zeroed accordingly.

3. Test data transmission from the pressure transducer in the bottom of the well to the data logger or telemetry unit.

Monitoring Procedures

The recommended monitoring procedures for the Alluvial Fan Project include baseline, flood response, and periodic procedures. Baseline procedures are steps which must be completed prior to data collection which are not part of the installation plan. Flood response procedures are tasks done in the office or field required to organize and systematize data collection after a flood occurs at one of the sites. Periodic procedures are completed at regular time intervals as part of the long-term data collection plan. A summary of these procedures for each site is presented in the following section and in Tables 16 to 19.

Baseline Procedures

Baseline procedures are steps which must be completed prior to data collection which are not part of the gauge installation plan. These procedures are required to determine proper installation parameters, to interpret data as it is collected, and to set up quality control and data management criteria.

Precipitation

Effective precipitation monitoring requires at least two baseline procedures: Rainfall weighing and HEC-1 modeling. Rainfall weighing involves construction of Thiessen polygons for each watershed. Thiessen polygons are used to determine the relative influence of the nearest rain gauges to a particular watershed. The Thiessen polygons will also be used in rainfall-runoff modeling.

Detailed HEC-1 modeling of each watershed should be completed which reflects the locations of precipitation and streamflow gauges. The HEC-1 models completed by the FCDMC for Part I of this study may be modified to reflect concentration points at streamflow stations, and watershed divisions based on precipitation gauges. Thiessen polygons will be used to properly weight rainfall input for flood forecasting models. For reconstruction of specific storm events, the isohyetal method of weighting rainfall is recommended. FCDMC ARC/INFO-ARC/DATA software is capable of performing isohyetal weighting and directly infacing results with HEC-1.

HEC-1 modeling can be used in several ways. First, ALERT HEC-1 software can be used in conjunction with real-time precipitation measurements to improve lead-time for flood observation and manual sampling. Second, HEC-1 modeling can be used for quality control of streamflow and transmission loss measurements. Third, HEC-1 models can be used for hindcasting and extrapolation of measured data to other watersheds.

Streamflow

Baseline procedures for streamflow monitoring involves construction of rating curves for discharge measurement stations. Rating curves will be used for several key procedures. First, rating curves are required to translate stage measurements obtained by pressure transducer, float, and crest stage gauges into discharge values. Second, velocity rating curves will be used to determine expected scour depths. Scour depth estimates are required to set gauge anchoring and piezometer well depths, and to determine potential error ranges for rating curves. Third, rating curves will be used to determine thresholds for sending field crews for data collection, for initiating aerial photography, and for determining flood frequency. Finally, rating curves will be used in conjunction with sediment sampling to determine transport capacities and rates.

Determination of a rating curve is not truly a one-time procedure. As new data from scour chains, stage gauges, and manual measurements are collected, the rating curves should be checked and revised where appropriate. Conclusions based on early versions of the rating curves, such as sampling thresholds, should also be revised as rating curves are adjusted.

Sediment Transport

Baseline procedures for sediment transport include sieve analysis of channel and overbank sediments. Sieve analyses of bed material in sediment transport gauging reaches may be used as a baseline estimate of bed load gradations. These data, in conjunction with velocity ratings, may be used to determine erosive thresholds needed to estimate the likelihood of significant scour. Sieve analysis of overbank sediments on the fan surface may be used to quantify changes due to overbank deposition or erosion occurring in conjunction with fan aggradation.

Scour

Scour baseline procedures include estimation of maximum expected single event and long-term scour depths for each in-stream gauge installation. Scour computations may be based on rating curves and standard engineering procedures described elsewhere.

Transmission Loss

Transmission losses in fan channels will be monitored at two sites, Tiger Wash and South Mountain. Baseline procedures for transmission loss monitoring include dual-ring infiltrometer tests, sieve analyses, and geophysical testing. Dual-ring infiltrometer testing of saturated channel bed infiltration rates within the transmission loss reaches will be used as the first approximation of expected infiltration. Infiltrometer tests should be equally spaced throughout the entire reach. Sieve analyses of channel bed sediments should be conducted at each infiltrometer test site so that a relationship between bed sediment distribution and infiltration may be established. These data will facilitate extrapolation of results.

Geophysical testing, such as seismic refraction, will be used to estimate bedrock depths along these channels, to determine if caliche is developed strongly enough to prevent infiltration, and to set piezometer well depths. The refraction surveys should be performed using 200-foot spreads, with a gap of 200 feet between spreads. Each spread should consist of 12 geophones set in the ground at 20-foot intervals, except for the interval at each end which should be set at 10 feet. There will be two shotpoints used for each spread located 10 feet from each end of the spread. Shotgun shells (black powder blanks) may be used as the seismic energy source at each shotpoint.

Geomorphology

Site geomorphology includes fan aggradation, channel bank erosion, avulsions, and soils mapping. Baseline procedures for geomorphology not completed in Part I of the study include surveying fan transects, preparing detailed fan topography, and identifying likely erosion areas. Fan transects shown on Figures 58 to 61 should be surveyed in conjunction with installation of small crest stage gauges and scour collars. Detailed photo-based DTM topography for the South Mountain and Sierra Estrella sites is provided as a deliverable with this report. Similarly detailed topography for the White Tank Mountain and Tiger Wash sites should also be prepared. From the photo-based detailed DTM topography and surveyed transects, geomorphological information such as aggradation, degradation, channel erosion, and avulsion location can be monitored.

The baseline aerial and topographic mapping effort for each of the four fans includes the following tasks: (1) establish permanent ground monumentation; (2) prepare aerial photographs providing stereo coverage on 9" x 9" format; (3) create DEM (digital elevation models) compatible with Microstation and ARC/INFO software; (4) prepare scanned images of the photos for overlay on topography in Microstation environment.

Level and stadia surveys of stream cross sections in all streamflow and sediment gauging reaches should be performed. These cross sections will be used to construct rating curves, set baseline conditions for determining channel changes, and determine fan aggradation rates. Final section location and alignment should be determined in the field during installation of the gauging equipment. Vertical and horizontal control should be tied to the permanent monuments established for the aerial survey. Permanent monumentation should be installed at the end points of each cross section during the first or baseline field survey. Station and elevation should be defined for top and toe of banks, and inverts for all channel and braids, high water elevation, and slope breaks. Where grades are relatively constant, points should be taken at regular intervals not to exceed 50 feet. Elevations should be measured to the nearest 0.1 foot. Stations should be numbered from left to right facing downstream. Photo-documentation of each section is recommended.

Remote Sensing

Baseline remote sensing tools include composite radar imaging and aerial photography. Aerial photography baseline requirements were described elsewhere.

Radar-based data used in conjunction with ALERT data will be a key tool for making decisions about mobilization of field crews. Video records of the radar images will be used to augment the field and gauge data after storm events for determining storm tracking and areal distribution of rainfall. Data obtained from the radar images may be interfaced with a GIS database using such techniques as stepped-gain contour tracing or grid overlay methods. With time it may be possible to interface HEC-1 modeling with radar overlays in GIS for flood forecasting and hindcasting.

The existing FCDMC radar link may be inadequate for monitoring of the four alluvial fan sites. In addition to the system limitations described elsewhere, portions of the White Tanks, Sierra Estrella, and Tiger Wash fans are located in "radar shadows," areas where mountains block radar transmissions. Radar coverage of these areas, therefore, is incomplete. Therefore, it is recommended that NOWrad imaging be used to eliminate radar shadows and enhance site monitoring.

Staffing and Equipment

Staffing for baseline procedures should include a 2-man survey/gauging team accompanied by a hydrologist/geomorphologist with training in gauge installation. Staffing requirements for the instrumentation phase of the project are discussed elsewhere in this report.

Equipment needs for field procedures include:

- Waterproof field notebook and markers
- Shovel
- Posthole digging tool
- Sample collection bags
- Sample bottles
- Marking labels
- Engineer's level or transit and stadia
- Survey chain
- 100 ft and 25 ft tape measures
- 35mm camera or VCR recorder
- Drinking water
- Safety and first aid equipment
- Tools and replacement parts for gauging and logging equipment
- High visibility spray paint
- 4-wheel drive vehicle and radio communication.

Flood Response Procedures

This section summarizes the flood response procedures for the entire monitoring plan, and discusses procedures not directly related to specific gauges. Flood response procedures for specific gauge types are described elsewhere in this report.

Field Procedures Summary

1. Check of all equipment. Without disturbing the gauges, document vandalism, sediment buildup around gauges, eroded gauges, tilting gauges, reference mark condition, missing locks, aggradation or degradation of channel, etc. Document high water marks with pictures, stakes (or some temporary mark), or flags. Photograph each gauge.

2. Check and document condition of recorders. Download data from data loggers.

3. Read the full-size crest stage gauges according to the procedures outlined elsewhere.

4. Collect suspended sediment samples from the U-59D and bedload samplers according to procedures outlined elsewhere.

5. Locate and inspect the scour chain reaches. If scour has occurred, determine the scour depths as outlined elsewhere.

6. Locate and service painted boulders.

7. Resurvey all crest stage, scour chain, and streamflow gauge reaches using reference marks located at the gauge stations, including all high water marks.

8. Service gauge transects on the fan surface, and photograph highwater marks, fresh erosional or depositional surfaces.

9. Service transmission loss gauges.

10. Record all activities in the site log book.

Office Procedures Summary

Aerial Photography. Aerial photography and topographic mapping will provide the core data for evaluating long-term changes in the channel systems of the study areas. A series of aerial photographs can be used to identify and quantify changes in channel location and alignment, flow path and pattern, sinuosity, and braiding. If the area is flown immediately following major flood events, inundated areas and areas of scour and deposition also may be discernable. The photographic series should be produced in constant scales and/or be digitized into an electronic data format such as Microstation to facilitate comparisons. Characteristics identifiable from the photographs can be coded as attributes in a GIS database coverage for future comparison and analysis.

Two separate flights will be required. The first flight would be a low level, vertical or oblique photograph taken without ground control immediately after the storm. Saturated soils and recent fine-grained sediment deposits may be readily distinguishable in these photographs. These photos can also be used to confirm the need for preparing more expensive, ground-controlled photographs and topographic maps as described below.

When the flood event exceeds a predetermined threshold that is expected to result in significant channel changes or movement of sediment, revised photography should be provided and new topographic mapping prepared for the affected reaches. The threshold parameters may include precipitation-based or streamflow-based data gathered and received through the gauging network. Specific threshold values must be developed for each study area and revised based on experience as the data are collected. Recommended beginning values are the 10-year, 6-hour precipitation depths, and the 5-year discharge at the hydrologic apex.

Similar thresholds may be used to initiate topographic resurveys. However, due to the cost of preparing DTM models, field conditions should be checked to determine the need for new topography. In addition, if flood impacts are found to affect only a small portion of the fan, topography for only that portion may be prepared to minimize cost.

Radar Images. NOWrad images should be taped on a VCR as threatening storm conditions arise. If no runoff occurs on the fan the VCR tapes or disks may be erased and reused. Tapes of radar images of storm movement for events that produce runoff and channel changes should be kept and archived for detailed analysis. NOWrad images may be archived on floppy disks or VCR tape.

Periodic Procedures

Periodic procedures for the monitoring plan include updates of aerial photography, DTM topographic models, and radar technology, as well as scheduled maintenance of the gauges. Periodic maintenance requirements for gauges are described elsewhere.

Aerial Photography and Mapping

Periodic mapping updates will provide a time series record of topographic changes in the study areas. These updates should be performed at 5-year intervals, including field-checking ground control monumentation, resetting control panels, and production of new photography. The updated photographs can be compared with the previous set to determine whether new DTM topographic mapping is needed. If no significant changes have occurred, the new photographs can be added to the database and archived. If significant channel changes have occurred, revised topography can be prepared for the affected reaches or for the entire study area.

Field Survey

Field surveys and measurements should be performed at regular time intervals, as well as after major flood events. These tasks can be done along with the regular semi-annual maintenance of the gauging equipment.

Radar

Periodic maintenance of radar technology is not needed. However, NEXRAD imaging scheduled for delivery to the Phoenix area in 1994, should be investigated for its utility and effectiveness in the monitoring network.

Data Management

As the data collection phase of the Alluvial Fan Data Collection and Instrumentation Study Project progresses, a large quantity of information will be generated. These data will vary greatly in format, medium, priority, and accuracy. Information used to trigger mobilization of field crews or flood warning must be acted upon immediately. Other information will only be used for quality control, or as models are developed which use or simulate those data months or even years after collection. These data will be collected by a diverse staff, at irregular intervals, over a period of years while the technology for collecting, storing, and interpreting the data changes. This section describes the anticipated database attributes and parameters that are recommended for this project.

Recommendation of a specific data base management system (DBMS) or DBMS vendor was not made as part of this report. Rather, it is recommended that given the anticipated expense of a fully functional DBMS which meets the criteria outlined below, a thorough survey of the needs of the entire FCDMC staff be made to determine appropriate systems. The FCDMC ALERT database, software, and applications programs are adequate to store data collected through telemetry and data loggers. In addition, the FCDMC ARC/DATA GIS system may also be used to store geographically based information and generate maps of specific floods. Finally, a generic database software package such as dBase IV+, may be programmed to accept and store manually collected non-spatial data such as sediment gauge measurements, crest stage gauge measurements, and field notes and descriptions.

The District's ARC/INFO-ARC/DATA GIS system lends itself well to the storage and use of many of the types of data that will be generated through this program. Base coverages for topography, stream channels, soil and vegetation types, and other geographically distributed parameters should be created. Measured values for each gauge can be stored as attributes at each gauge location. Evaluation of the data can then be streamlined using the graphical and analytical capabilities of the software. The major constraints to this application are the quantity of the data, and the data entry and manipulation effort. This effort may be significantly reduced by developing linkages between the electronic data from the data loggers and ALERT system, and the GIS.

Data Base Management System Selection Criteria

Data management encourages integration and correlation of the District's stored data. When selecting the data base management system (DBMS), the District should consider the variables described in the following paragraphs.

Flexibility

The most important characteristic of the DBMS is flexibility. Given the expected project duration and the originality of both the project and instrumentations systems which comprise the project, a flexible DBMS is required to allow for changing technologies and project goals. The DBMS should be expandable to handle new categories of data (for instance, water quality) and accept changes in format. To be fully flexible, the DBMS should provide a variety of data types as well as time series and geographic data. The DBMS should store and access information on reports, files, changes to record, changes to sampling techniques, equipment modifications, quality of data, dates of data entry, gauge information, etc. The system should be able to store and access not only raw data but quantities derived from calculations, such as streamflow calculated from gauge height.

Other flexibility criteria include the ability to refer to data temporarily or spatially, and to include data not necessarily generated by this study, such as USGS or NWS data; and to backtrack to raw data to see what formulas, etc., were used for computations.

On-line Direct Access

On-line direct access offers a flexible, user-friendly, menu-driven user interface. Benefits include easy access to data, especially by non-technical users. On-line direct access also allows quick response time to inquiries. Finally, on-line direct access allows detailed data requests to be retrieved in a short, fixed interval (for instance, 15 minute) format for use in data review and modeling.

PC Based

The DBMS system should use PC operating systems, or should down- and up-load to personal computers to facilitate communication between standard programs such as spreadsheets, ASCI text files, HEC-1, and HEC-2. Users would be able to generate and format groups of data for reports, engineering applications, and to save formats for future use using a menu generator that customizes the view screen.

Statistical Analyses

The DBMS system should provide summary statistics in readily available minimum, maximum, average and durational values for a series of annual or partial duration time periods. In this way the system should also allow access to regression and statistical analyses. The system could be used to estimate design flows (for instance, 100- or 50-year discharges).

Similarly, an effective system would interrelate data for analysis, including relating data values to associated rating curves; mixing and comparing data for analysis (for instance, precipitation vs. streamflow, water velocity vs. length of minor axis of median particle size transported in bedload). The DBMS should be able to display interrelated data graphically in two or three dimensions. The DBMS can integrate and correlate data within data types such as time series data, geographic data, sediment characteristics, and equipment maintenance as well as across data types.

Report Generation

The DBMS should provide a report generator with request screens. Standard detail and summary reports could be developed and stored as needed. The DBMS should also provide ad hoc query capability with simplified, on-line query language. It should also allow selection of records based on complex criteria, then sort the selected data and generate a summary report. Individually created input data files should also be available as a report feature. This would allow automated development of input files for other applications such as HEC-1 or HEC-2.

The DBMS system should also be able to provide summaries for the current water, fiscal or calendar year, with historic data for comparison. Summary data should appear in annual, monthly, daily, hourly, or minute time increments. Output should be able to be displayed graphically.

Security

To maintain appropriate security measures, multiple security levels are recommended. Access to change raw, historical data entry could be limited to certain staff. Since multiple users are anticipated, simultaneous modification of data is prevented so as not to lose data integrity.

The DBMS system selected should provide an established, regular backup procedure. Transaction processing (e.g., modification of data) is applied completely so that all other data affected are appropriately modified thus maintaining consistency of the database. If the transaction is not completed properly, then the completed parts of the transaction are reversed or backed-out to ensure database consistency. Automatic recovery from hardware or software failure is desirable to minimize data loss. In addition, the system should have the ability to perform logical as well as physical back-up and recovery.

Durability

For future use, the system needs to be easily upgraded and compatible not only with other computer systems, but also with support modeling applications. Finally, the system should provide a guarantee of long-term support from the vendor, protecting data integrity through advances in software and hardware technology.

Quality Control

The ultimate success of the monitoring project and its goals depend primarily on the quality of the data collected. A data collection plan has been presented in the previous sections to ensure the quality of information types collected. Some quality control procedures are outlined in the following section to help ensure that information gathered from the gauges accurately reflects field conditions.

Data Verification and Quality Control

Evaluating the accuracy of the collected data will be especially difficult for this project for several reasons. First, several techniques employed are either new or modified applications of techniques developed for other uses. In both cases, calibration and ranges of accuracy may be limited. Second, the levels of redundancy designed into this program are unusual and result in a unique problem. Although the redundant measurement of a single parameter obviates errors simply by the variation in resultant data, it is difficult to determine the "right" data. It also does not differentiate between random and systematic errors until many measurements are collected and analyzed. Third, the quantity of data that may be collected during a single event will require significant resources to evaluate and store. Finally, because of the non-homogeneous nature of the four sites, data from each site must be considered independently.

Since the objective of this project is to collect data that can be used for research, including the development and verification of predictive relationships of alluvial fan processes, it is essential that the degree of accuracy and error in the measurements be evaluated. Accepted statistical methods should be used for this evaluation. These methods will not be addressed here, however, the data management program should include a review of the collected data to identify outliers and missing data. As a series of records is produced, random and systematic error sources should be differentiated wherever possible. When systematic error is identified, data collection methodologies should be adjusted.

Both digital and analog data must be routinely examined for sudden changes not correlated to similar changes in related parameters. For example, rapid changes in stages not accompanied by similar changes in the rainfall record, may indicate clogged intakes or faulty recorder action.

When a flow event has occurred, and has resulted in several estimates of the water surface elevation,an interactive computer program should be developed to accept the data; output an answer; and recommend if the output is reasonable or if further consideration is necessary. In the case of a peak flood flow estimation, both precipitation data and previous modeling results should be available. Therefore, the interactive program could require the recorded precipitation data and a rainfall-runoff model be used to compute a modeled peak flow. If the distribution of peak flows has already been estimated, the estimated peak flow could be compared to the peak flow probabilities associated with the estimated probability distribution and determine by standard statistics if it should be considered an outlier.

Site Monitoring Plans

Monitoring plans for each of the four alluvial fans sites are summarized in Tables 16 to 19. These tables are intended to be used by field crews and office personnel for scheduling specific tasks required for successfully monitoring alluvial fan flooding. These tables are based on procedures outlined in preceding sections of this report. Figures 58 to 61 show the location of each gauge at each monitoring site. Site monitoring plans outlined below summarize the following:

- Specific or unique objectives for each site
- Site access routes
- A schedule of monitoring procedures

South Mountain

Site Objectives

Key objectives for data collection at the South Mountain Park site are manual measurements and observation of flooding. Proximity of the site to FCDMC headquarters make rapid response possible. Monitoring of channel migration and flow distribution are key goals for the instrumentation phase. Construction of the South Mountain Freeway Loop at the base of the fan will provide opportunities for sediment gauging and flow volume measurements. Inclusion within park boundaries ensures that development will not directly alter the geomorphology, and will provide some protection against vandalism.

Access

Access to the fan apex follows paved park roads. From Central Avenue, go south to the South Mountain Park main entrance. Continue west and south on the main road, through a four-way stop. Turn right on the San Juan Vista Road 1.2 miles after the stop sign. San Juan Vista Road parallels the primary fan wash, crossing its main tributaries several times. Continue west on San Juan Vista Road to a broad turn north just past milepost 4.0. The fan apex is approximately 1,000 feet southeast of this bend. The proposed locations of gauges are shown in Figure 58.

White Tank Mountains

Site Objectives

The White Tank Mountains site has both fan terraces and a distributary flow system, which are by far the most common type of alluvial fans in Maricopa County. This site offers opportunities to gauge both. Because runoff recombines in the fan terrace downstream of the DFA, flow attenuation and transmission losses in the DFA can be gauged. Portions of the area have the potential to develop within a 20 to 50 year

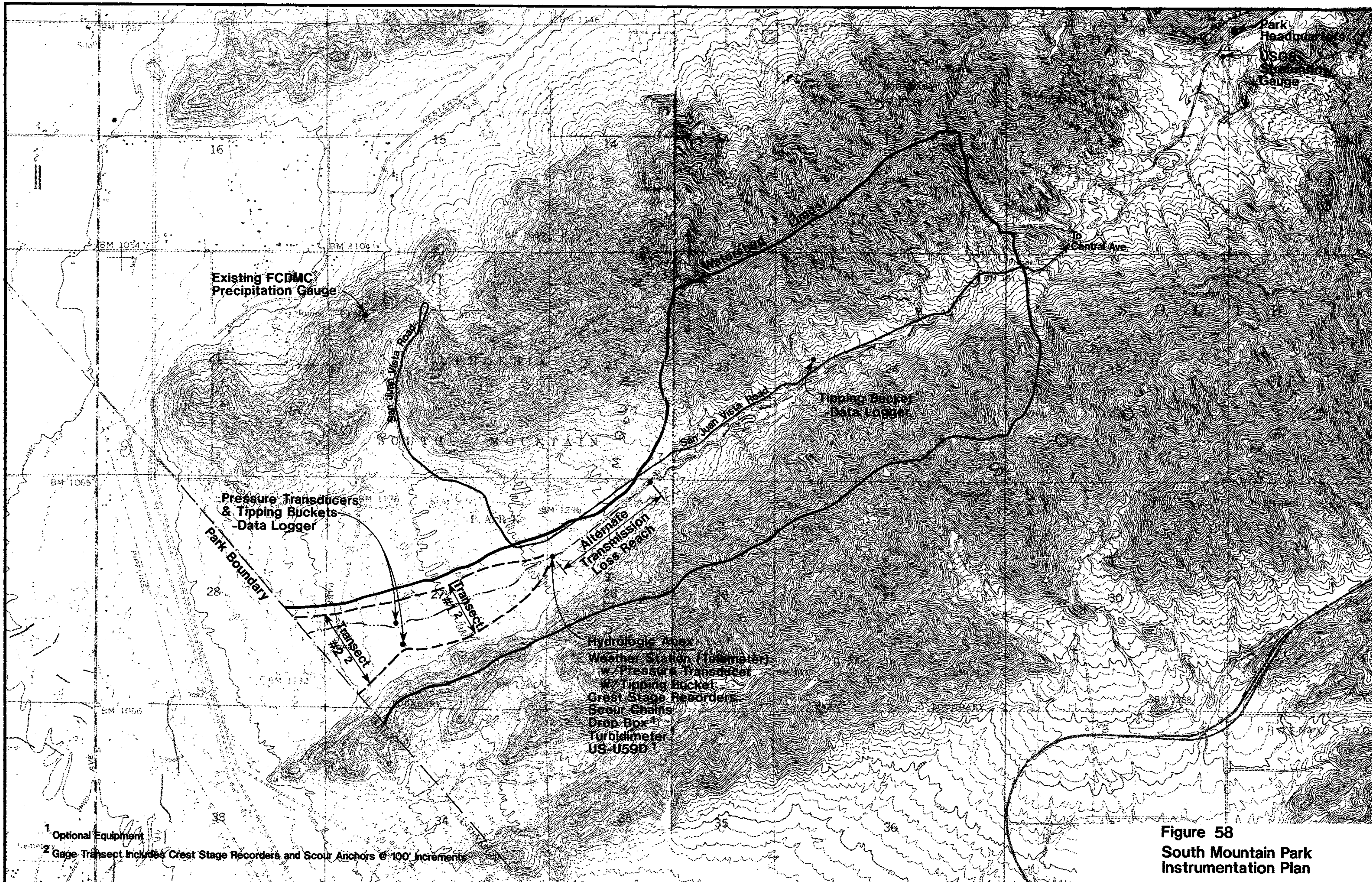


Figure 58
South Mountain Park Instrumentation Plan

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period. Most importantly, gauging the White Tank site will help distinguish active alluvial fan processes from distributary flow system processes.

Access

Access to the site follows paved highways and graded dirt roads. To reach the site, take Interstate 10 west to exit 114 (Miller Road). Take Miller Road north less than 0.25 mile, and turn west on a graded dirt road. Continue west and northwest to the first powerline road. Veer north on powerline road for 3.0 miles past several bedrock knobs, then turn north on a privately maintained dirt road. Proceed north 0.8 miles, and turn west at a "Y" in the road. The primary channel of the White Tanks site below the distributary flow area crosses the road here in a culvert/dip crossing. Turn north after the crossing and travel 0.6 miles to a "No Trespassing" sign. Turn east at the sign and go 0.7 miles to another powerline road, then turn northwest toward the distributary flow area.

To reach the hydrologic apex, travel northwest through the widest portion of the distributary flow area for 0.6 miles and turn east on a dirt road which parallels the wash. Travel 0.8 miles, then turn south through the wash. The apex is located 0.2 miles downstream from this crossing. The upper portion of the watershed is accessed by staying on the road which parallels the wash. The proposed locations of gauges are shown in Figure 59.

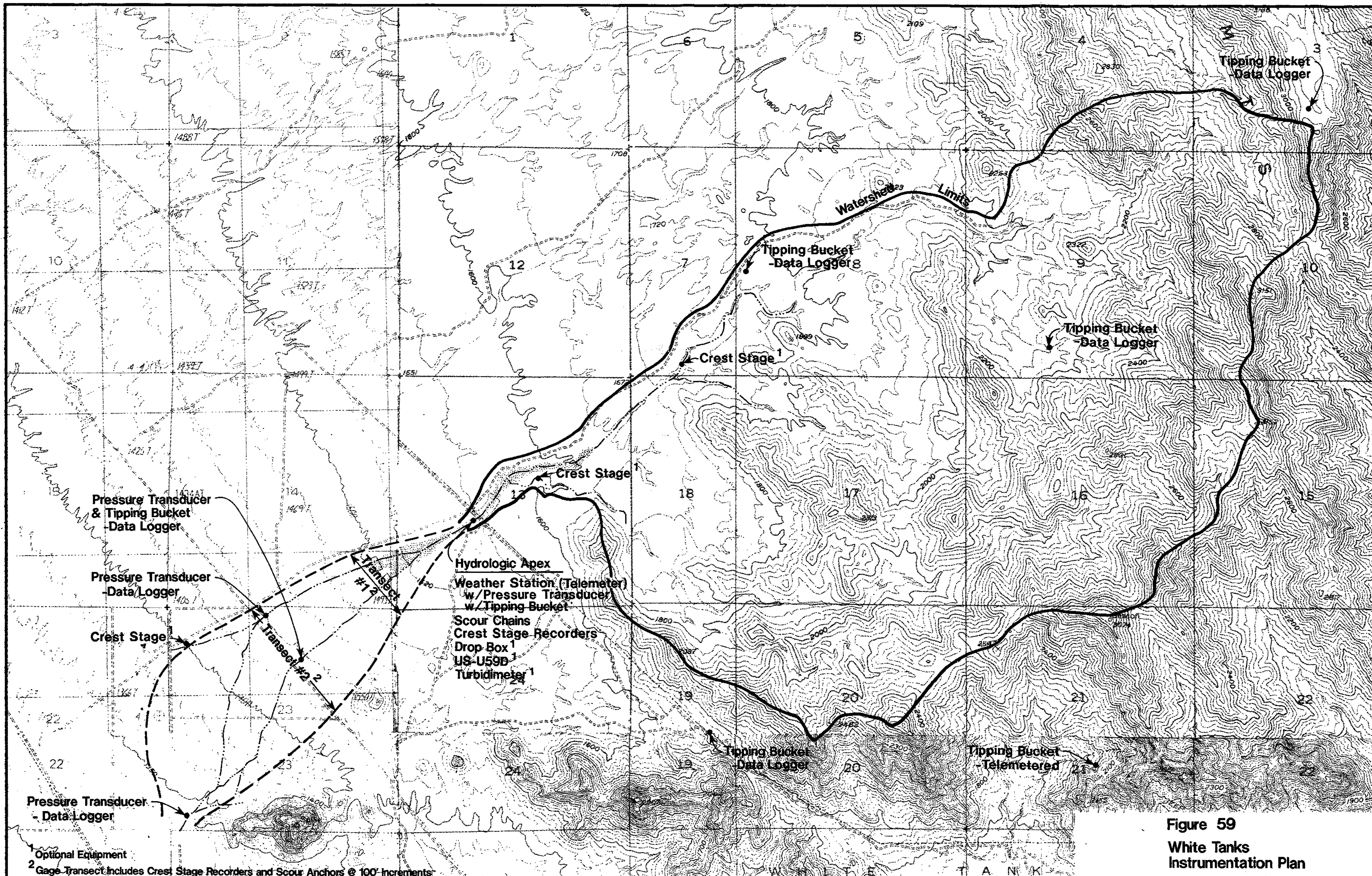
Tiger Wash

Site Objectives

The Tiger Wash alluvial fan was selected because it is an active alluvial fan and a distributary flow system, is likely to remain natural, has good all-weather access, and has a good historical and paleoflood record. In addition, there are opportunities to collect sediment samples and monitor transmission loss. It is also the largest of the four sites, and probably experiences the most frequent runoff. Primary gauging objectives include transmission loss, channel movement, sediment deposition, and sheet flooding.

Access

The site area can be reached via publicly maintained paved roadways. From Phoenix, take Interstate 10 west to exit 81 (Buckeye-Salome Highway). Proceed northwest 9 miles to Eagle Eye Road and turn due north. Eagle Eye Road follows a shallow ridge between the east and west braids of the distributary flow paths. The active alluvial fan is located along the western braid. Access to the active alluvial fan apex is an unmarked dirt road (heading west) located approximately 3 miles north of the intersection of Buckeye-Salome Highway and Eagle Eye Road. The apex access road is located between the cattle guard and a well travelled dirt road to a large stock pond



[1] Optional Equipment
[2] Gage Transect Includes Crest Stage Recorders and Scour Anchors @ 100' Increments

Figure 59
White Tanks
Instrumentation Plan

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east of Eagle Eye Road. Access to the distributary flow apex is through the upper abandoned gravel pit located upstream of the dip crossing on Eagle Eye Road. The proposed locations of gauges are shown in Figure 60.

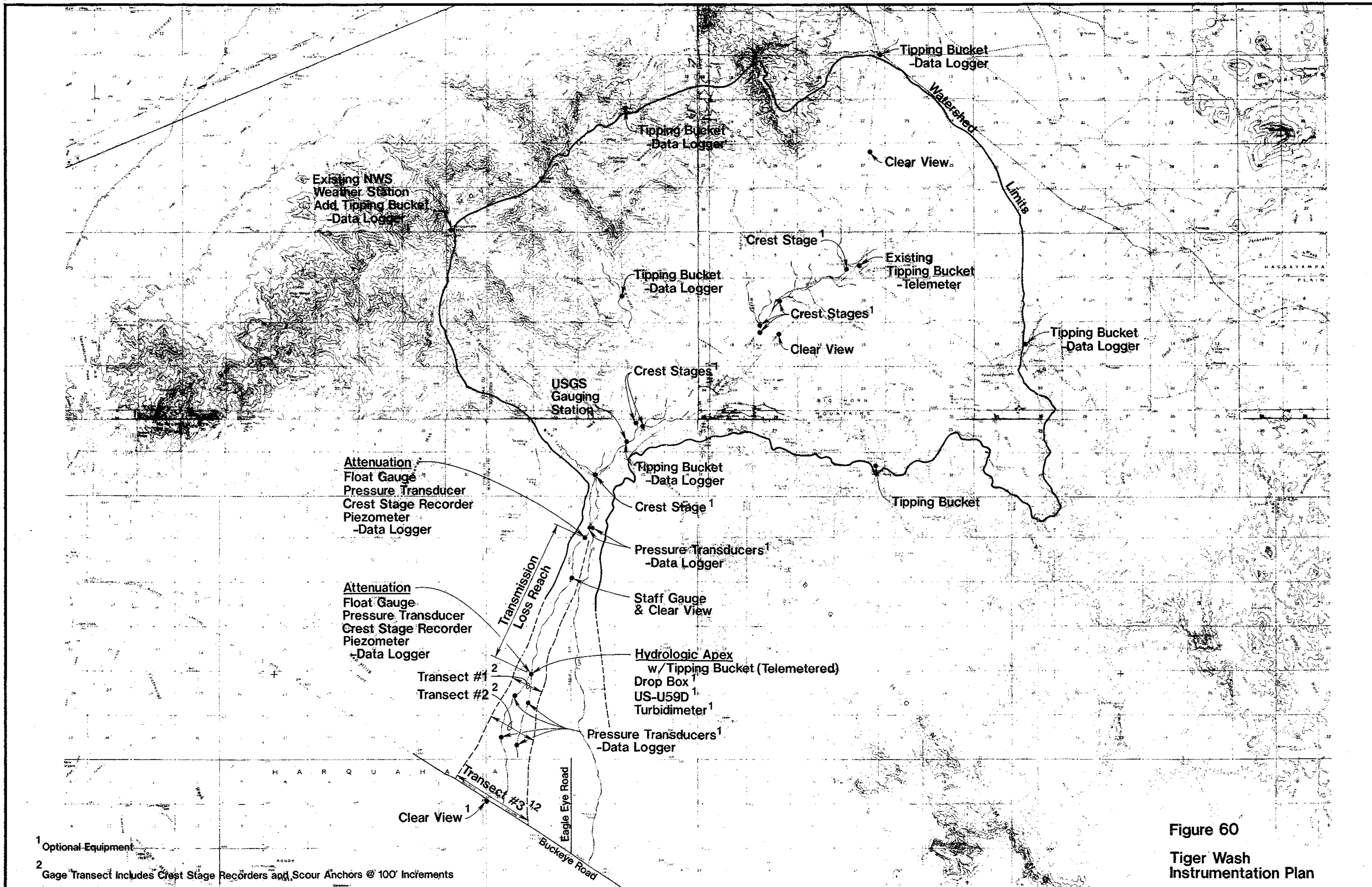
Sierra Estrella

Site Objectives

The west side of the Sierra Estrella Mountains has a number of apparently active alluvial fans, unlike the other mountain ranges in the County. Comparison of this fan to other Maricopa County fans will yield important information regarding formation of active fans. This fan is different from many of the other active alluvial fans in Maricopa County in that it is located immediately adjacent to the mountain front. However, the Sierra Estrella site may be more like active fans located in Nevada and southern California, and thus will serve as a comparison with what FEMA considers to be "typical" fans.

Access

Access to the site is via paved public roads and publicly maintained dirt roads in poor condition. From Phoenix, take Interstate 10 west to the Estrella Parkway exit. Travel south to the end of the pavement on Estrella Parkway. Continue south approximately 4 miles, past and around a large stock pond and several bedrock knobs to the east. The road then follows a fallow field and dry swale for approximately one mile and then intersects a fence line. Turn east at the fenceline and proceed to a large bermed channel and dip crossing. After crossing the channel, jog south then east and follow the winding, well-tracked dirt road to the Salt River Project (SRP) powerline seen in the distance. Turn east at the SRP powerline. Follow the powerline road about 2 miles east to the point where the powerline road turns southeast. The braids of the fan cross the road at this point. A jeep trail breaks off to the northwest which leads to the hydrologic apex. The proposed locations of gauges are shown in Figure 61.



[1] Optional Equipment

[2] Gage Transect Includes Crest Stage Recorders and Scour Anchors @ 100' Increments

Figure 60

Tiger Wash Instrumentation Plan

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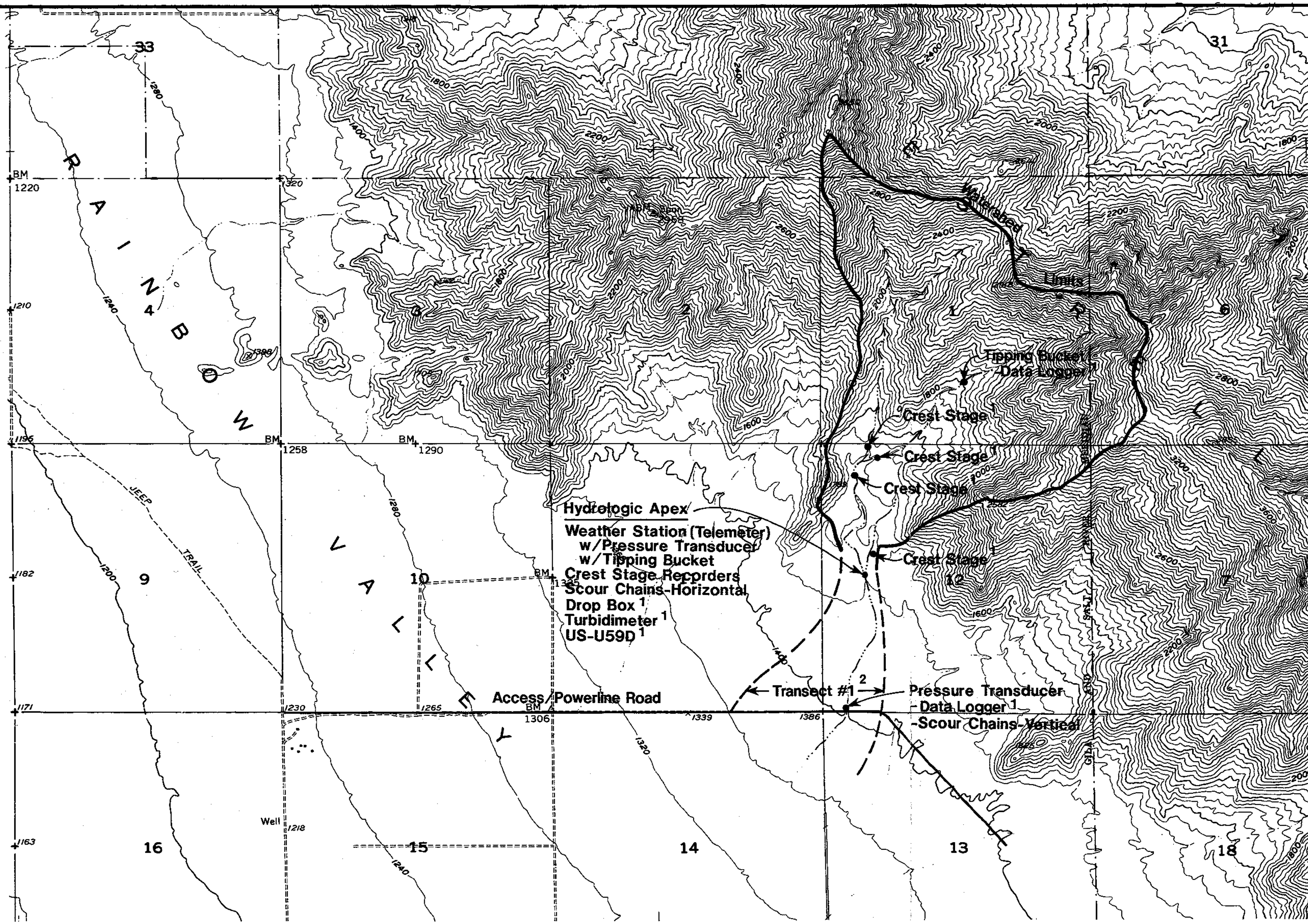

[1] Optional Equipment

[2] Gage Transect Includes Crest Stage Recorders and Scour Anchors @ 100' Increments

Figure 61
Sierra Estrella Instrumentation Plan

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TABLE 16
SOUTH MOUNTAIN
MONITORING PLAN

ACTIVITY	BASELINE	POST FLOOD	6-MONTH	ANNUAL	5-YEAR
Mapping					
Aerial Photography	D	D			D
Ground Control	D	I			D
Set/Check Monuments	D	I		I	D
Topographic Mapping/DTM	D	I			D
Satellite Images	D	D			D
Field Survey Sections	D	D			D
Seismic Survey	D				
Infiltration Testing	D				
Hydrologic Modeling	D				
Sediment Transport/Scour					
Sieve Samples	D				D
U-59 Sediment Sampler		D,M	I,M		
Manual Samplers		D	I		
Drop Box Sediment Sampler		D,M	I	M	
Excavate/Survey Scour Chains	D	D			D
Excavate/Survey Scour Discs	D	D			D
Locate & Document Painted Boulders	D	D			D
Gauges					
Tipping Buckets		D,M	I		
Pressure Transducers		D,M	I,M		
Crest Stage Recorders		D,M	I,M		
Weather Stations		D,M	I		
Water Temperature Gauges		D,M	I		
Data Loggers		D,M	I,M		
Telemetry Equipment		D,M	I		

RECOMMENDED ACTIVITIES	(dark shading)
CONDITIONAL ACTIVITIES	(light shading)
NO ACTIVITIES	(blank)

INSPECTION	I
MAINTENANCE	M
DATA COLLECTION/MEASUREMENT	D

TABLE 17
WHITE TANKS
MONITORING PLAN

ACTIVITY	BASELINE	POST FLOOD	6-MONTH	ANNUAL	5-YEAR
Mapping					
Aerial Photography	D	D			D
Ground Control	D	I			D
Set/Check Monuments	D	I		I	D
Topographic Mapping/DTM	D	I			D
Satellite Images	D	D			D
Field Survey Sections	D	D			D
Seismic Survey	D				
Infiltration Testing	D				
Hydrologic Modeling	D				
Sediment Transport/Scour					
Sieve Samples	D				D
U-59 Sediment Sampler		D,M	I,M		
Manual Samplers		D	I		
Drop Box Sediment Sampler		D,M	I	M	
Excavate/Survey Scour Chains	D	D			D
Excavate/Survey Scour Discs	D	D			D
Locate & Document Painted Boulders	D	D			D
Gauges					
Tipping Buckets		D,M	I		
Pressure Transducers		D,M	I,M		
Float Gauges		D,M	I,M		
Crest Stage Recorders		D,M	I,M		
Weather Stations		D,M	I		
Water Temperature Gauges		D,M	I		
Piezometers		D,M	I		
Data Loggers		D,M	I,M		
Telemetry Equipment		D,M	I		

RECOMMENDED ACTIVITIES
CONDITIONAL ACTIVITIES
NO ACTIVITIES

INSPECTION	I
MAINTENANCE	M
DATA COLLECTION/MEASUREMENT	D

TABLE 18
TIGER WASH
MONITORING PLAN

ACTIVITY	BASELINE	POST FLOOD	6-MONTH	ANNUAL	5-YEAR
Mapping					
Aerial Photography	D	D			D
Ground Control	D	I			D
Set/Check Monuments	D	I		I	D
Topographic Mapping/DTM	D	I			D
Satellite Images	D	D			D
Field Survey Sections	D	D			D
Seismic Survey	D				
Infiltration Testing	D				
Hydrologic Modeling	D				
Sediment Transport/Scour					
Sieve Samples	D				D
U-59 Sediment Sampler		D,M	I,M		
Manual Samplers		D	I		
Drop Box Sediment Sampler		D,M	I	M	
Excavate/Survey Scour Chains	D	D			D
Excavate/Survey Scour Discs	D	D			D
Locate & Document Painted Boulders	D	D			D
Gauges					
Clear Views		D,M	I,M		
Tipping Buckets		D,M	I		
Pressure Transducers		D,M	I,M		
Float Gauges		D,M	I,M		
Crest Stage Recorders		D,M	I,M		
Weather Stations		D,M	I		
Water Temperature Gauges		D,M	I		
Piezometers		D,M	I		
Data Loggers		D,M	I,M		
Telemetry Equipment		D,M	I		

RECOMMENDED ACTIVITIES
CONDITIONAL ACTIVITIES
NO ACTIVITIES

INSPECTION	I
MAINTENANCE	M
DATA COLLECTION/MEASUREMENT	D

TABLE 19
SIERRA ESTRELLA
MONITORING PLAN

ACTIVITY	BASELINE	POST FLOOD	6-MONTH	ANNUAL	5-YEAR
Mapping					
Aerial Photography	D	D			D
Ground Control	D	I			D
Set/Check Monuments	D	I		I	D
Topographic Mapping/DTM	D	I			D
Satellite Images	D	D			D
Field Survey Sections	D	D			D
Seismic Survey	D				
Infiltration Testing	D				
Hydrologic Modeling	D				
Sediment Transport/Scour					
Sieve Samples	D				D
U-59 Sediment Sampler		D,M	I,M		
Manual Samplers		D	I		
Drop Box Sediment Sampler		D,M	I	M	
Excavate/Survey Scour Chains	D	D			D
Excavate/Survey Scour Discs	D	D			D
Locate & Document Painted Boulders	D	D			D
Gauges					
Tipping Buckets		D,M	I		
Pressure Transducers		D,M	I,M		
Crest Stage Recorders		D,M	I,M		
Weather Stations		D,M	I		
Water Temperature Gauges		D,M	I		
Data Loggers		D,M	I,M		
Telemetry Equipment		D,M	I		

RECOMMENDED ACTIVITIES (dark shading)
CONDITIONAL ACTIVITIES (light shading)
NO ACTIVITIES (no shading)

INSPECTION	I
MAINTENANCE	M
DATA COLLECTION/MEASUREMENT	D

Cost Opinions

Introduction

An opinion of cost for the acquisition, installation, and maintenance of the alluvial fan instrumentation and monitoring networks is presented below. Cost opinions for acquisition of standard equipment are based on a 1991 price list supplied by A-TEK, Inc., the Arizona vendor for several manufacturers of electronic gauging instruments. Materials or other costs for non-standard equipment are based on field experience, or from 1991 price lists distributed by quasi-governmental agencies who sell non-standard equipment. Installation, fabrication, maintenance, and monitoring costs are reported as estimates of manhours. Labor estimates are based on information provided by the FCDMC (Naud, 1992), and on field experience and engineering judgement. All costs are order-of-magnitude accuracy and reflect 1992 pricing unless otherwise noted. Actual costs may vary depending on supply of materials, number purchased, efficiency of personnel, or other factors. A summary of the opinion of total cost and annual labor for each site is provided in Table 28.

The opinions of cost shown, and any resulting conclusions on funding requirements, have been prepared for guidance in project evaluation and implementation from the information available at the time the opinion was prepared. The final costs of the project and resulting feasibility will depend on actual labor and material costs, competitive market conditions, actual site conditions, final project scope, implementation schedule, continuity of personnel and engineering, and other variable factors. As a result, the final project costs will vary from the opinions of cost presented herein. Because of these factors, project feasibility, benefit/cost ratios, risks, and funding needs must be carefully reviewed prior to making specific financial decisions or establishing project budgets to help ensure proper project evaluation and adequate funding.

Acquisition

Cost opinions for acquisition of equipment are divided into costs for standard and non-standard gauges, as defined elsewhere. Acquisition costs are reported in Tables 20 and 21. Costs for gauging equipment available from vendors are described in Table 20. Costs for gauging equipment not available from commercial vendors are described in Table 21.

Standard Equipment

Costs for standard gauging equipment includes cost of acquisition from established commercial vendors. Some additional minor costs may be incurred for cabling or other attachments, which are not included in cost opinions shown. Labor required for installation is summarized elsewhere.

Telemetry

Weather stations and streamflow gauges located at the hydrologic apex of each site will be equipped with telemetry units (NovaLynx 130-002WS, $2,720) that will provide real-time monitoring of rain and flow events. NovaLynx transmitters are capable of storing up to 8k bytes of data on-site to prevent loss of data in case of transmission failure.

Data Loggers

At most precipitation, streamflow, turbidity, and transmission loss stations data loggers (NovaLynx 270-001, $895; additional 32k RAM, NovaLynx 260-370, 260-371, $475) are recommended for electronic storage of data. Expanded RAM requires less frequent service.[12] Additional analog inputs may also be added (NovaLynx 270-190, approx. $150/input). PC-compatible software (NovaLynx 90-185-210, $895) is required to download stored data.

Weather Station

Weather stations (NovaLynx 90-400, $6,600, including telemetry) will include sensors for wind speed and direction, temperature, relative humidity, barometric pressure, solar radiation, precipitation (tipping bucket as described elsewhere), and streamflow (pressure transducers). It was assumed that all sensors and telemetry near the weather station could be housed in a single standpipe.

Water Temperature

Real-time water temperature measurements will be made with a submersible linear thermistor (NovaLynx 210-600, $195) installed at each weather stations.

Precipitation

Precipitation gauges include tipping bucket systems and clear view gauges. Twelve-inch diameter tipping bucket precipitation gauges will measure instantaneous rainfall in 0.01 inch increments (NovaLynx 260-302, $805). The tipping buckets will transmit information to data loggers and will be housed in a standpipe (NovaLynx 90-880, $980). The price reported in Table 19 for the tipping bucket gauge does not include the cost of the data logger. NWS approved wind shields are available for $510 (NovaLynx 260-593).

[12] 32k memory will store 112 days of data from 2 analog sensors set for 10 minute intervals.

Clear view precipitation gauges with mounting brackets are available from several meteorological supply companies for less than $10[13]. Clear view gauges may be mounted on a fence post or equivalent structure.

Streamflow

Streamflow will be gauged with pressure transducers and float gauges. Most pressure transducer (PT) stream stations (NovaLynx 200-310-50, $795; NovaLynx 200-330, $125; NovaLynx 90-880, $980) will transmit stage measurements to a data logger. The cost of the PT stream station shown in Table 19 does not include the data logger. New standpipes will not be required where standpipes for weather stations or precipitation stations are installed. Combined PT/precipitation stations housed in a single standpipe are priced at $3,015, not including the data logger.

Float gauge stream stations (NovaLynx 90-230, $1,995) include a stilling well, a stand-alone optical encoder with 0.01 inch resolution, a 12-inch pulley, a 10-inch float and counterweight, float tape, and miscellaneous cables and connectors. The float gauge will transmit stage measurements to a data logger. The listed cost of a float gauge station does not include the data logger.

Sediment

Real-time suspended sediment load measurements will be made using turbidimeter. Turbidimeters (NovaLynx 210-550, $3,350, without data logger) will transmit measurements to data loggers housed in the weather station standpipes.

[13] E.G.: Ben/Meadows Co., P.O.Box 80549 Atlanta,GA 30366 1(800)241-6401; Tru-Chek Rain Gauge, $7.25.

Table 20 Cost Opinion for Instrumentation Standard Equipment Available from Vendors					
		Number of Instruments Needed			
Recommended Equipment	Unit Cost[1] ($)	South Mountain	White Tank	Tiger Wash	Sierra Estrella
Weather Station w/ Telemetry	7,520	1	1	1	1
Precipitation: Tipping Bucket	1,785	1	5	7	1
Precipitation: Clear View	10	0	0	4	0
Streamflow: Pressure Transducer	1,915	0	2	5	0
Combination: Tipping Bucket + Pressure Transducer	3,015	1	1	2	1
Streamflow: Float Gauge	1,995	0	0	2	0
Sediment: Turbidimeter	3,350	1	1	1	1
Water Temperature	195	1	1	1	1
Data Logger, 32k RAM	1370	2	8	14	2

[1] Unit costs for Novalynx equipment reflect prices from the August 1991 catalog, provided by the A-TEK, Inc. vendor.

Non-Standard Equipment

Costs for non-standard gauging equipment include cost of materials, or costs of direct acquisition, but do not include labor costs for installation and fabrication. Rather, an estimate of the manhours needed for installation and fabrication is presented in Tables 22 and 23.

Streamflow

Additional streamflow measurements will be made using crest stage gauges. Crest stage gauges are available commercially through the US Geological Survey to public agencies. However, crest stage gauges specifically suited to the alluvial fan monitoring project can probably be fabricated less expensively by the FCDMC. Materials cost for full-size crest stage gauges was estimated at $125 to $175. Materials cost for small crest stage gauges was estimated at $20 to $50. Labor costs are not included.

Sediment

Sediment transport rates will be measured using a US U-59D automatic suspended sediment sampler, a drop box bedload sampler, and where feasible, manual samplers. The US U-59D suspended sediment sampler is available commercially or may be fabricated to meet site-specific requirements using conceptual design sketches shown in Figure 47. The estimated cost of materials for the US U-59D is $620. Sample bottles for the US-U59D cost about $38 each. The cost listed in Table 20 assumes 6 bottles are required. The drop box bedload sampler can be fabricated for about $150, not including labor, using the conceptual design sketch shown in Figure 46. The US BHM-60 ($800) and US DH-59 ($619) manual samplers may be obtained from the US Army Corps of Engineers[14]. Prices are based on a price list supplied by the Corps of Engineers.

Scour

Direct measurement of event scour will be accomplished using horizontal and vertical scour chains, and scour collars. Scour chain materials cost varies with the length of chain required (horizontal: $2/ft.; vertical: $0.5/ft.). The costs reported in Table 20 are for a "typical" scour chain application at an alluvial fan site, assuming a 50-foot-wide, 4-foot-deep channel with an expected scour depth of 3 feet. Scour collars will be mounted on the small crest stage gauges. The collars will consist of a heavy steel ring.

Transmission Losses

Transmission losses will be estimated by using the three streamflow measurement stations described elsewhere, as well as by using piezometer wells. The cost of PT and float gauge streamflow stations were described elsewhere. Piezometer well costs may vary depending on the depth of the well, the soil characteristics of the substrate, and site conditions. The cost listed in Table 20 assumes an 8-foot channel depth, drilling via angled auger at 60 degrees or greater, 3-foot expected scour depth, a single drilling contract for both reaches, and site conditions as shown in Figures 54 to 56. The cost of the data logger is not included.

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[14] US Army Corps of Engineers, Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS, 39180-6199. Attn: Dr. Ronald Copeland; c/o Ms. Peggy Hoffman.

Table 21 Cost Opinion for Instrumentation Non-Standard Equipment					
Recommended Equipment	Unit Cost ($)	Number of Instruments Needed			
		South Mountain	White Tank	Tiger Wash	Sierra Estrella
Streamflow: Crest Stage Gauge-Full Size	150	5	18	31	9
Streamflow: Crest Stage Gauge-Small	35	25	48	48	25
Sediment: US-U59D	845	1	1	1	1
Sediment: Drop Box	150	1	1	1	1
Sediment: US-DH59	619	1	0	0	0
Sediment: US-BMH60	800	1	0	0	0
Scour: Vertical Chains	15	4	4	8	4
Scour: Horizontal Chains	210	1	2	4	1
Scour: Collars	5	25	48	48	25
Infiltration: Piezometer Unit	5100	0	2	2	0

Installation

Order-of-magnitude gauge fabrication and installation labor estimates per individual gauge are reported in Tables 22 and 23, respectively. Labor estimates are based on information provided by the FCDMC (Naud, 1992), field experience with gauge installation, and engineering judgement. Labor estimates do not include travel time. Special equipment required for installation, if any, is summarized in Table 24.

Table 22 Labor Estimate for Fabrication (Man Hours)		
Recommended Equipment	# Men	Man Days
Crest Stage Gauge-Full Size	1	0.5
Crest Stage Gauge-Small	1	0.5
US-U59D Suspended Load Sampler	2	2
Drop Box Bedload Sampler	2	2

Table 23 Labor Estimate for Installation (Days)					
Recommended Equipment	# Men	Man Days	Recommended Equipment	# Men	Man Days
Crest Stage Gauge-Full Size	2	1	Weather Station	3	6
Crest Stage Gauge-Small	1	0.1	Water Temperature	1	0.5
US-U59D Suspended Load Sampler	2	2	Tipping Bucket	2	3
Drop Box Bedload	2	1	Clear View	1	0.1
Vertical Scour Chain	2	1	Pressure Transducer	3	5
Horizontal Scour Chain	2	2	Turbidimeter	2	1
Scour Collar	1	0.1	Float Gauge	3	7
Painted Boulders	1	0.5	Piezometer Wells	1	2

Table 24 Special Equipment for Installation and Fabrication	
Recommended Equipment	Special Equipment
Crest Stage Gauge-Full Size	Backhoe, Concrete Mixer, Survey
US-U59D Suspended Load	Welder, Backhoe, Survey
Drop Box Bedload Sampler	Welder, Backhoe, Survey
Scour Chains	Powered Hand Auger, Survey
Piezometer Wells	Auger Drilling Rig, Concrete Mixer

Maintenance

Annual labor estimates for periodic scheduled maintenance are summarized in Table 25. Scheduled labor means activity done for upkeep and inspection of the gauges. Labor summarized in Table 25 does not include flood response activities (monitoring) or travel time. In general, standard gauges require biannual recalibration and non-standard gauges require only site inspection to check for vandalism or other damage. It was assumed that minimal vandalism and flood damage will occur on a annual basis. Maintenance labor estimates are based on information provided by the FCDMC (Naud, 1992), field experience, and engineering judgement.

For planning purposes, it may be assumed that at least one of the biannual service visits may be scheduled near a flood response visit. This scheduling will help reduce the travel time and labor investment. The required frequency of maintenance for each gauge type and monitoring procedure is summarized in Tables 16 to 19, and is described elsewhere in this report.

Table 25
Labor Estimate for Scheduled Maintenance (Days/Year)

Recommended Equipment	# Men	Man Days	Recommended Equipment	# Men	Man Days
Crest Stage Gauge-Full Size	1	0.5	Weather Station	2	1
Crest Stage Gauge-Small	1	0.1	Data Logger	1	1
US-U59D Suspended Load Sampler	1	0.5	Tipping Bucket	2	1
Drop Box Bedload Sampler	1	0.5	Clear View	1	0.1
Vertical Scour Chain	1	0.5	Pressure Transducer	2	1
Horizontal Scour Chain	1	0.5	Turbidimeter	2	1
Scour Collar (each)	1	0.1	Float Gauge	2	1
Painted Boulders (site)	1	0.5	Piezometer Well	2	1

Monitoring

Opinions of cost for flood response monitoring and data management include required capital expenses and labor. Capital expenses includes monitoring procedures that require outside services from the FCDMC. Labor includes manhours required to collect data in response to measurable flood events. The amount of labor required to accomplish monitoring, data reduction and archiving for this project is difficult to estimate. The actual labor investment will depend on the frequency and magnitude of rainfall and flood events, incidence of flood damage or vandalism, equipment break down, and the amount of data collected for each flood. For these reasons, the labor estimates summarized in the following tables are, at best, order-of-magnitude assessments. Labor opinions are reported as manhours per gauge per year in Table 26 unless otherwise noted. Because labor for each gauge type was determined separately, some labor savings may be achieved if monitoring for an entire site is done concurrently. Detailed descriptions of monitoring procedures are provided in other sections of this report.

In order to estimate the labor required for monitoring, several assumptions were made. First, it was assumed that 5 measurable floods occur at each site per year[15]. Given the seasonality of rainfall in central Arizona, it was assumed that 4 of these floods occur in late summer, and only one occurs in winter. Second, it was assumed that scheduled maintenance labor estimates summarized in Table 26 adequately account for the time required for repair of damaged instruments. Third, it was assumed that information collected through telemetric data transmission or data logger transfer would not require any manual entry into the data bases or data archives. However, time for quality control and review of electronic data was allowed. Fourth, it was assumed that flood response ground surveys (channel cross sections at crest stage gauges, scour chains, and gauging transects) would be performed by FCDMC gauge maintenance personnel.

Capital expenditures associated with flood response and monitoring include service fees for NOWrad, aerial photography, survey control for DTM topography, DTM topography, and laboratory analysis of sediment samples. Aerial photography, survey control, and DTM modeling cost opinions are based on actual costs incurred as part of this study. It was assumed that survey control would only require resetting targets at permanent monuments and that DTM modeling would be required at 10 year intervals. Laboratory sediment analysis cost estimates were provided by Westech Laboratories. US U59D samples require total solids analysis. Bed material samples require sieve and hydrometer analysis. Some sediment sample analysis will be required after each flood. Cost opinions for capital expenditures are reported as costs per square mile unless otherwise noted in Table 27.

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[15] Precise information on the frequency of runoff at the gauging sites is lacking. However, USGS gauge data from South Mountain indicates that between 1961 and 1989, an average of three runoff events per year occurred.

Table 26 Labor Estimate for Flood Response (Days/Year/Gauge): Equipment					
Recommended Equipment	**# Men**	**Man Days**	**Recommended Equipment**	**# Men**	**Man Days**
Crest Stage Gauge-Full Size	2	2	Telemetered Gauge (each)	1	0.1
Crest Stage Gauge-Small	1	0.1	Data Logger Gauge (each)	1	0.1
US-U59D Suspended Load Sampler	1	2.0	Clear View	1	0.5
Drop Box Bedload Sampler	2	2.5	Quality Control	1	30
Vertical Scour Chain	2	4	Data Archiving	1	30
Horizontal Scour Chain	2	5	Survey (per transect)	2	2
Scour Collar (each)	1	0.1	Manual Sampling	3	1.5
Painted Boulders (site)	1	2.5			

Table 27 Capital Costs for Monitoring	
Cost Item	**Opinion of Probable Cost ($)**
Aerial Photography (sq.mi.)	$ 500
DTM Modeling (sq.mi.)	9,000
Survey Control (site)	4,000
NOWrad (project/year)	6,600
Sediment Analyses (per sample)	
Total Solids (%)	10
Sieve Analysis (Sands)	75
Hydrometer Analysis (Clay)	50

Cost Opinion Summary

A summary of the order-of-magnitude opinion of cost in dollars and annual manhours for each of the four alluvial fan monitoring sites is shown in Table 28. The cost opinions for each site are based on the full gauging effort described in this report. Cost reflect 1992 pricing. One time costs for items not specifically assigned to a particular site are divided evenly between the four sites. Equipment expenses and installation and fabrication labor are not annual expenses.

Table 28 Acquisition, Installation, Maintenance, and Monitoring Opinion of Annual Costs					
Cost Category	Site				
	South Mountain	White Tank	Tiger Wash	Sierra Estrella	Total
One-Time Costs					
Equipment ($)	22,000	54,500	81,455	22,600	180,600
Fabrication (days)	20	37	44	22	123
Installation (days)	38	82	144	40	304
				Total Labor	427
Annual Costs					
Maintenance (days)	18	44	68	20	150
Monitoring (days)	53	99	155	68	375
				Total Labor	525
Monitoring ($)	4,850	6,350	10,750	4,850	26,800

Discussion

Based on the results discussed in this report, CH2M HILL recommends the following:

- **Implement Project.** The instrumentation phase of the project should be implemented as soon as possible. Four alluvial fan sites for instrumentation and monitoring were recommended, and feasible instrumentation plans were developed for each site. If full instrumentation of any site is to be delayed, a streamflow station should be installed at the hydrologic apex, and detailed topographic mapping of the fan area should be prepared.

- **Review Collected Data.** As data are collected for several storm events at the site, the instrumentation and data collection plan should be reviewed for quality and ability to meet the project objectives. Changes to the instrumentation system should be implemented as soon as possible.

- **Floodplain Modeling.** Floodplain limits should be determined using existing alluvial fan methodologies and entered as layers in the FCDMC GIS mapping of the fan sites. These maps may be used to compare the predictive accuracy of various modeling methodologies as data are collected. Determining floodplain limits prior to data collection is appropriate so that any potential prejudice or bias is eliminated.

- **Research Opportunities.** Opportunities to use the monitoring sites as research sites for graduate students and faculty at the Arizona universities as well as other U.S. research institutions should be fully explored. In addition, opportunities for coordination with ongoing research by public agencies should be fully explored. For example, USDA-ARS remote sensing research or NTSB scour gauging instrumentation research could potentially use the FCDMC alluvial fans as beta test sites.

- **Baseline Studies.** Baseline analyses should be conducted to support the data collection effort. These baseline studies were described in the monitoring plan section. Recommended analyses include: (1) dual ring infiltrometer testing of the main channels, particularly in the transmission loss reaches; (2) event and long-term sediment yield and scour analyses to support scour, sediment transport, and transmission loss gauging; (3) detailed HEC1 modeling which considers stream gauge and precipitation gauge locations; and (4) testing of bank resistance using hand tensiometers.

Summary

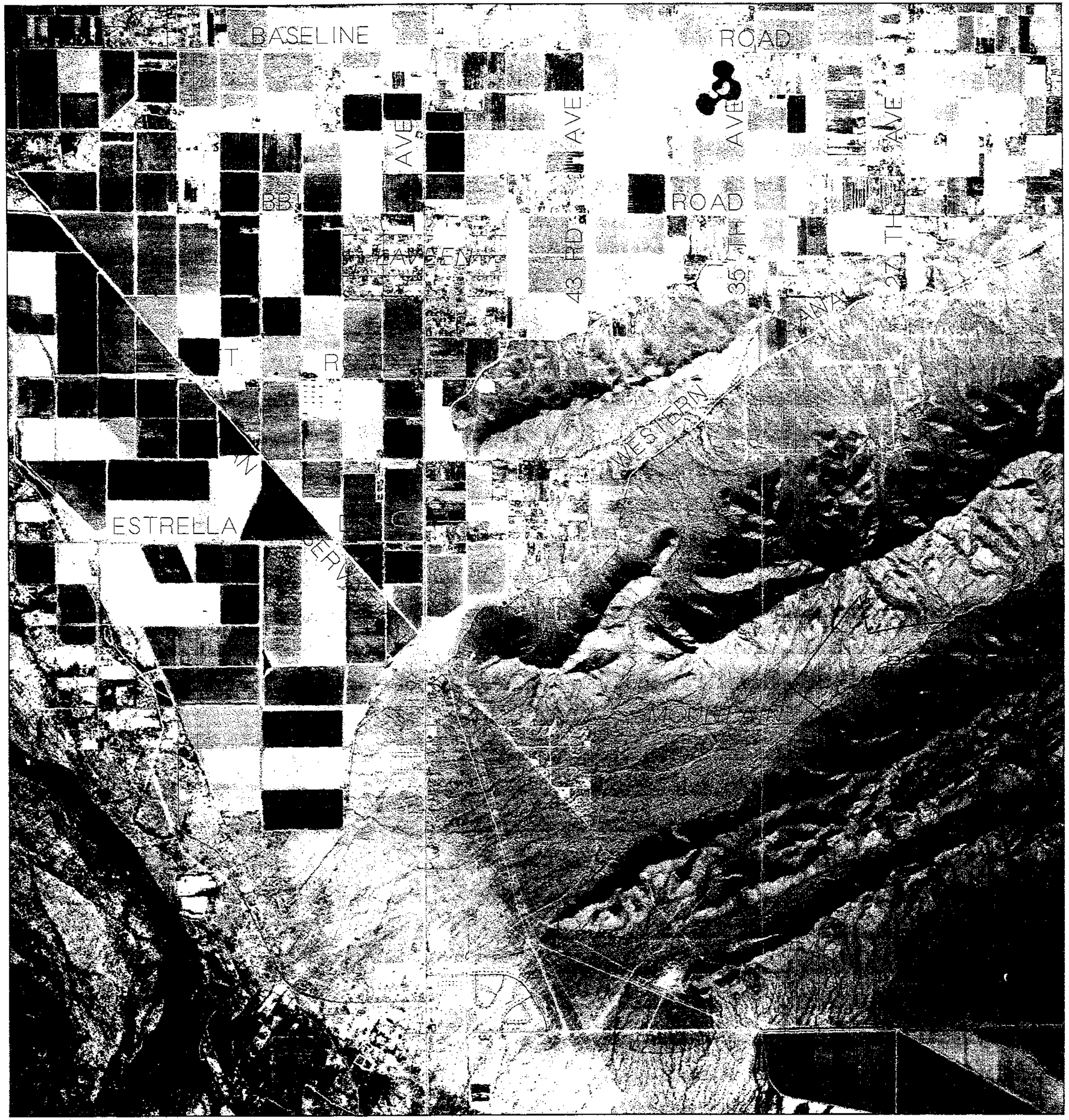
The alluvial fan data collection and monitoring study embodies the FCDMC proactive approach to floodplain management. In anticipation of the need to properly map and manage flood hazards on alluvial fans within Maricopa County, the FCDMC initiated a study to better define those needs. The study approach was threefold: (1) identify the types of alluvial fans found in the FCDMC jurisdictional area, (2) identify specific, measurable flood processes which occur on each type of alluvial fan, and (3) design and implement a program to collect and interpret data describing these processes.

For the first phase of the study, three unique types of alluvial fans were defined: active alluvial fans, distributary flow systems, and fan terraces. Identification criteria for each fan type were defined and tested in the field. Four alluvial fan sites which best exemplify these types of fans were identified and analyzed. Detailed analysis included geomorphic and geologic data collection, historical research into flood and rainfall records, collection of land use and jurisdiction information, soils and vegetation data collection, and hydrologic modeling of each site.

For the second phase of the study key alluvial fan processes were identified. These processes included rainfall, streamflow, sediment transport, channel scour and deposition, bank erosion, channel migration, fan aggradation, transmission loss, and regional weather. Specific instruments and monitoring procedures capable of quantifying these processes were evaluated according to design guidelines developed for this project. The recommended instrumentation reflects the long-term goals and intended use of the data to be gathered. An array of real-time, automatic, and manual techniques were developed for each site.

For the third phase of the project, long-term monitoring plans were developed to guide data collection efforts throughout the duration of the project. Specific installation guidelines, standard operating procedures, and maintenance requirements were developed for each gauge and site. Cost and labor estimates for each part of the implementation phase were summarized.

Finally, discussion of potential implications of the data collection effort was presented to highlight the need for implementation of the project. This discussion focused on apparent weaknesses in the FEMA model in light of the preliminary findings of this study.



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APPROX. MILES

Plate 1

South Mountain Park Overview

CH2M HILL

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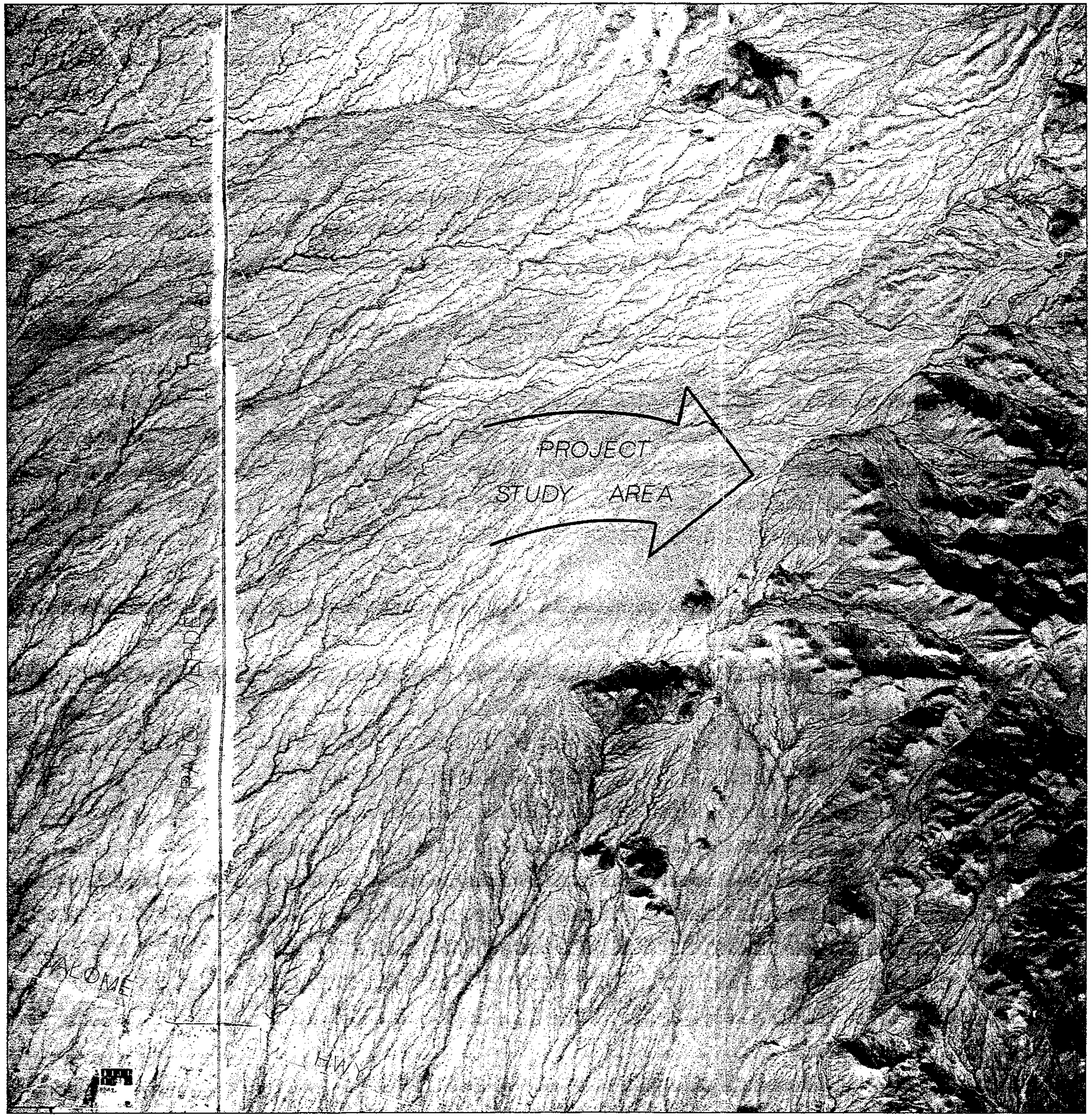

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APPROX. MILES

Plate 2
White Tank Mountain Overview

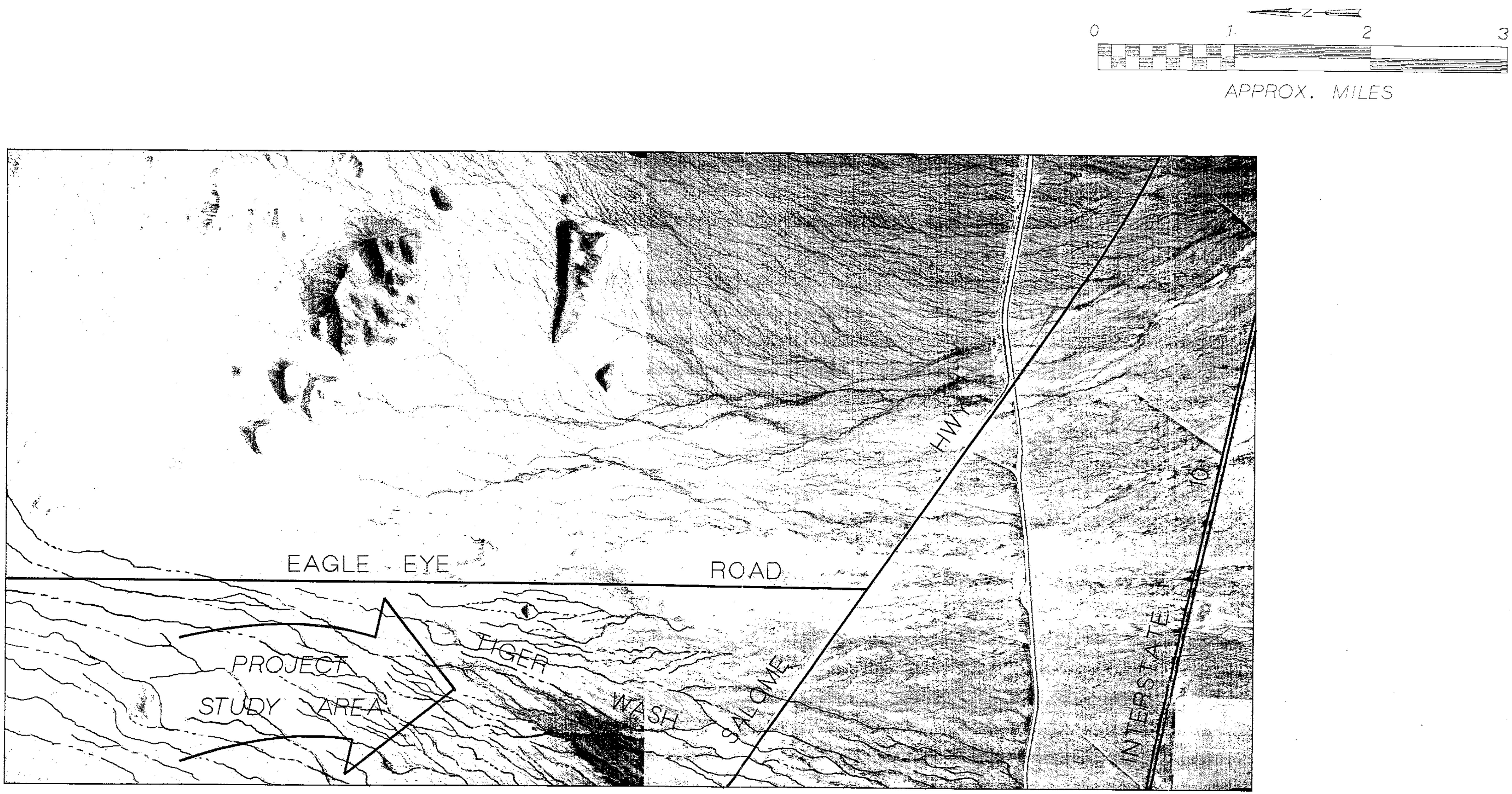

Plate 3
Tiger Wash Overview

CH2M HILL

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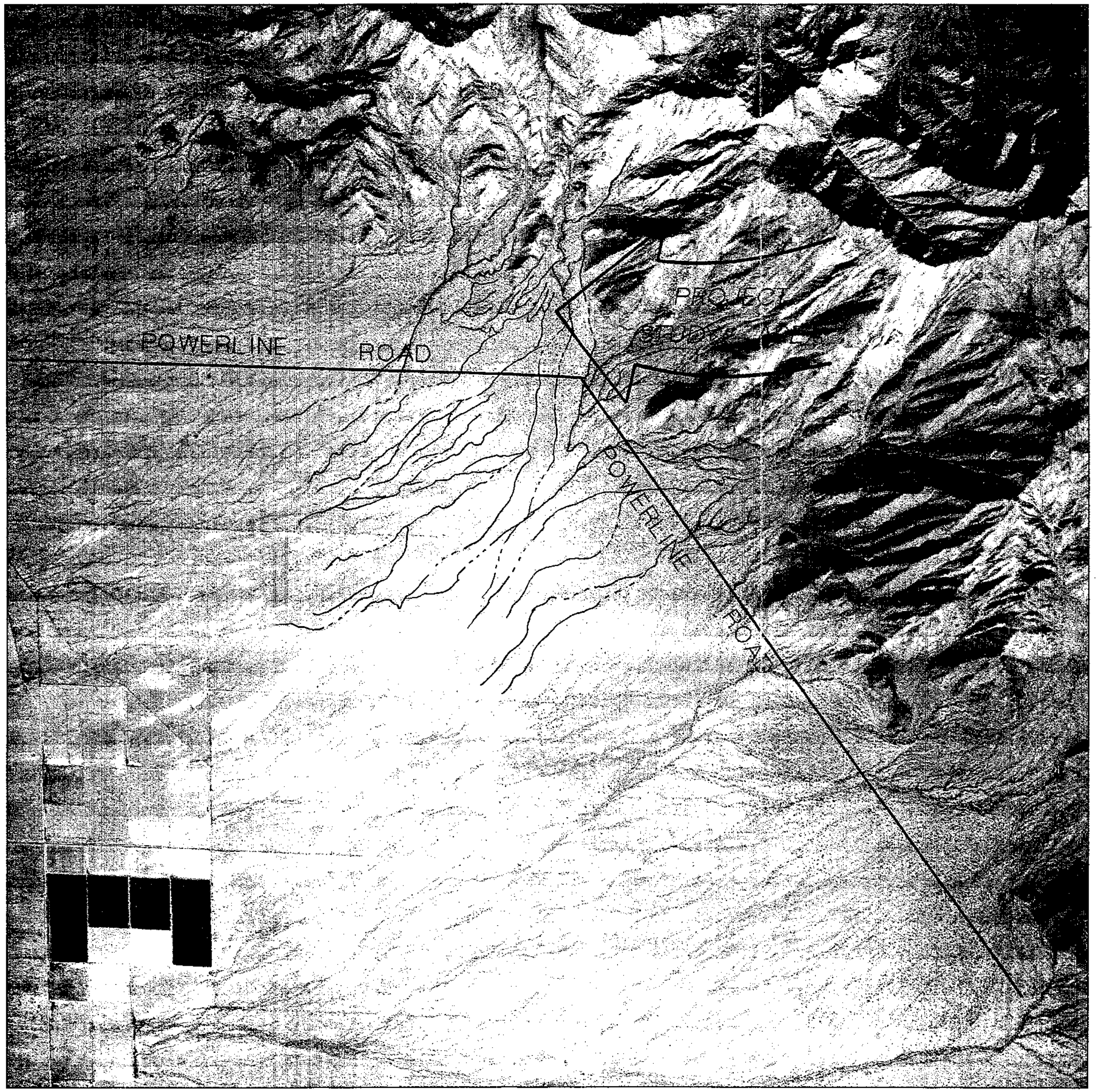

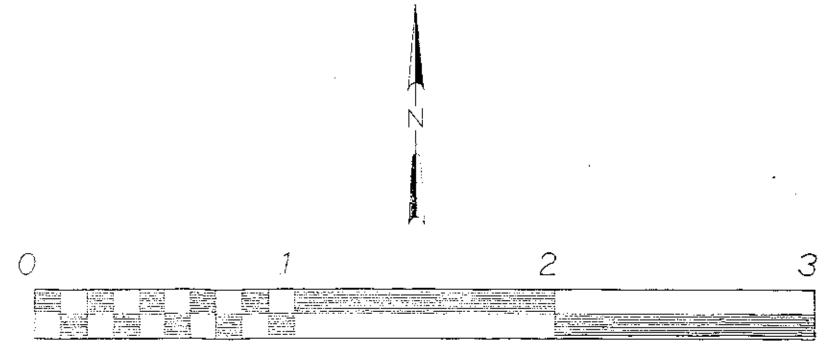

Plate 4
Sierra Estrella Overview

CH2M HILL

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Glossary

Agglomerate. Sedimentary rock type formed of detrital volcanic material explosively ejected from a volcanic vent, with clasts larger than 32 millimeters.

Anastomosing. A stream pattern characterized by a net-like or interwoven channel pattern, with individual flow paths better defined or permanent than braided channel flow paths.

Andesite. A volcanic rock type mostly composed of plagioclase and other mafic minerals.

Arkosic. Rock type, generally sandstone, composed of more than 25 percent silica-feldspar minerals.

Avulsion. The sudden relocation of a stream away from its original flow path, usually due to catastrophic sediment deposition in the original flow path.

Bajada. An piedmont comprised of coalescing alluvial fans.

Bar and Swale Channel Form. Channel bars are small islands composed of the larger clasts of bed load material deposited during high flow and exposed during low flow. Channel swales are the low flow areas located between bars; the low flow thalweg.

Bed Load. The portion of sediment in a stream which is transported by rolling, bouncing, or sliding on the stream bed.

Bifurcation. The division of a stream into two or more channels in the downstream direction; a channel split.

Breccia. A rock unit composed of coarse highly angular fragments.

Calcalkaline. Basic calcium bearing rock.

Calcareous. Calcium rich.

Carbonate Stage. Stage I carbonate is loose disseminated $CaCO_3$ in the soil matrix. Stage II carbonate is thin, discontinuous coatings of $CaCO_3$ on the bottoms of coarse clasts in the soil matrix. Stage III carbonate is continuous coatings of $CaCO_3$ on the majority of coarse clasts in the soil matrix. Stage IV carbonate is replacement of the original soil matrix by a thick, well-cemented layer of $CaCO_3$.

Caliche. Calcium carbonate ($CaCO_3$) deposited and illuviated in arid region soils cemented into a petrocalcic horizon; often as Stage IV carbonate.

Clastic. Rock fragments or other material which has been transported.

Cratonic Sequence. A series of rock types deposited in a tectonically stable environment, usually on a continental shelf.

Crenulation Index. The ratio of the topographic contour length to the straight line distance along the arc of the contour. A low crenulation index indicates low relief and a uniform surface.

Crystalloblastic. A crystalline texture due to metamorphic recrystallation such that original mineral may have inclusions of minerals formed during metamorphism.

Dendritic Drainage Pattern. A drainage system with tributaries which join at all angles, similar to the branching pattern of a tree. The number of flow paths decrease in the downstream direction.

Desert Pavement. A layer of tightly packed coarse sediment found on the surface of desert soils formed by winnowing away finer sediment by wind, rainfall, or local runoff. Degree of pavement development is related to the intensity of the formative processes.

Desert Varnish. A dark stain substance with a glistening luster, composed of manganese or iron oxide, found on the exposed surfaces of coarse rock material in arid climates. Desert varish is formed as microbiotic organisms fix eolian cations with oxygen during infrequent wetting by rain.

Difluence. See bifurcation. The point of separation of stream channel into two or more channels.

Embayment. Fault-bounded mountain ranges have highly linear mountain fronts upon formation. Headward erosion along stream forms canyons. With time, these canyons cause the mountain front to be increasingly non-linear, or "embayed".

Evaporites. Sedimentary rock types formed by evaporation of water; for example, halite and gypsum.

Fanglomerate. Rock and soil material originally deposited as an alluvial fan which has since been transformed into bedrock. Fanglomerates are characterized by a wide range of grain sizes and bedding types.

Felsic. A term applied to K-feldspar and silica rich rock types.

Gneiss. A type of metamorphic rock characterized by a lineation of the mineral grains which comprise the rock.

Grabens. Downdropped blocks of rock material bounded by normal faults. See Horsts.

Granoblastic. A secondary texture found in metamorphic rock characterized by recrystallization to equigranular size.

Graywacke. A type of sandstone characterized by detrital sand grains in a clay matrix. A dirty hard sandstone.

Horsts. Uplifted blocks of rock material bounded by normal faults. See Grabens.

Hyperconcentrated Sediment Transport. Sediment transport with a high ratio of sediment volume to water volume, such that some of the newtonian properties of the mixture are lost.

Illuviation. The downward transport of mineral or other material in a soil layer, usually the B or C soil horizon.

Imbricate. Overlapping alignment of pebbles and cobbles due to transport in water. The tail of one clast overlies the head of the next clast downstream.

Immature Vegetative Species/Communities. This term is used by the Soil Conservation Service to describe invasive plant species which are first to colonize a devegetated area. In Maricopa County, these species often include creosote, bursage, and salt cedar. Small, young plants of more stable species may also be included.

Inselbergs. Isolated remnants of bedrock exposed as small hills or buttes in the alluvial plain or pediment.

Interfluves. The area between braided flow channels. The area is usually vegetated, in contrast to the sandy channel beds.

Isoclinal. A structural fold of a rock unit with parallel limbs.

Listric. Spoon-shaped. A listric fault is a spoon-shaped thrust fault, which curves upward toward a vertical plane.

Mafic. Referring to dark, magnesium-rich minerals.

Mylonitization. The process of forming mylonite, a fine-grained metamorphic rock characterized by mineral grains subjected to milling and brecciation by movement along a fault zone.

Paleoflood. Any flood which occurred prior to, or without, human records.

Paleosols. Buried or relict soil layers, not formed during the present climatic conditions or at the existing soil surface.

Pediment. A gently sloped erosion surface composed of bedrock with a thin veneer of alluvium, often formed by mountain front planation.

Petrocalcic. Calcium-rich rock material.

Piedmont. A general term for the sloping land area adjacent to a mountain front.

Pluton. A body of igneous rock which formed beneath the earth's surface by crystallization of molten material.

Porphyritic. A term describing rock texture in igneous rocks where larger crystals are set in a glassy or fine-grained matrix.

Rhyolite. A rock type with mineral content equivalent to granite, but with individual mineral grains too small to distinguish with the naked eye.

Runout Distance. The distance a debris flow travels from the mountain front or base of a slope to its resting point.

Secondary Entrenchment. Degradation of a geomorphic surface, usually a stream channel or piedmont below its initial deposition surface, often forming terraces.

Slackwater. A low-energy zone in a stream characterized by near-zero velocity and sediment deposition.

Strath Terrace. A stream terrace formed by erosion, rather than deposition.

Stream Order. A geomorphic parameter used to describe the complexity of a drainage system. A first order stream has no tributaries. A third order stream is formed by the confluence of two second order streams. No stream order system specifically for alluvial fans exists.

Strike-slip Faulting. Tectonic movement along a fault line which is dominantly horizontal, rather than vertical. The San Andreas Fault is a strike-slip fault.

Suspended Load. The part of the total sediment load that moves above the bed load. The weight of the suspended sediment is totally supported by the fluid.

Syntectonic. Occurring in conjunction or concurrently with tectonic activity, usually emplacement of a pluton.

Talus. A loose, steeply sloped accumulation of rock debris deposited at the base of a mountain slope.

Tectonic. Tectonism. Deformation of the structure of the earth's crust by movement of crustal plates; includes mountain building by vulcanism and faulting.

Torrifluvents. A type of soil characterized by stream deposits of gravelly, sandy material, and lack of significant soil horizon development.

Trellis Drainage Pattern. A stream pattern where master and tributary channels are aligned at nearly right angles.

Tuff. A rock type formed of compacted volcanic fragments and ash.

Wash Load. The part of the sediment load composed of fine particles carried in permanent suspension, and generally not found in the stream bed.

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