EROSION STUDY TO DETERMINE BOUNDARIES FOR ADJACENT DEVELOPMENT - CALABACILLAS ARROYO BERNALILLO COUNTY, NEW MEXICO

Submitted to

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Flood Control Authority
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EXECUTIVE SUMMARY

An erosion study has been conducted of the Arroyo de las Calabacillas (hereafter Calbacillas Arroyo) to develop criteria for future development adjacent to the arroyo in the lower reach. The project area was the mainstem of Calabacillas Arroyo from Coors Road west to the confluence of the north and west forks of the arroyo, thence along the north fork to the Bernalillo-Sandoval County line. The specific result of the study was a map delineating boundaries, referred to as offset tangents, along both sides of the arroyo beyond which development would not be prudent.

Definition of the term "prudent" for purposes of this study is based on the concepts of hydrologic uncertainty. The offset tangents are based on a consideration of the erosion potential of both a single, large-scale hydrologic event (short term) and the cumulative impact of a series of smaller events over the long term. In this context the operational definition of the term prudent is to avoid any risk associated with the single-event erosion and flooding potential of a 100-year flood, or the cumulative erosion potential of a series of smaller flows extending over a 25-year period, whichever is greater.

For the short-term event it is important to realize that both erosion and <u>flooding</u> potential are considered. Consequently the study results are in accordance with FEMA guidelines. The 100-year flood plain boundaries for Calabacillas Arroyo were established previously by another engineering firm, and their results were adopted in this study. Additionally, available hydrologic information was accepted as-is; however, hydrologic data were adjusted to reflect the influence of the proposed 7-Bar channel entering Black's Diversion, which is a tributary to the Calabacillas Arroyo in the lower portion of the study reach.

The basic erosion analysis involves the first two levels of the Simons, Li & Associates, Inc. (SLA) three-level approach. Level I is a qualitative geomorphic analysis and Level II is a basic engineering analysis. The more complex water and sediment routing techniques of Level III were not considered necessary for this study. Level I analysis is based primarily on available data, observations and information collected during a three-day site reconnaissance, historical aerial photographs, and SLA's extensive experience in the analysis of ephemeral streams and arroyos. Level II analysis involves primarily an application of the sediment continuity principle based on hydraulic data generated for the flood insurance study. Results of Level I analysis provide valuable information and insight for Level II analysis.

Calabacillas Arroyo is a steep, relatively straight channel with a large width-to-depth ratio. Characteristics of the watershed and the large alluvial fans present at the mouths of tributaries indicate that a large sediment load is delivered to the system. Typical of many streams and arroyos in the southwest, Calabacillas Arroyo is a dynamic system with significant potential for lateral and vertical instability.

Old meander scars in the middle third (see Figure 3.3) of the study reach document the long-term historical lateral instability that is possible. More recent activities, as documented by aerial photographs spanning 45 years, have included straightening of the channel in the lower third (see Figure 3.4) and significant disturbance due to man in the upper third (see Figure 3.2). Excavation of a large borrow pit at the confluence of the north and west forks will impact the entire system for many years to come. The most significant impact will be degradation downstream of the borrow pit as the pit refills with sediment. Lateral stability in the reach immediately below the borrow pit (middle third) can be documented historically and suggests that the channel is strongly influenced by the steeply sloping mesa edge to the south.

Data available for the lower third are adequate for a longitudinal profile analysis. Changes in the thalweg elevation over the last eight years in this reach suggest significant vertical instability is possible over relatively short time periods. Degradation of four to five feet along the thalweg was documented with both degradation and aggradation occurring over a relatively short reach of the channel. The observed headcut in the vicinity of Black's Diversion channel was well documented by this analysis.

Level II analysis provides quantitative estimates of aggradation/ degradation (changes in the vertical direction) and lateral migration (changes in the horizontal direction). The analysis was based on available hydraulic data, the sediment continuity principle and the slip circle principle for evaluating soil and bank stability. Initial results indicated that it would require over 40 years to refill the borrow pit excavation. Consequently, the borrow pit was assumed to remain throughout the 25-year period defined for long-term analysis. In degradational subreaches such as the subreach below the borrow pit, maximum lateral migration potential was estimated by assuming the required volume of erosion came entirely from the channel banks. Furthermore, in the absence of geological controls the entire erosion amount was first assumed to come from one bank and then the other, since it is not possible to precisely determine the direction the channel will meander. Degradational reaches that have not shown significant lateral movement historically, for example the subreach upstream of Coors Road, were evaluated by a slip circle analysis to estimate the maximum bank height possible before failure from vertical incision and bankline undercutting.

Offset tangents were then evaluated considering results of both Level I and II analyses and the established flood plain boundary. The governing physical processes were considered in establishing the mode of lateral migration most applicable to a given subreach of the study area. For example, in the subreach below Golf Course Road, historical evidence as established in Level I analysis indicated significant lateral migration potential. Consequently, the historical meander belt was used to define the offset tangents in this subreach. In the subreach above Coors Road the slip circle analysis defined the offset tangents, and in the subreach below the borrow pit the assumption that all erosion occurred from the bankline established offset tangents. In all cases, the 100-year flood plain boundary was used as the minimum possible offset tangent.

The resulting offset tangents defined the boundaries beyond which it was not considered prudent to develop without channel improvements. The results indicate that beyond the 100-year flood plain boundary approximately 100 acres of land should not be developed without channel improvements. Based on proposed platting, approximately 150 lots are contained within the offset tangents; however, about thirty-five percent of these lots are also located within established 100-year floodway boundaries defined on FEMA Flood Boundary and Floodway maps. Adoption of FEMA guidelines prohibits all development within the floodway. An additional twelve percent of the total lots impacted by offset tangents are situated within the 100-year flood plain and can only be developed if a floodway is constructed. The recommended offset tangents were established using the best information available and state-of-the-art analysis techniques and represent limits for development that are neither overly conservative, nor subject to excessive risk.

I. INTRODUCTION

1.1 Problem Statement

The Arroyo de las Calabacillas (hereafter Calabacillas Arroyo) drains an area of approximately 100 square miles in northwestern Bernalillo County and south central Sandoval County, New Mexico. Presently, the drainage basin is largely undeveloped; however, development pressures are increasing from Rio Rancho to the north and Paradise Hills to the south. Although Calabacillas Arroyo is predominantly a dry channel, flowing only in response to rainfall, the size and characteristics of the drainage area creates the potential for significant floods in the arroyo system. Coupled with this potential for large flows is the erosion potential of bed and bank materials, which are generally silty sands.

To develop criteria for controlling and permitting future development adjacent to the banks of Calabacillas Arroyo, Simons, Li & Associates, Inc. (SLA) was retained by the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) to conduct an erosion study of the Calabacillas Arroyo. Specifically, this study was undertaken to develop a map delineating boundaries, referred to as offset tangents, along both sides of the arroyo beyond which development would not be prudent. An operational definition of "prudent" is provided in Section 1.2. This report describes the methods of analysis and rationale used to develop the offset tangents.

1.2 Operational Definition of the Term "Prudent"

An operational definition of the term "prudent" for purposes of this project should be related to the concepts of hydrologic uncertainty. For example, adopting a design flood for a given project requires a consideration of flood characteristics and flood frequencies, as well as economic and other practical considerations. In the design of flood control projects it would obviously be desirable to provide protection against the maximum probable flood, if this were feasible within acceptable limits of cost. However, it is seldom practical to provide absolute protection, and, as a rule, some degree of risk must be accepted. The problem, then, is one of relating the term "prudent" to an acceptable degree of risk. That risk is commonly based on the calculated return period (recurrence interval) of a hydrologic event.

The National Flood Insurance Program establishes as a precedent that when considering hydrologic events it is generally not considered an exercise of sound judgment to accept a degree of risk any greater than that associated with the 100-year event (base flood). With reference to the calculated risk diagram (Figure 1.1), using the 100-year event as a basis for the definition of prudent implies that there is a 90 percent certainty that the event will not occur in a 10-year period and about 78 percent certainty that it will not occur in 25 years. Conversely, this means acceptance of a calculated risk of 10 percent in a 10-year period and 22 percent in a 25-year period if offset tangents are based on the erosion and flooding potential of a 100-year flood. Asking a property owner to accept a greater risk than this would not appear to be prudent.

While damages due to flooding are generally associated with a single, short-term event, the impacts of erosion can also be cumulative over the long term. Consequently, one should assess the erosion potential of not only a single event such as a 100-year flood, but also the cumulative impact of a series of smaller flows. One approach to evaluating long-term erosion impacts is to develop a "representative" annual storm and then to extrapolate in time the effect of this storm. This concept is similar to the practice in hydrology of adopting the two-year flood as being representative of the annual event; however, for purposes of long-term erosion the representative annual event can be more accurately defined by a probability weighting of the erosion resulting from several single storms (see Section 6.5). Using this methodology SLA has found that the representative annual storm for erosion purposes will generally be equivalent to the single event erosion associated with a storm of a 5- to 10-year magnitude.

After establishing the representative annual storm for erosion purposes, the duration in years defining the "long term" must be established. Based on both the limitations of the probability weighting approach and the single-event probability of occurrence of a 100-year flood in a 25-year period (22 percent), a reasonable definition of the "long term" for purposes of this study is 25 years. Thus the offset tangents determined by this study represent the envelope established by the reach-by-reach calculation of the erosion potential of either the 100-year flood (short term) or the cumulative impact of a series of smaller events over a 25-year period (long term).

In this context, the operational definition of the term "prudent" for this study is to avoid any risk greater than that associated with the single-event erosion and flooding potential of a 100-year flood or the cumulative erosion potential of a series of smaller flows extending over a 25-year

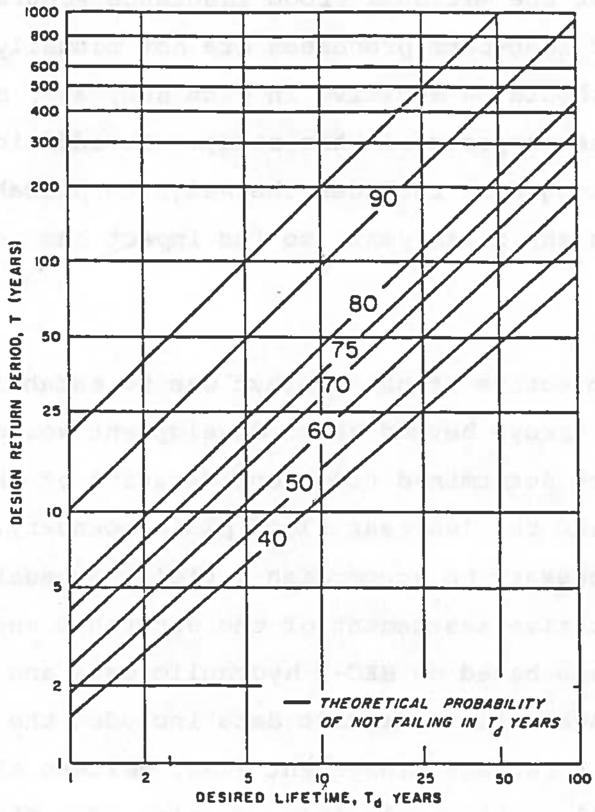


Figure 1.1. Calculated-risk diagram (U.S. Weather Bureau).

period, whichever is greater. The selection of this definition is supported by the short- and long-term degree of risk associated with the 100-year return period event, the accuracy of the methodology used for estimating long-term erosion impacts if extrapolated beyond a 25-year period, and the legal and policy precedents of the National Flood Insurance Program. It could be argued that the short- and long-term processes are not mutually exclusive and that the erosion rates should be additive in each subreach, but this seems far too conservative for the purposes of this study. In addition, the computational procedure for the long term includes the weighted probability of occurrence of a 100-year event in any given year, so its impact has not been overlooked.

1.3 Scope of Work

The primary objective of the project was to establish offset tangents along Calabacillas Arroyo beyond which development would not be prudent. The offset tangents were determined from consideration of short- and long-term erosion potential and the 100-year flood plain boundary. To establish offset tangents it was necessary to accomplish a field reconnaissance and data gathering, a qualitative assessment of the watershed and channel system, and a quantitative analysis based on HEC-2 hydraulic data and the sediment continuity concept. Available hydraulic data included the 100-year flow rates established in the "Drainage Management Plan, Western Albuquerque Metropolitan Area" (1975) as well as the preliminary results of a Flood Insurance Study (August 18, 1982).

To accomplish project objectives the following scope of work was adopted for this study.

1. Collect, collate, review and evaluate available hydrologic, hydraulic, cross-sectional, aerial photographic, structural, sediment transport and soils data pertinent to the proposed study.

2. Conduct a field reconnaissance of the watershed and channel system and accomplish the necessary field work to fill gaps in the existing data base with the bulk of the field work devoted to obtaining sediment samples from the watershed area and bed, banks, and overbank areas of the channel in the study reach. Conduct laboratory analysis of the sediment samples and develop gradation curves.

3. Perform a qualitative geomorphic analysis using available data, historical information, aerial photographs, and geomorphic principles to identify key factors that govern the bank stability of the arroyo system.

4. Using existing hydrologic data, determine hydrographs for the 2-, 10-, 25-, and 100-year return period events and select flow ranges to fully describe the 100-year flood.

5. Review available HEC-2 data and modify as necessary. Establish hydraulic conditions for the selected discharge levels used to characterize the 100-year flood.

6. Develop a sediment transport relationship for the arroyo system.

7. Based on the hydraulic and sediment transport data, analyze the sediment balance in the arroyo by characteristic subreaches for selected flows and determine aggradation/degradation trends by subreach.

8. Determine the equilibrium slope for the selected subreaches of the arroyo system for a range of discharges.

9. Using the results of the qualitative geomorphic assessment and the analysis of aggradation/degradation trends and equilibrium slopes, evaluate the lateral migration potential of the channel in the study area considering both short-term (100-year flood) and long-term response.

10. Determine offset distances and delineate boundaries along both sides of the channel beyond which development would not be prudent.

11. Develop legal descriptions of the offset tangents and relate to existing survey data (section corners, platting, and/or the New Mexico plane grid system).

12. Make an oral presentation on the study results and rationale for the recommended boundaries to the AMAFCA Board of Directors and submit a final project report and maps showing boundary tangents and legal descriptions of the tangents. These will be presented on mylar base maps provided by AMAFCA.

1.4 General Solution Procedure

The solution procedure developed and used by SLA for all problem solving efforts involves up to three levels of analysis. The multiple level solution approach stresses that knowledge of governing physical processes plays the most important part in deciding an appropriate level of mathematical analysis. If the governing physical processes are emphasized in the analysis, the degree of complexity required to represent the physical system can be defined.

Level I analysis is qualitative, involving application of geomorphic concepts (geomorphology is the study of surficial features of the earth and the physical and chemical processes changing landforms, while fluvial geomorphology is the morphology (and mechanics) of rivers and river systems). Level

II is quantitative, involving more complex geomorphic concepts and basic engineering relationships. Level III is quantitative based on detailed mathematical modeling. Most problem solving efforts begin with Level I. The general knowledge obtained from this level provides understanding and direction to Level II or III quantitative analysis. Additionally, governing physical processes are usually identified in the general solution of Levels I and II, allowing proper selection (or development) of a model for Level III that is efficient to use and applicable to the problems being analyzed. The three-level approach has been used extensively by SLA and has been found to provide the most efficient analysis approach with the greatest accuracy for a given problem. Additionally, all results and conclusions are cross-checked to the other levels of analysis.

To complete the proposed scope of work for this study only Levels I and II are necessary. The more complex approach of water and sediment routing with computer modeling techniques as applied in a Level III analysis is not considered necessary. Level I analysis is based primarily on available data, information collected during the field reconnaissance, and SLA's extensive experience in the analysis of ephemeral streams and arroyos. Level II analysis involves primarily application of the sediment continuity principal based on HEC-2 hydraulic data. The qualitative and quantitative evaluations of lateral migration potential are based on the results of Level I and II analyses.

II. PHYSICAL DESCRIPTION OF THE STUDY AREA

2.1 General

Calabacillas Arroyo is located in northwestern Bernalillo County and south central Sandoval County, New Mexico, and is tributary to the Rio Grande at a location north of the city of Albuquerque, New Mexico. The arroyo is located in the West Mesa region of Bernalillo County. The study reach was defined as the mainstem of the arroyo from State Highway 448 (Coors Road) west to the confluence of the north and west forks of the arroyo, thence along the north fork to the Bernalillo-Sandoval County line. The downstream boundary of the study (Coors Road) is approximately 2,000 feet upstream of the confluence with the Rio Grande where six 180-inch culverts pass flow under Coors Road. Figure 2.1 illustrates the study boundaries.

2.2 Climate and Flood Potential

The climate in the Albuquerque Region is classified as arid continental with an average annual precipitation of seven to ten inches. Half of this precipitation falls from July to October, typically as brief, heavy thunderstorms. An average of 44 such storms occur each year, mostly during this period (SCS, et al., 1977). Consequently, flash flooding is common when runoff from these short but intense thunderstorms is concentrated in local arroyos. This runoff is commonly delivered to populated low-lying portions of the region, where it spreads and inundates large areas, often causing widespread damage although seldom leading to a risk of loss of human life (Matotan, 1975). Flooding of this type can result from both the East and West Mesas flanking the Rio Grande. Flooding of the Rio Grande flood plain is also possible from the Rio Grande itself due to rapid snow melt or widespread thunderstorms.

2.3 Soils

The soil association in the study reach is the Bluepoint-Kokan association, the same as the Rio Grande and Rio Puerco river valleys. The Bluepoint soil series consist of deep, somewhat excessively drained soils with rapid permeability that formed in sandy alluvial and eolian sediments on alluvial fans and terraces. The Kokan soil series consist of deep, excessively drained soils with rapid permeability that formed in old alluvial sand and gravel of mixed sources. Throughout the study reach, Calabacillas Arroyo lies

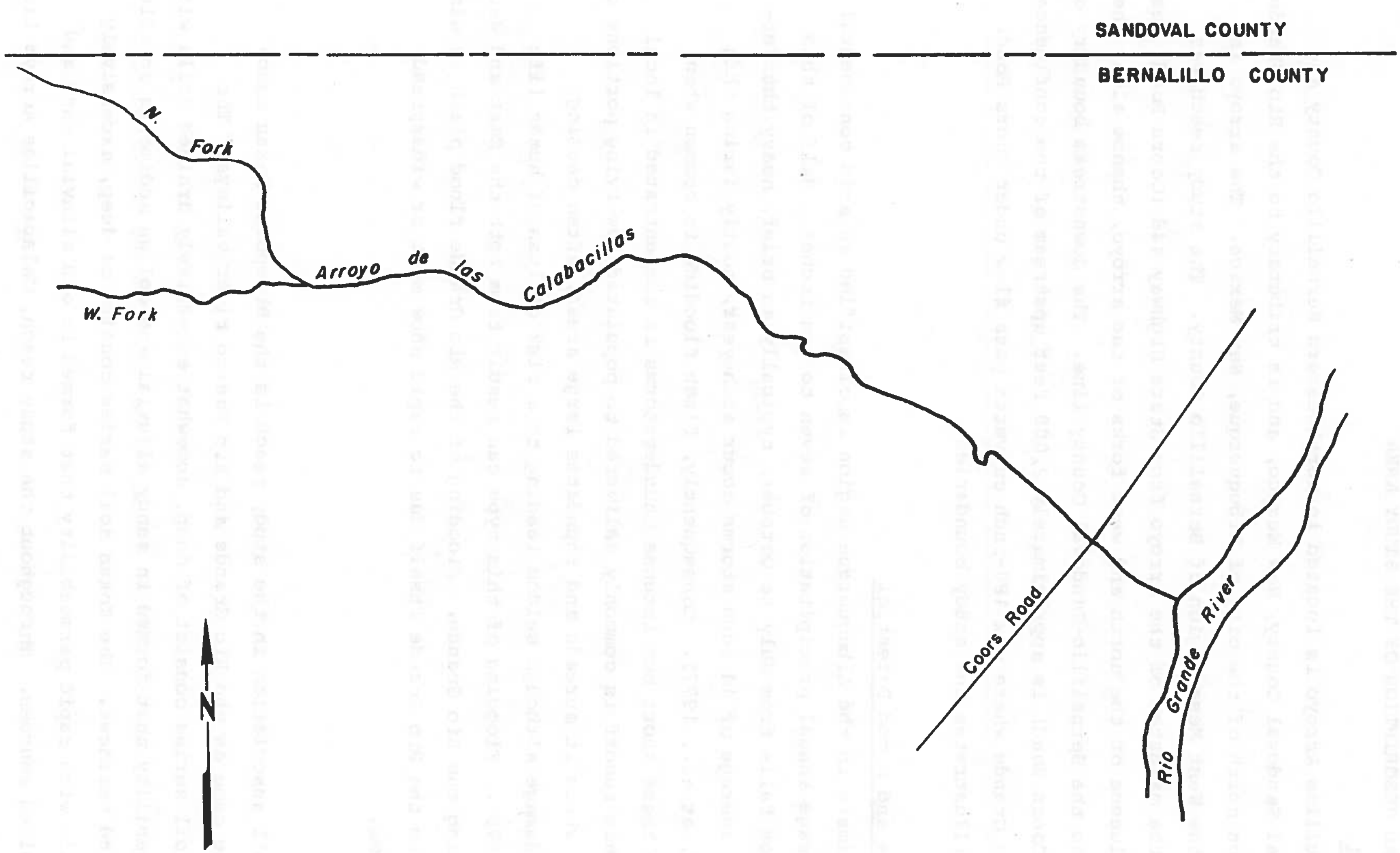


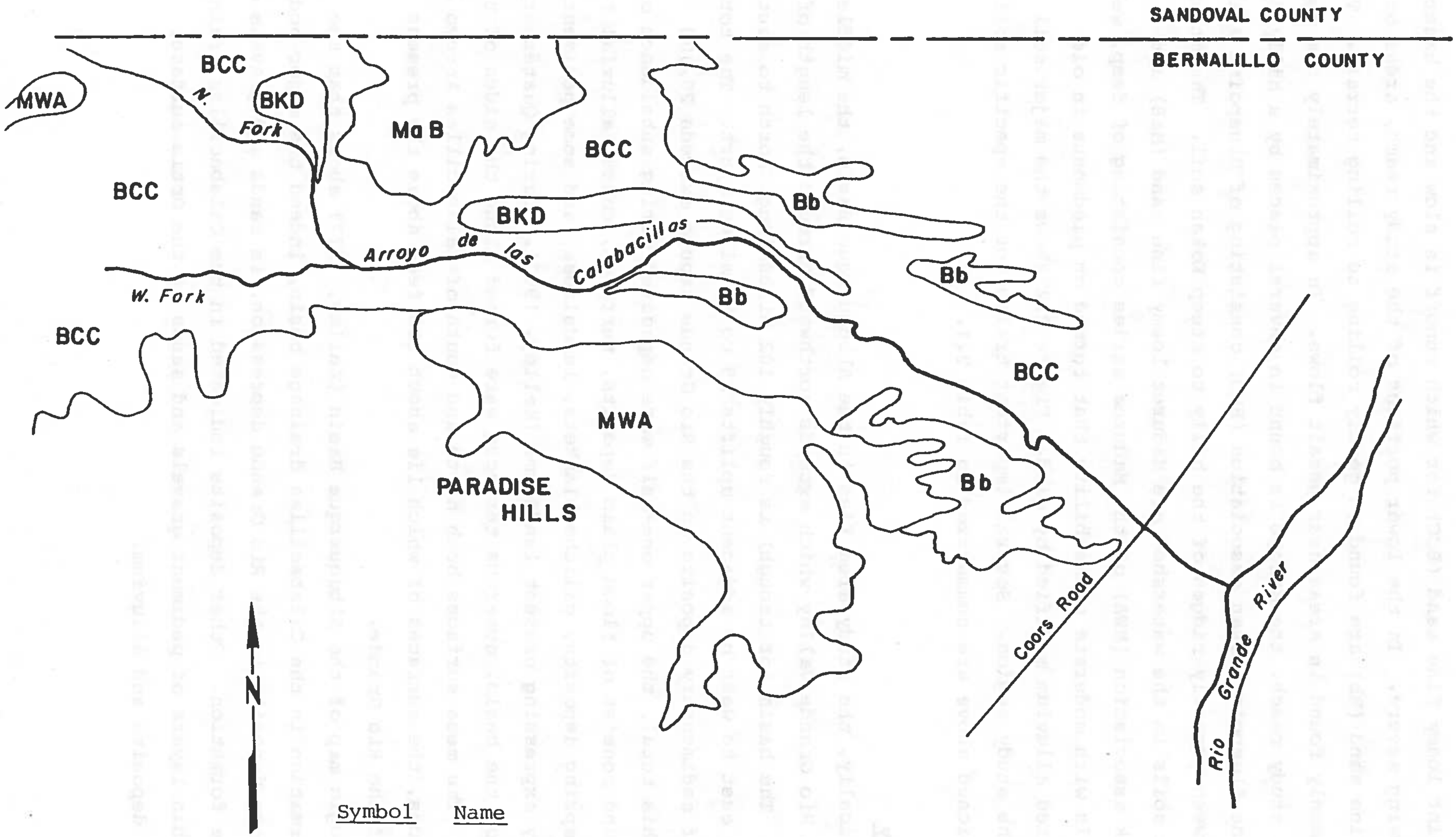
Figure 2.1. Study area.

in a Bluepoint loamy fine sand (BCC) for which runoff is slow and the hazard of soil blowing severe. In the lower portions of the study reach, areas of Bluepoint fine sand (Bb) are found on gently rolling to rolling terrain. This soil is commonly found in areas near basalt flows. In approximately the upper half of the study reach, the arroyo is bound in several places by a hilly formation of the Bluepoint-Kokan association (BKD) consisting of Bluepoint soil on fans between gravelly ridges of the hilly to steep Kokan soil. The other predominant soils in the watershed are Madurez loamy fine sand (MaB) and Madurez-Wink association (MWA) of the Madurez series consisting of deep, well drained soils with moderate permeability that formed on piedmonts in old unconsolidated alluvium modified by wind. Figure 2.2 shows the major soil series in the study region. Several important traits for the specific soil series mentioned above are summarized in Table 2.1.

2.4 Geology

Geologically, the study area lies in the Albuquerque Basin, the middle part of the Rio Grande Valley which extends northward through the length of New Mexico. The basin (or trough) is roughly 102 miles long, north to south, and defined east to west by adjacent uplifts 25 to 50 miles apart. The total thickness of sedimentary deposits in the Rio Grande trough exceeds 20,000 feet. Of this total, the upper one-half were deposited during subsidence of the trough and consist of flood plain deposits, terraces, dunes, alluvial fans and cones, spring deposits, caliche blankets, landslides, and some pediments - all directly expressing present landforms (Kelley, 1977). During Quaternary dissection of the basin, numerous terraces were formed along the sides of the Rio Grande. The mesa surfaces both north and south of Calabacillas Arroyo are river terraces, the surfaces of which lie about 200 feet above the present elevation of the Rio Grande.

A geologic map of the Albuquerque Basin (Kelley, 1977) shows that the dominant formation in the Calabacillas drainage basin, indeed the major body of sedimentary deposits in the Rio Grande depression, is sands and gravels of the Santa Fe formation. Other deposits indicated in the Calabacillas drainage basin are thin layers of pediment gravels and sands of the Ortiz surface, eolian sand deposits and alluvium.



Symbol	Name
Bb	Bluepoint fine sand
BCC	Bluepoint loamy fine sand
BKD	Bluepoint-Kokan association
MaB	Madurez loamy fine sand
MWA	Madurez-Wink association

Figure 2.2 Major soil series in study region.

Table 2.1. Characteristics of Soils in the Study Area.

Soil Series and Map Symbol	USDA Texture Range	Permeability Range (in/hr)	Degree and Limitations for Shallow Excavation	Hydrologic Soil Group
Bluepoint (BCC) (Bb)	Loamy fine sand Fine sand	6-20	Severe-cutbanks cave	A
Bluepoint-Kokan (BKD)	Loamy fine gravel to very gravelly sand	6-20 (Bluepoint) 0.6-2.0 (Kokan)	Severe-cutbanks cave, small stones	A
Madurez (MaB) (MWA)	Fine sandy loam, sandy clay loam, loamy fine sand, sandy loam	0.6-6.0	Slight	B

Located to the south of Calabacillas Arroyo is the Albuquerque volcanic field. Kelley (1974) describes six flow sheet eruptions of the Albuquerque volcanos. The second of the six lava flows reached as far northward as Paradise Hills. This sheet eruption was thin (6 to 20 feet) and rather smooth, indicating high fluidity (Kelley, 1974). The lava flow rests on and is surrounded by sands and gravels of the Santa Fe formation. In the vicinity of Paradise Hills, sands and gravels have been washed down onto the basalt surface from sources higher in elevation to the west. According to Kelley (1977), with the exception of some surficial and marginal erosion, the Albuquerque volcano field has remained essentially the same since its formation.

III. QUALITATIVE GEOMORPHIC ANALYSIS

3.1 General Approach

Qualitative geomorphic analysis employed in Level I relies strongly on individual expertise and practical experience with similar physical systems. Qualitative geomorphic techniques are based primarily based on a well-founded understanding of the physical processes governing watershed and river response. Therefore, an important first step is to assemble and review previous work and data applicable to the study area, and for key project participants to become familiar with the study area. A site visit by key personnel ensures identification of important characteristics of the study reach.

After completing the necessary site visits there are a number of simplified concepts and procedures that contribute to a qualitative analysis. These include analysis of aerial photography and bed and bank material composition, arroyo profile analysis and application of relatively simple relationships describing basic geomorphic concepts.

3.2 Site Visit Observation

During the week of November 8, 1982, a site-visit trip was made by SLA personnel. The purpose of this trip was to gather available documents related to the study, to collect soil samples from the bed and banks of the arroyo and the surrounding watershed, and to gain better understanding of the physical conditions existing in the study reach. Reconnaissance of the main arroyo channel and the surrounding watershed was undertaken to assess present conditions in the study reach, pinpoint potential problem areas, and identify physical features significant for the analysis. General observations and conclusions that resulted from the site reconnaissance are summarized below.

During the site visit, several features significant to an erosion/sedimentation study of the Calabacillas system were noted. In particular, a large excavated area (borrow pit) was found to exist in the main channel at the confluence of the north and west forks of the Calabacillas. Plate 3.1, taken from a commercial flight into Albuquerque, shows the location and areal extent of the borrow pit. The view in this photograph is eastward towards the Rio Grande. A portion of the Paradise Hills development is visible beneath the wing of the aircraft. Plate 3.2 is another view of the excavated area looking upstream to the northwest. The north fork of Calabacillas Arroyo enters the borrow pit in the upper left corner of this picture. The wide, relatively

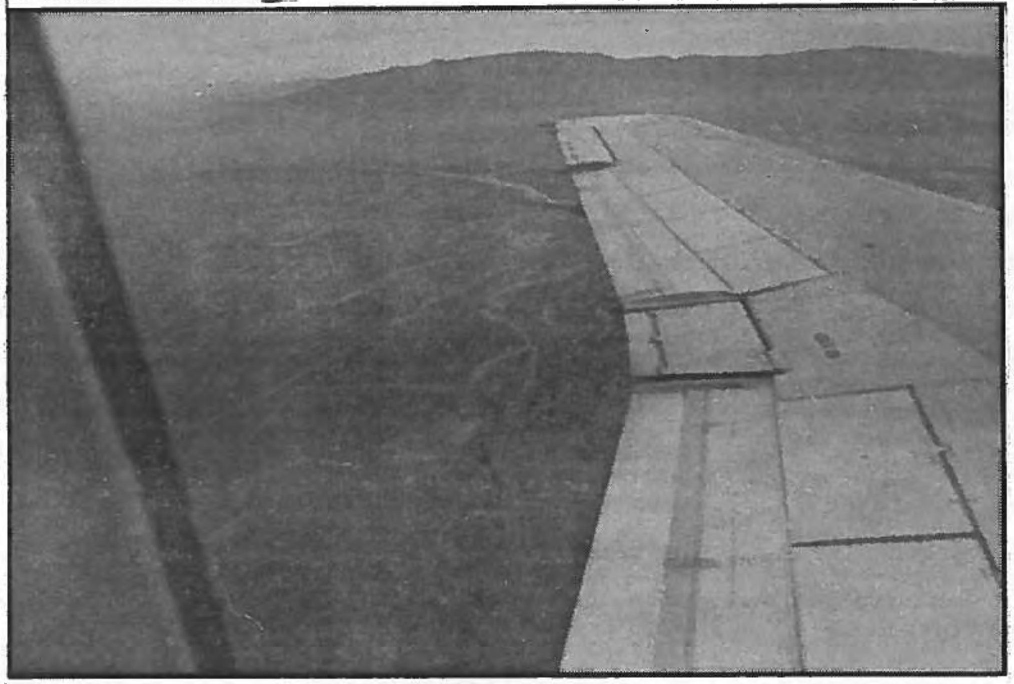


Plate 3.1. Aerial view of Calabacillas Arroyo study area including location of borrow pit.

Plate 3.2. Borrow pit characterisitics at confluence of north and west forks of Calabacillas Arroyo.

level surface of the borrow area was thought to have potential significance as a depositional zone for sediment, which could produce highly erosive, clear water releases downstream of the pit. This possibility was reinforced by observation of small headcuts in the channel below the outlet of the borrow pit. Plate 3.3, looking upstream, shows one of these headcuts, which appears to be working upstream towards the borrow area. (The borrow pit is out of sight beyond the banks to the right of the photograph.) Small headcuts were also observed in the main channel of Calabacillas Arroyo.

From the Sandoval-Bernalillo county line downstream to the Golf Course Road crossing, channel banks are predominantly low (one to three feet) and nearly vertical. Plate 3.4 illustrates channel banks characteristic of this portion of the arroyo. In a short section of the channel directly above the borrow pit, four- to six-foot vertical banks were observed along both sides of the channel. Of particular interest in this area is the block mode of bank failure observed. Large blocks of the bank have collapsed into the channel bed, resulting in a nearly vertical bankline.

Over much of its length in the study area, Calabacillas Arroyo is bounded to the south by the steeply sloping eroded edge of a mesa. The vertical elevation difference between the mesa top and the arroyo bed is 80 feet or more in places. Basaltic rock outcrops observed on the mesa slopes (Plate 3.4) indicate a possible impediment to southward lateral migration of the channel in this area.

Downstream of the Golf Course Road Crossing, channel characteristics begin to change. In particular, the arroyo becomes more incised and in places exhibits high, nearly vertical walls. In plan view the arroyo alternates between highly sinuous, meandering reaches and fairly straight reaches. Figure 3.1 is a definition sketch of the study reach which shows the approximate location of the two most significant meander bends. These will be referred to as the "S" bend, located below Golf Course Road, and the horseshoe bend, situated downstream of the Black's Diversion confluence. Plate 3.5 shows the steep walled, sinuous characteristics of the horsehoe bend.

The remainder of the study reach, from the horseshoe bend downstream to the Coors Road Crossing, is a reasonably straight incised channel with fairly steep banks on both sides.

Plate 3.3. Channel headcut below borrow pit.

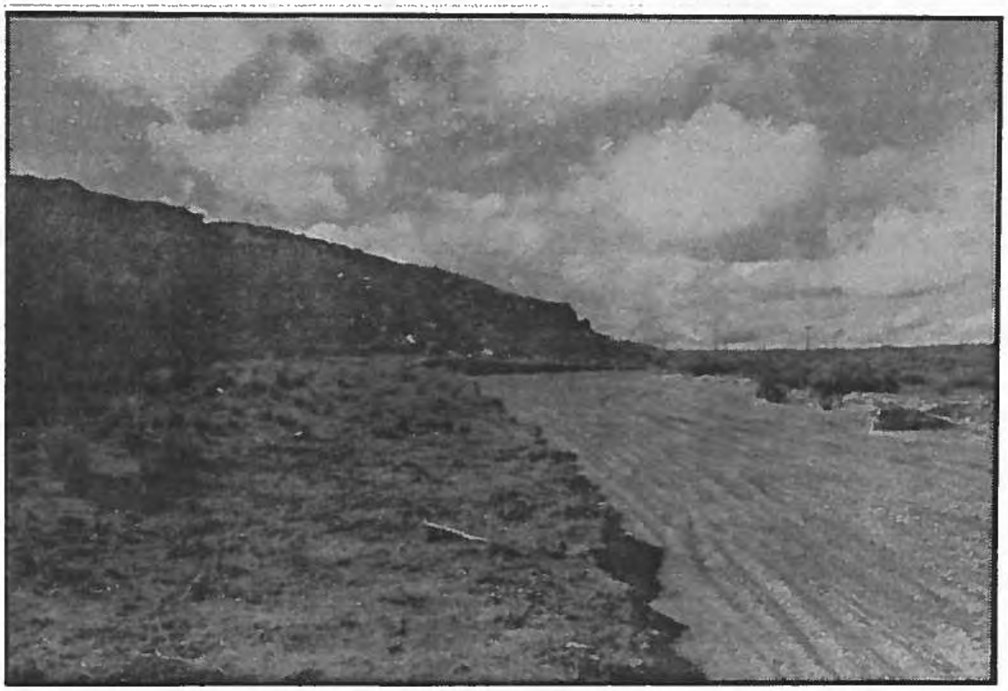


Plate 3.4. Arroyo channel characteristics in the vicinity of Paradise Hills.

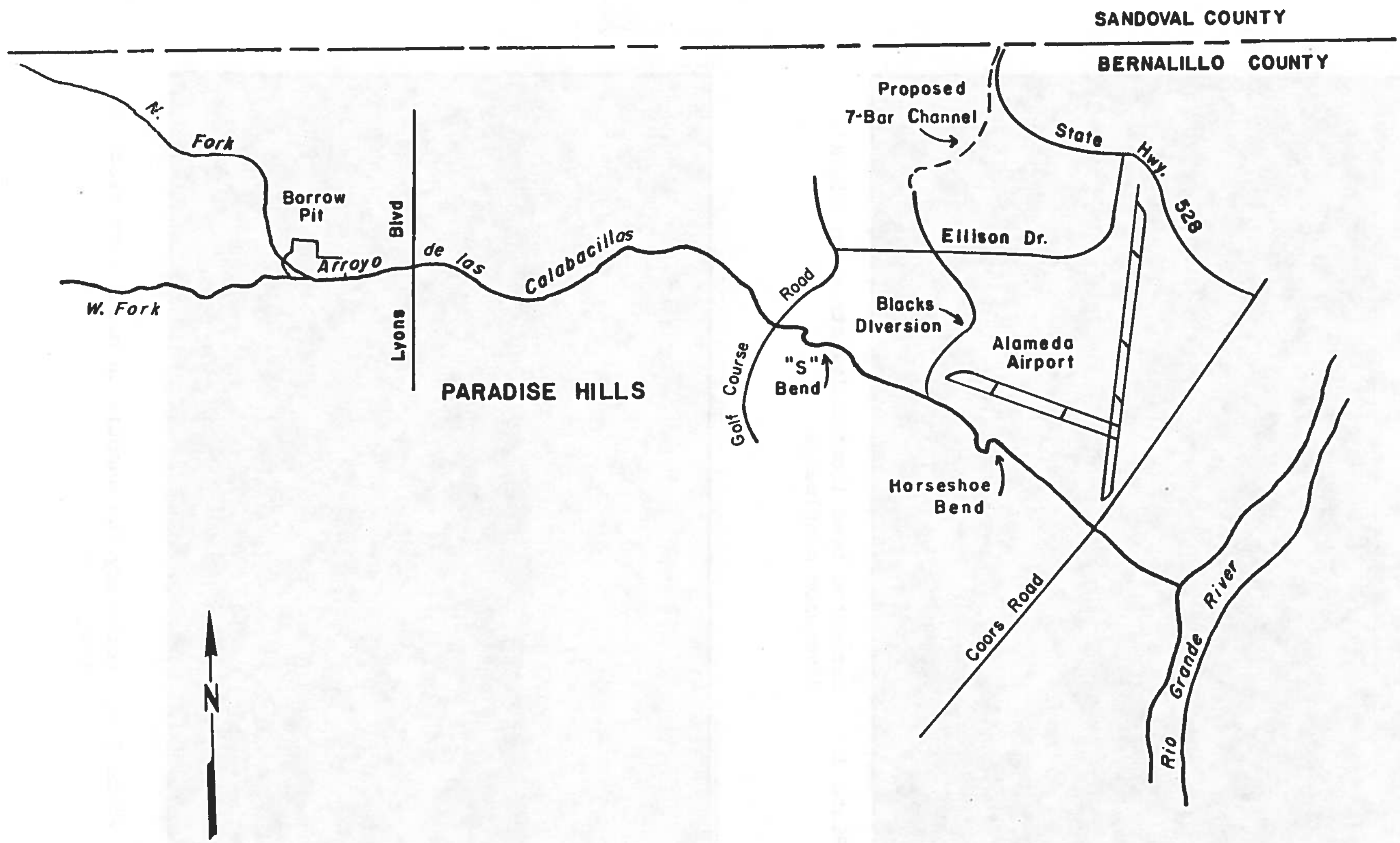


Figure 3.1. Study reach with major features identified.

Plate 3.5. Horseshoe bend located downstream of Black's diversion confluence.

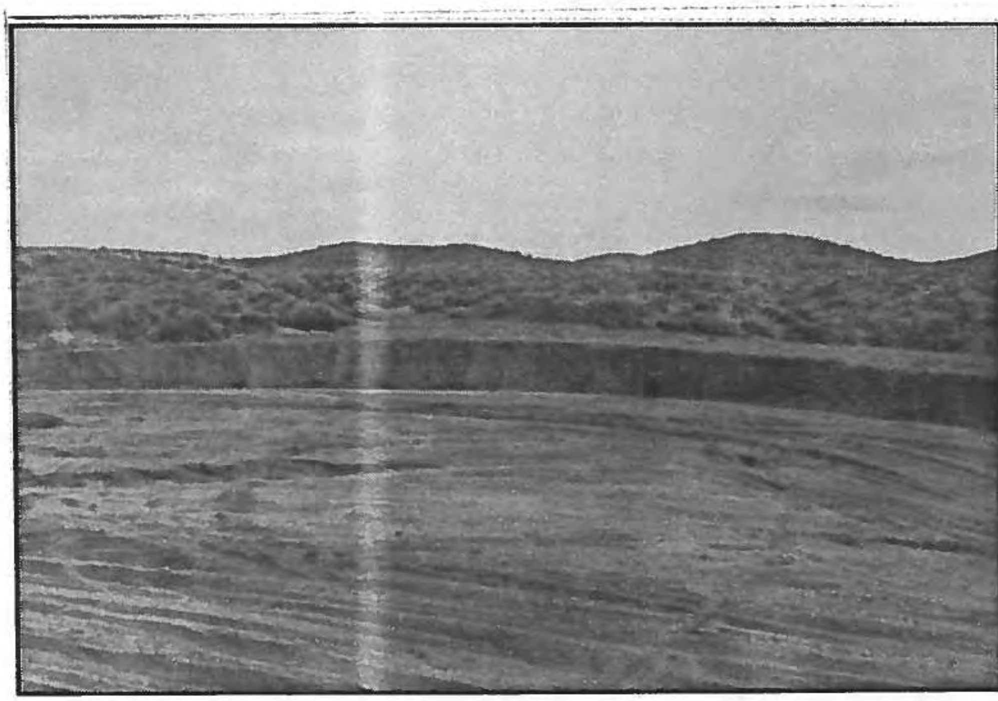


Plate 3.6. Tributary fan deposit on north fork reach of study area.

The alluvial fan deposit of the tributary entering from the left bank above the confluence of the north and west forks (Plate 3.6) provides evidence of the large sediment loads delivered to the main channel from tributary sources. The tributary channel producing the fan deposit shown enters the main channel approximately in the middle of the photograph. A meander bend in the main channel is eroding the fan deposit, creating the vertical bankline shown in the photograph.

A reconnaissance of Black's Diversion, which discharges into Calabacillas Arroyo above the horseshoe bend, also indicates the large sediment loads delivered to the arroyo main channel. From its entrance near Cibola High School to its outlet in Calabacillas, the entire length of concrete-lined channel contained sediment deposits 12 to 18 inches thick at the time of our reconnaissance.

Erodibility of the sandy soil found throughout the Calabacillas system is indicated by large eroded areas observed below drainage rundowns in the Paradise Hills development. Drainageways consisting of asphalt pavement and revet mattresses had been constructed to convey runoff from streets in Paradise Hills to Calabacillas Arroyo. However, flows have completely undermined the mattress protection, and large headcuts were observed to be working up the rundowns. Without periodic maintenance, further erosion will completely destroy the rundowns and begin to undermine the roadways. The inadequate performance of these rundown drainage devices illustrates the potential problems that may be encountered as development begins to encroach on the arroyo.

3.3 Aerial Photograph Analysis

3.3.1 General

Aerial photographs provide valuable information for qualitative analysis of hydraulic parameters and channel geometry changes. Furthermore, availability of aerial photographs over a span of many years provides a time-sequenced documentation of historical trends and changes. For Calabacillas Arroyo, three sets of photographs covering a time period of 45 years are available. A 1935 Soil Conservation photograph was obtained from the National Archives. The scale of the original photograph was 1:35,000; however, for purposes of this analysis, a four times enlargement (approximately) was requested, resulting in a scale of about 1:7,920. A 3 by 3 foot mosaic developed from 1967 photography was available from NASA. The scale of the original photographs was 1:26,000 and with a four times enlargement (exact), the scale of the mosaic was 1:6,500. From Bohannan-Huston, Inc., a 1980 set of 9 by 9 inch photographs covering the majority of the study reach was available. The scale of these photographs was 1:10,800.

The following sections discuss observations and qualitative assessment of historical changes derived from a study of the aerial photography. To facilitate presentation of results obtained from study of the photographs, the study reach was divided into thirds. System configuration, as depicted in the 1967 photography, was used as a basis for comparison with the 1935 and 1980 coverage. Thus, the following sections discuss system changes from 1935 to 1967 and from 1967 to 1980.

It should be noted that the scale of an aerial photograph is generally based on the average elevation difference between ground surface and aircraft flight path for all the photographs taken during the flight. Consequently, when a large area is covered and the terrain is relatively flat, scaling errors are possible which can limit the accuracy of any quantitative measurements. Scaling errors were significant for the three sets of photographs available for this study, and consequently any numbers given must be considered approximate.

3.3.2 Analysis of the Upper Third of the Study Reach

From 1935 to 1967, the most significant changes in the upper third of the study reach were: (1) along the right bank immediately upstream of the West Fork, (2) straightening and enlargement of a side channel, and a change in the location where it rejoins the main channel, (3) filling along the south bank opposite the location where the side channel rejoins the main channel, and (4) straightening and enlargement of the West Fork. These changes are depicted in Figure 3.2. The right bank above the West Fork has migrated approximately 200 feet laterally (northward), significantly reducing channel width in this reach. Changes in the side channel, particularly the location where it rejoins the main channel, and the fill on the opposite bank may be related to earthwork done for the Paradise Hills well. It is possible that borrow material was taken from the left bank to enlarge the area of the right bank for the well building and related structures. The 1967 photograph shows considerable disturbance of the left bank, and the outlet of the side channel is

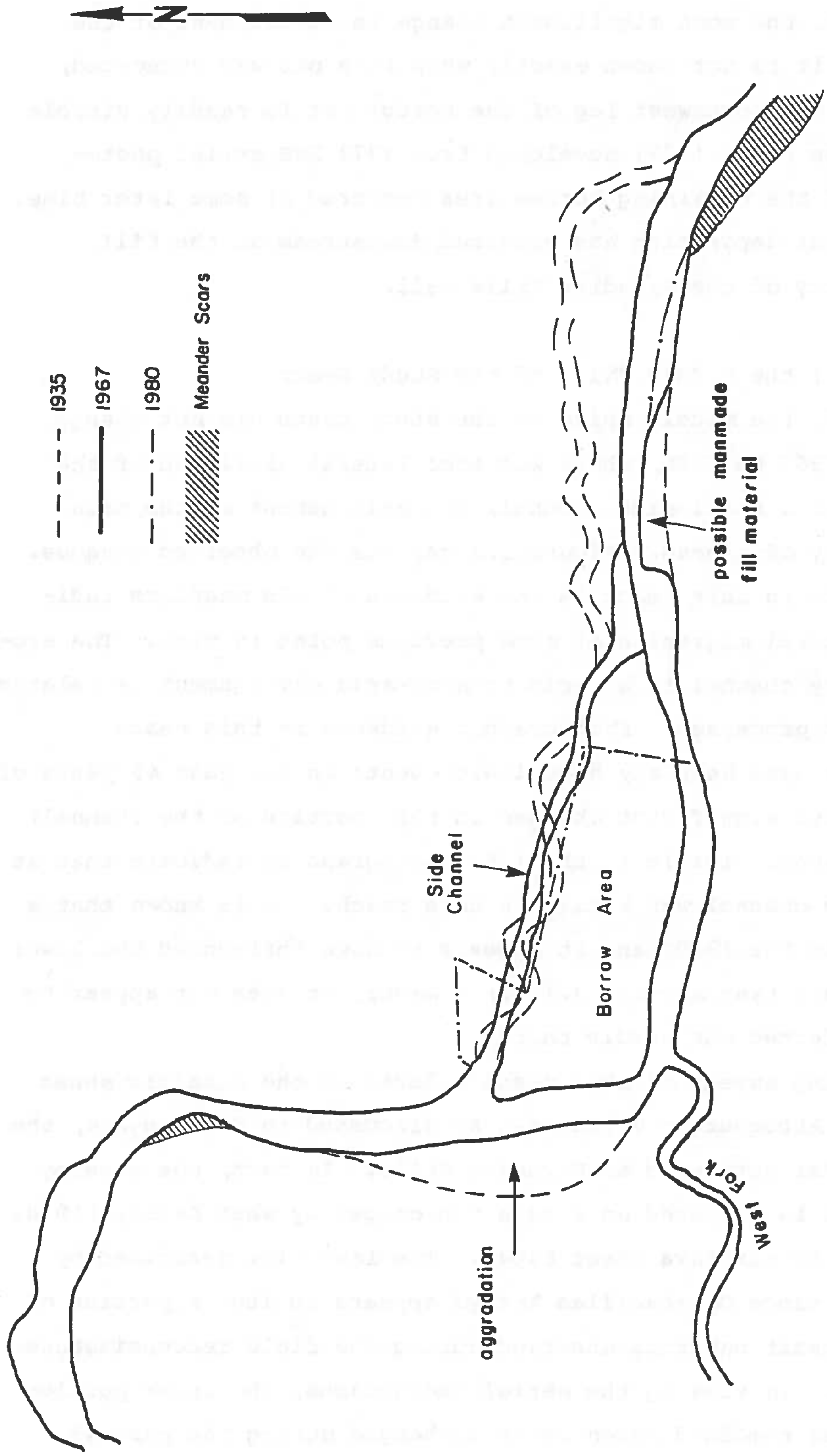


Figure 3.2. Aerial photograph results for the upper third.

no longer well defined, although it certainly rejoins the main channel upstream of where it did in 1935.

From 1967 to 1980, the most significant change is development of the borrow pit. Although it is not known exactly when this pit was excavated, initial excavation in the northwest leg of the borrow pit is readily visible in SCS soil survey maps (SCS, 1977) developed from 1973 SCS aerial photography. Excavation of the remaining borrow area occurred at some later time. It is also apparent that deposition has occurred downstream of the fill material in the vicinity of the Paradise Hills well.

3.3.3 Analysis of the Middle Third of the Study Reach

From 1935 to 1967, the middle third of the study reach did not change significantly. From 1967 to 1980, there was some lateral migration of the channel, development of a small side channel, and enlargement of the main channel in the vicinity of a bend. Figure 3.3 depicts the observed changes. Of greater significance in this reach is the evidence of old meanders indicating significant lateral migration at some previous point in time. The erosional evolution of any channel in an arid to semi-arid environment is related directly to hydrologic processes. Photographic evidence in this reach suggests there may not have been any hydrologic events in the past 45 years of sufficient size to cause significant changes in this portion of the channel; however, the meander scars visible in the 1967 photograph do indicate that at some point in time the channel was active in this reach. It is known that a large event occurred in the 1940s and it appears to have influenced the lower third of the study reach (see section 3.3.4); however, it does not appear to have significantly affected the middle third.

Another interesting aspect of this reach relates to the basaltic sheet flow eruptions of the Albuquerque volcanos. As discussed in Section 2.4, the lava flows extend as far northward as Paradise Hills. In fact, the development of Paradise Hills is situated on a mesa top capped by what Kelley (1974) defines as the second of six lava sheet flows. The lava flow described by Kelley is significant since Calabacillas Arroyo appears to abut a portion of the mesa edge. The basalt outcrops observed during the field reconnaissance tend to bear this out. In viewing the aerial photographs, the upper portion of the middle third has remained essentially unchanged during the past 45

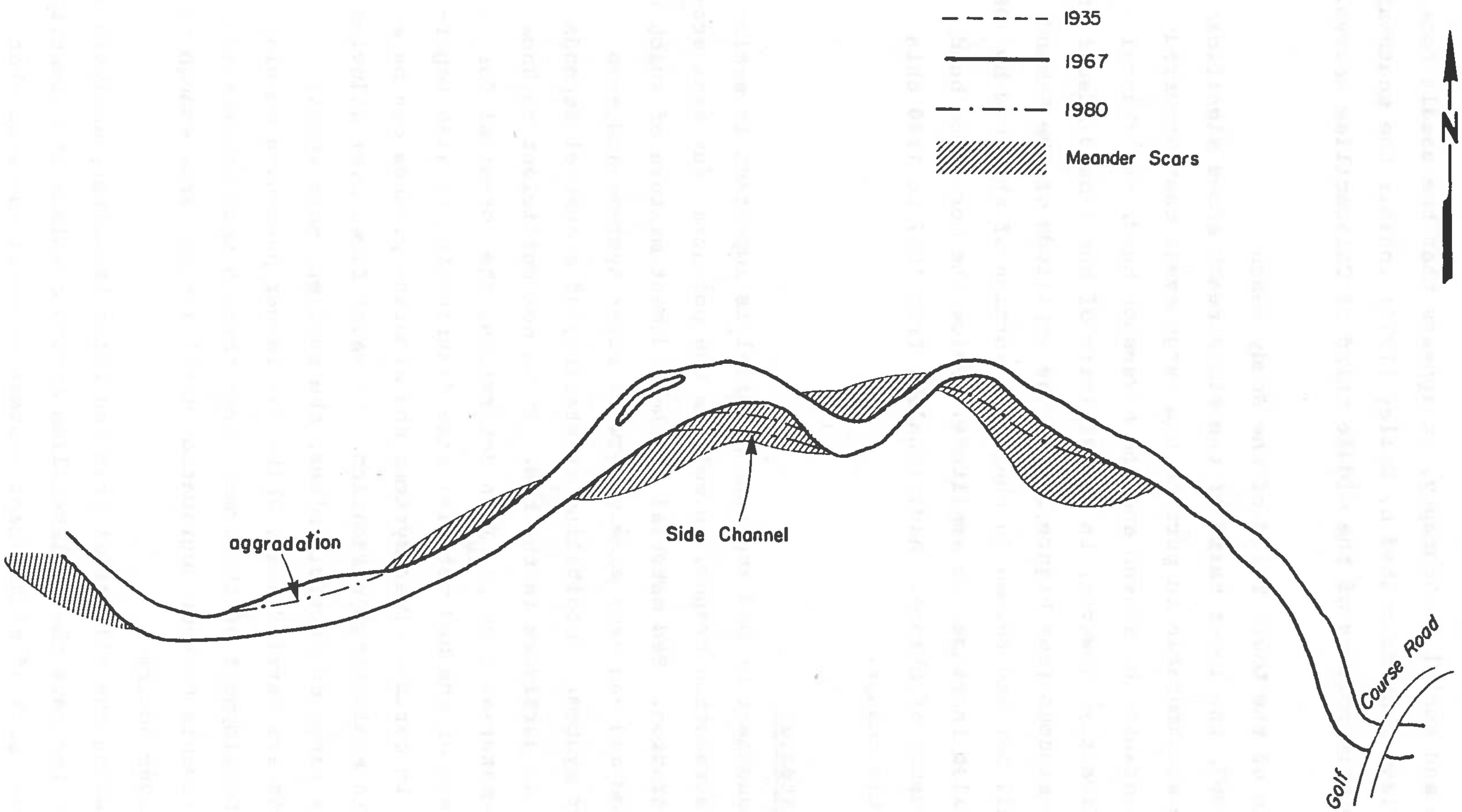


Figure 3.3. Aerial photograph results for the middle third.

years and meander scars indicate that historically movement of the channel in this reach has been relatively small. Based on field observations, and study of the geologic map and aerial photography, it appears that the basalt rock escarpments of the lava flow described by Kelley (1974) inhibit the southward lateral movement in this portion of the middle third of Calabacillas Arroyo.

3.3.4 Analysis of the Lower Third of the Study Reach

From 1935 to 1967, the lower third of the study reach shows significant changes that may be attributable in part to the large event that occurred during the 1940s. Between the S-bend and the horseshoe bend, the channel straightened significantly; however, in the vicinity of the S-bend itself, the channel became more sinuous (see Figure 3.4). The amplitude of the S-bend increased and a small bar had formed in the upper portion of the bend by 1967. The horseshoe bend also increased in amplitude. Below the horseshoe bend, there is little evidence of change. Additionally, from 1967 to 1980 this reach shows negligible change.

3.4 Bed and Bank Material

Qualitative assessment of bed and bank material is important in evaluating aggradation/degradation trends, as well as the potential for bank erosion and lateral migration. Bed material is the sediment mixture of which the streambed is composed and can vary widely between river systems and even within a given river system. Erodibility or stablity of a channel depends largely on the size of particles in the bed. It is not sufficient to know only the median bed-material size (D_{50}) in determining the potential for degradation. Knowlege of the bed material size distribution is also important. For example, in certain river systems the armoring process can be a significant factor in evaluating degradation. As water flows over alluvium consisting of a wide range of particle sizes, the smaller, more easily transported particles are carried away, while the larger particles remain, armoring the bed. Development of the armor layer through this process of hydraulic sorting prevents further degradation until a flow large enough to disrupt the armor layer occurs.

Observations during the site-visit trip and later laboratory analysis of samples (Chapter VI) indicate that Calabacillas Arroyo consists of primarily fine to medium sands. Lack of significant coarser material suggests that

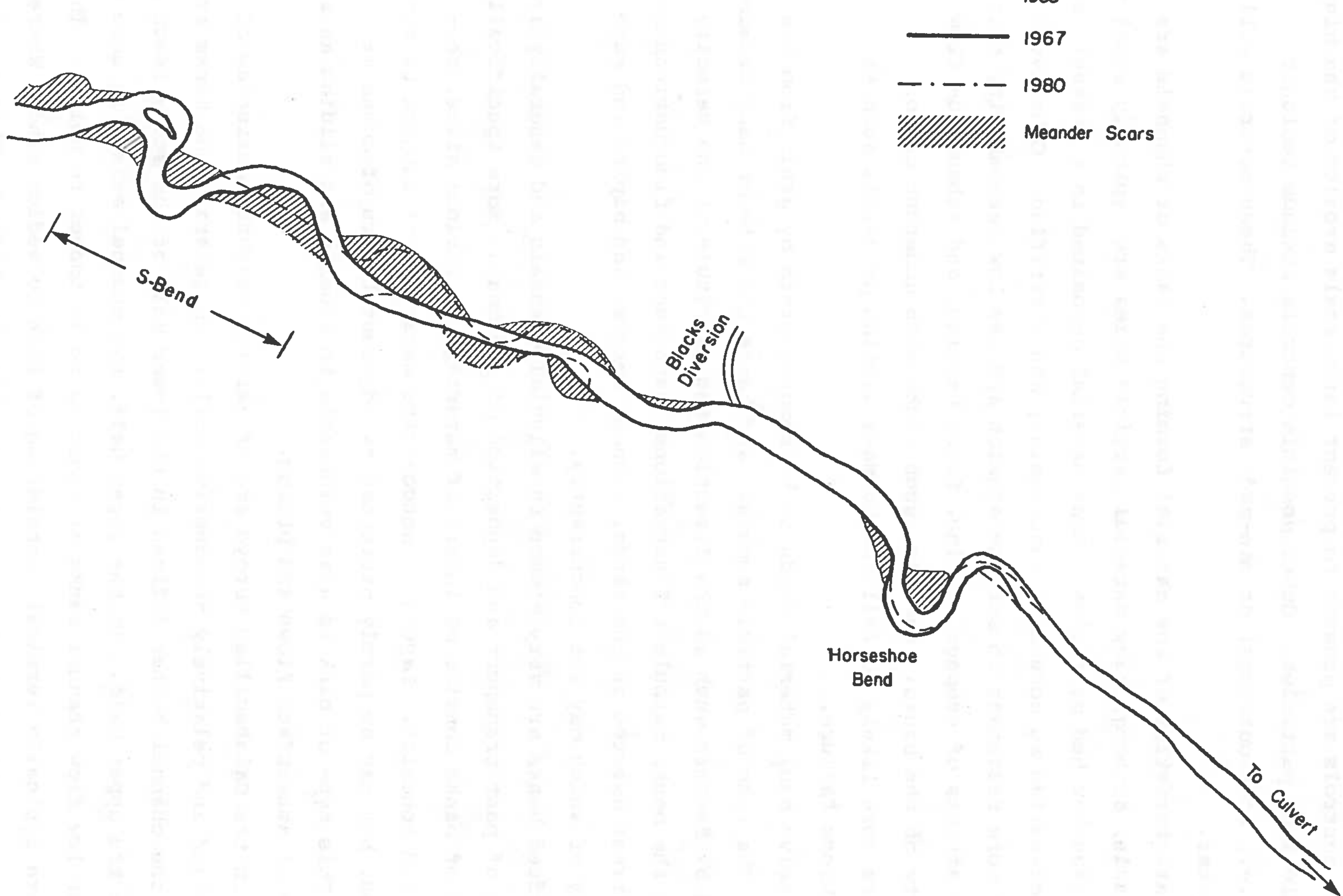


Figure 3.4. Aerial photograph results for the lower third.

armoring is not a significant factor in Calabacillas Arroyo (a more quantitative evaluation of armoring potential is given Chapter VI). Consequently, large amounts of degradation and aggradation would be expected in the arroyo, unless other controls are present to prevent large-scale erosion of the highly transportable sand particles. Other possible controls include geologic controls (i.e., rock outcrops) or man-made structures. These controls will be discussed later.

The characteristics of the material forming the banks of channels are highly variable, although bank material particle sizes are typically equal to or smaller than the bed particles. Bank material deposited in a channel can be broadly classifed as cohesive, noncohesive, and stratified. Cohesive material is more resistant to surface erosion and has low permeability that reduces the effects of seepage, piping, frost heaving, and subsurface flow on the stability of the banks. However, such banks when undercut and/or saturated are more likely to fail due to mass wasting processes such as sliding or block failure.

Noncohesive bank material tends to be removed grain by grain from the bank line. The rate of particle removal, and hence the rate of bank erosion, is affected by factors such as the direction and magnitude of the velocity adjacent to the bank, turbulent fluctuations, magnitude and fluctuations in the shear stress exerted on the banks, seepage forces, and piping and wave forces, many of which may act concurrently.

Stratified banks are very common in alluvial channels and generally are the product of past transport and deposition of sediment. More specifically, these types of banks consist of layers of materials of various sizes, permeability, and cohesion. Layers of noncohesive material are subject to surface erosion, but may be partly protected by adjacent layers of cohesive material. This type of bank is also vulnerable to erosion and sliding as a consequence of subsurface flows and piping.

Banks in the Calabacillas Arroyo are of varying heights consisting of both stratified and relatively noncohesive soils. In general, the banks are higher and the channel better defined in the lower half of the study reach as compared to the upper half. In the upper half, the channel exists in more of a swale with low flow channel banks of about 12 to 18 inches in height. These low banks are typically vertical, consisting of fine to medium sand. Where taller vertical banks exist, the soil is typically stratified. This is particularly true in the S- and horseshoe shaped bends. Otherwise, the taller banks, particularly in the lower half of the study area, exist at, or slightly less than, the angle of repose.

3.5 Arroyo Profile Analysis

Topographic maps developed from time-sequenced aerial photography provided the information necessary for analysis of recent profile changes in the study reach of Calabacillas Arroyo. Detailed topographic maps, showing two-foot contour intervals, were available for the years 1972 and 1980. The 1972 map was developed from USGS coverage of the area. In 1980, the 1972 topography was revised based on aerial photography taken by Bohannan-Huston, Inc. The 1980 map was the base map for a floodway study of the Calabacillas Arroyo performed for the Albuquerque area by FEMA. As furnished for use on this project, the 1980 topographic map also showed floodway boundaries and the HEC-2 cross section locations used during the flood insurance study (see Chapter V).

In comparing the 1972 and 1980 maps, topographic contour descriptions of the arroyo upstream of Golf Course Road appeared to be identical on each map. Furthermore, the borrow pit previously discussed was readily visible in the 1980 photography yet its existence was not reflected in the 1980 topographic map. It was later verified (personal communication with Dan Sabo of AMAFCA) that only the lower portion of the arroyo topography had been updated during the 1980 flood study. As a result, profile changes could be evaluated only for approximately the lower third of the study reach.

To evaluate changes in channel profile between the years 1972 and 1980, cross sections used for the HEC-2 analysis were superimposed on the 1972 topographic map. Channel thalweg elevation at each cross section was then plotted versus horizontal stationing of the cross section, producing an average representation of the channel profile. By plotting channel profiles for both 1972 and 1980, aggradational/degradational characteristics of the arroyo during this time interval could be assessed. Figures 3.5 and 3.6 illustrate the thalweg channel slopes between each cross section location (the letter designations used to describe cross section locations are defined in Chapter V). As Figure 3.6 illustrates, the channel has tended to aggrade over approximately 3,000 feet of its length between cross sections R and N. The remaining length of the arroyo which could be evaluated, shows degradation of the channel. Potential for significant vertical instability within

Calabacillas Arroyo is indicated by the two to five feet of erosion shown to have occurred between section N and E during an eight-year period.

It should be noted that Figures 3.5 and 3.6 depict an average profile of the system, based on the assumption of a constant slope between cross sections. As a result, changes in thalweg elevation shown in these figures represent only average changes in the system, and do not reflect localized changes (or the lack of change) that may actually occur between cross sections. In addition, the trends in thalweg elevation change are generally consistent with the trends in change of the average bed elevation, but the absolute amount of elevation change is generally greater for the thalweg than it is for the average bed elevation.

3.6 Other Qualitative Geomorphic Analyses

The slope discharge relation is a methodology suggested by Lane (1957) to define the planform classification of watercourses. Figure 3.8 summarizes Lane's results. The slope of Calabacillas Arroyo is typically 1.0 to 1.5 percent. Consequently for any discharge the Calabacillas would be classified as a braided channel according to Figure 3.7. A braided channel is defined as a relatively wide channel characterized by a steep shallow watercourse. Typically, a braided channel has unstable banks and multiple channel diversions around alluvial islands. Lane (1957) concluded that two primary causes for the braided condition are: (1) the channel is supplied with more sediment than it can carry, resulting in deposition, and (2) steep slopes produce a wide, shallow channel where bars and islands often form. All of these characteristics of braided channels can be observed in Calabacillas Arroyo, although development of bars and islands is not as common in this system as observed in other braided systems.

A basic physical process that occurs in a stream or river is its tendency, in the long run, to achieve a balance between the product of water flow and channel slope and the product of sediment discharge and sediment size. The most widely known geomorphic relation embodying this equilibrium concept is known as Lane's principle.

Lane (1955) studied the changes in river morphology caused by modifications of water and sediment discharges. Similar but more comprehensive treatments of channel response to changing conditions in rivers have been presented by Leopold and Maddock (1953), and others. The relation is:

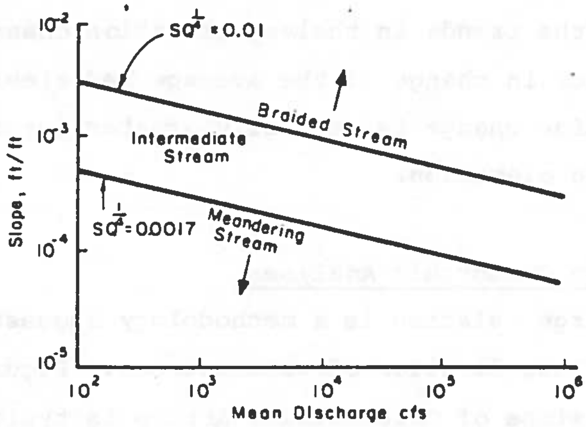


Figure 3.7. Slope-discharge relation for braiding or meandering in sand-bed streams (Lane, 1957).

$$QS \propto Q_S D_{50} \tag{3.1}$$

where Q is the water discharge, S is the channel slope, Q_s is the sediment discharge and D_{50} is the median diameter of the bed material. Applying this proportionality in a qualitative manner yields valuable insight to channel response.

Application of the Lane relation to the borrow pit on Calabacillas Arroyo provides an indication of the impact that this change has on downstream channel response. The borrow pit is equivalent to a sudden expansion in the channel which according to continuity will result in greatly reduced velocities. Since sediment transport is proportional to the third to fifth power of velocity, sediment transport capacity will be significantly reduced, causing aggradation in the pit. Depositon or aggradation results in relatively clear water being released downstream of the pit, that is, sediment supply Q_s will be reduced to Q_s^- downstream. Assuming water discharge and sediment particle size remain constant, slope must decrease downstream of the pit to maintain the proportionality of the Lane relation:

$$QS^- \propto Q_S^- D_{50} \tag{3.2}$$

Reduction in slope occurs through gradual degradation of the channel below the pit. With time, the pit will fill and sediment will again be available to the downstream reach. Then, except for local scour, the channel gradient will steepen in order to transport the increased sediment. In the long term some equilibrium value will be achieved.

3.7 Results and Conclusions of the Qualitative Geomorphic Analysis

Calabacillas Arroyo is a steep, relatively straight channel with a large width-to-depth ratio. The characteristics of the watershed and the large alluvial fans present at the mouths of tributaries indicate that a large sediment load is delivered to the system. Typical of many streams and arroyos in the Southwest, Calabacillas Arroyo is a dynamic system with significant potential for lateral and vertical instability.

Old meander scars in the middle third of the study reach document the long-term historical lateral instability that is possible. More recent activities, as documented by aerial photographs spanning 45 years, have included straightening of the channel in the lower third and significant disturbance due to man in the upper third. Excavation of a large borrow pit at the confluence of the north and west forks will impact the entire system for many years to come. The most significant impact will be degradation downstream of the borrow pit as the pit refills with sediment. Lateral stability in the reach immediately below the borrow pit (middle third) can be documented historically and suggests that the channel is strongly influenced by the steeply sloping mesa edge to the south.

Data available for the lower third are adequate for a longitudinal profile analysis. Changes in the thalweg elevation over the last eight years in this reach suggest significant vertical instability is possible over relatively short time periods. Degradation along the thalweg of four to five feet was documented, with both degradation and aggradation occurring over a relatively short reach of the channel. The observed headcut in the vicinity of Black's Diversion channel was well documented by this analysis.

IV. HYDROLOGY

4.1 Data Base

Hydrologic data for Calabacillas Arroyo were available from the Drainage Management Plan, Western Albuquerque Metropolitan Area (Matotan, 1975) and the Flood Insurance Study for the City of Albuquerque, Bernalillo County. A comprehensive hydrologic study of Calabacillas Arroyo was conducted for the Drainage Management Plan, including development of hydrographs by subbasins; however, the only information recoverable was peak discharge values and runoff volumes for the 25- and 100-year events at various locations in the arroyo. Estimates of peak discharge values for the 10- and 50-year events at the same locations were made by a frequency analysis for the Flood Insurance Study. For purposes of this project, the 2-year peak discharges were also evaluated from a frequency analysis (log Pearson Type III). Consequently, all hydrologic data for this study were derived from the original Drainage Management Plan. Table 4.1 summarizes peak discharge values for different flood events at various locations in the study reach. All underlying assumptions used in developing the peak discharge values in the Drainage Management Plan, including runoff characteristics, time to peak, etc. are accepted as accurate, although there is evidence that the hydrology is conservative (letter dated March 31, 1982, signed by R. Leonard, AMAFCA). Additionally, the hydrology estimates may not accurately reflect runoff conditions after development.

4.2 7-Bar Channel

The existing hydrologic data base accounted for Black's Diversion; however, it did not include the recently proposed 7-Bar Channel which will route additional runoff to Calabacillas Arroyo via Black's Diversion. Although the additional water enters in the lower end of the study reach, it was determined an important contribution due to: (1) existence of a headcut working upstream in the vicinity of Black's Diversion channel outlet, and (2) location of the horseshoe bend downstream of the Black's channel outlet.

To evaluate the 7-Bar contribution to the Calabacillas hydrograph for any given event, the 7-Bar hydrograph was assumed to be similar to the existing Black's Diversion hydrograph in terms of its shape, duration and time to peak (this is a conservative assumption; see Bohannan-Huston, Inc., "Design Memorandum for 7-Bar Channel", for more accurate routing). Consequently, the 100-year peak discharge in Black's Diversion after completion of the 7-Bar

Table 4.1. Peak Discharge Data (Q_p - cfs) at Various Locations in the Arroyo.

Location	Recurrence Interval - years					
	2[1]	10[2]	25[3]	50[2]	100[4] (Main Channel)	100[4] (Side Channel)
Upstream Boundary	365	2,300	4,613	7,200	10,976	--
@ AB	365	2,300	4,613	7,200	7,230	3,746
@ AA	390	2,460	5,038	7,800	8,128	3,746
@ Z	390	2,460	5,038	7,800	11,874	--
@ M	410	2,700	5,407	8,500	12,667	--

[1] Frequency analysis by SLA
[2] Bohannan-Huston, Inc.
[3] Matotan, Inc.
[4] As modified for sediment analysis by SLA

Channel is the sum of the peak discharges, or 3,332 cfs. The pre-7-Bar 100-year peak discharge in Black's Diversion is 2,375 cfs; however, due to differences in peaking times between Black's and Calabacillas the increase in the Calabacillas 100-year peak at their confluence is 793 cfs. Applying this same ratio to the post-7-Bar peak discharge in Black's results in an increase in the 100-year peak discharge in Calabacillas of:

$$\Delta Q_{Calabacillas} = \frac{793}{2,375} \times 3,332 = 1,113 \text{ cfs}$$

The contributions for all other flood events were then estimated by scaling according to the ratio of the 100-year result before and after completion of 7-Bar. Table 4.2 summarizes the peak discharges in Calabacillas Arroyo at the confluence of Black's Diversion and Calabacillas with and without the 7-Bar Channel. The estimated increase in peak discharge resulting from the 7-Bar Channel ranges from two to three percent.

4.3 Hydrograph Development

For lateral migration analysis (Chapter VII), the general shape of the hydrograph for each flood event is required to estimate the duration of potentially erosive flow. Unfortunately, the original hydrographs developed for the Drainage Management Plan were unavailable for this study. For purposes of this study, it was determined adequate to scale the hydrographs from an adjacent drainage. The 100-year hydrograph for Montoyas Arroyo, the drainage basin immediately north of Calabacillas, was available from the Soil Conservation Service (SCS). For drainage basins with similar runoff characteristics, runoff volume should be correlated with drainage basin area. To justify scaling the Calabacillas 100-year hydrograph from the available Montoyas 100-year hydrograph, the ratio of the runoff volumes (pre-7-Bar condition), were compared to the ratio of the drainage areas. Computed values were 1.72 and 1.88, respectively, indicating that the two drainages are similar in runoff characteristics. Consequently, it is justified to scale the Calabacillas hydrograph from the Montoyas hydrograph.

The ratio of peak discharges was 1.69, which is similar to the ratios of drainage areas and runoff volumes, making the selection of a scaling factor rather arbitrary. However, since the available peak discharges were assumed correct (see section 4.1), the discharge ratio was selected so that the peak

Table 4.2. Peak Discharge Data (Q_p - cfs) at the Confluence of Black's Diversion Channel and Calabacillas Arroyo.

	Recurrence Interval - years					
	2	10	25	50	100	500
Pre-7-Bar	410	2,700	5,407	8,500	12,667	28,000
Post-7-Bar	418	2,797	5,556	8,782	12,987	28,726

discharge of the generated hydrograph agreed with the given peak discharge. Furthermore, the peak discharge with the 7-Bar contribution was used in scaling so that the hydrograph accurately represented future conditions in Calabacillas below Black's Diversion.

To derive the remaining hydrographs, the 100-year hydrograph was used to develop a unit hydrograph (Figure 4.1). The known peak discharges were then used to generate the hydrograph for each flood event. The adequacy of this procedure was verified by comparing the estimated runoff volume for the 25-year event with the given value in the Drainage Management Plan. The final hydrographs for each flood event at the downstream boundary of the study area are given in Figure 4.2.

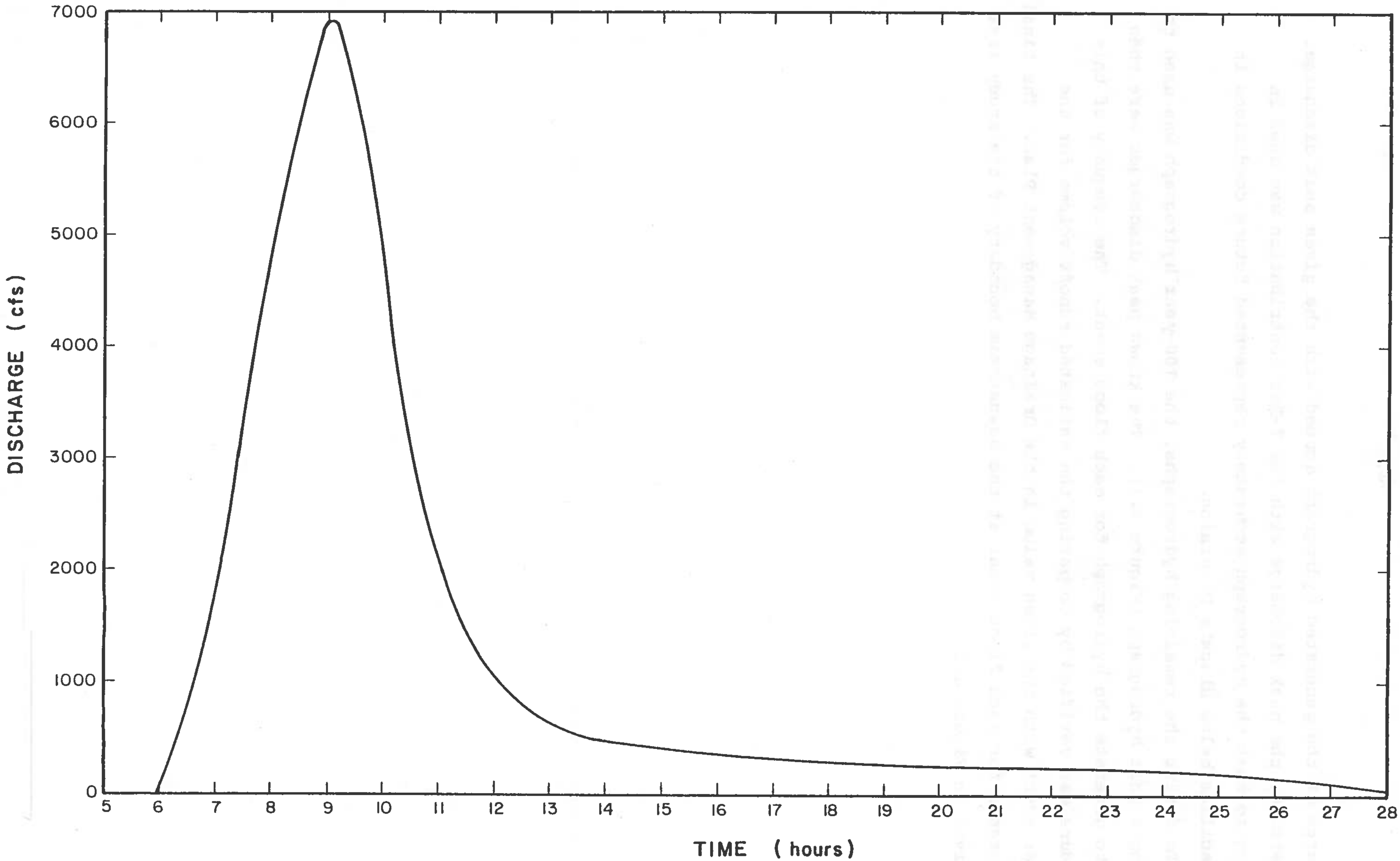


Figure 4.1. Unit hydrograph for Calabacillas Arroyo. (1 cm direct runoff)

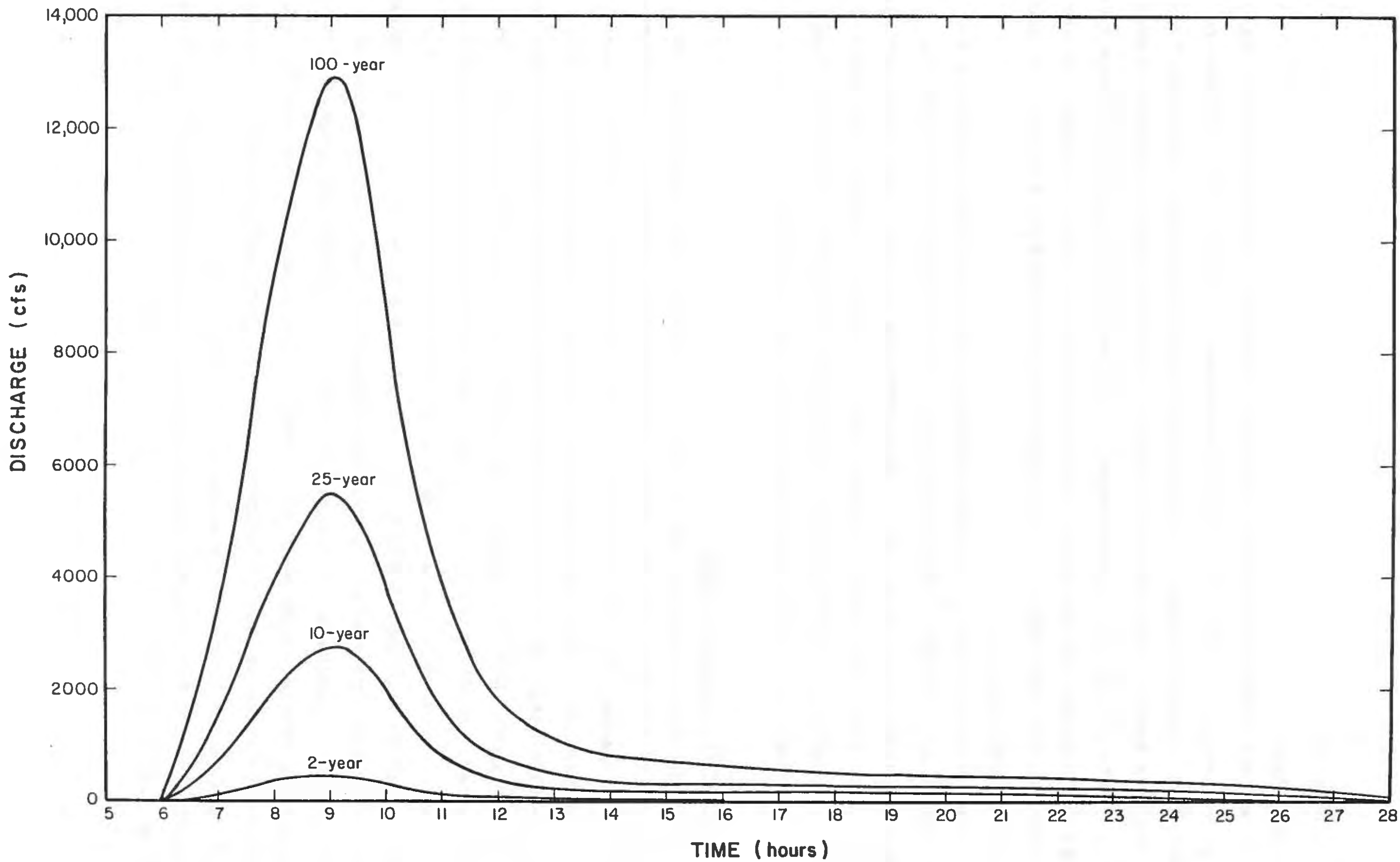


Figure 4.2. Flood hydrographs (100-, 25-, 10- and 2-year).

V. HYDRAULICS

5.1 Data Base

The HEC-2 data base used for the flood insurance study of Calabacillas Arroyo was available for this project from Bohannan-Huston, Inc. Data were provided on a magnetic tape and consisted of both input data and output for the 100-year event. Upon receipt, contents of the magnetic tape were transferred to the VAX 11/780 computer used by SLA and a test run was performed to verify the accuracy of the tape. Results of this run were compared with the 100-year results (available on the tape) and indicated that the tape was good and being read properly.

Cross section data on the HEC-2 tape was based on 1980 photography and topographic maps based on 1972 photography. A total of 33 cross sections labeled alphabetically (A-Z, AA-AG) upstream from the confluence with the Rio Grande were used. The cross sections from A to R were based on the 1980 aerial photography and from Section R upstream on the 1972 topographic map. Figure 5.1 depicts relative locations of the cross sections.

5.2 Borrow Pit Cross Sections

During field reconnaissance, a large borrow area was observed at the confluence of the North and West Forks of Calabacillas Arroyo. The excavated material had apparently been used as fill during construction of Paradise Hills subdivision. After the field trip, it was determined that the HEC-2 cross section data, as used in the flood insurance study, did not account for the borrow area. Although presence of the borrow area might not siginificantly affect the flood insurance study results, it would have a significant impact on the sediment transport analysis. Sediment transport is generally proportional to velocity to the third to fifth power (ie $Q_s \propto V^{3-5}$). Consequently, even slight changes in hydraulic conditions can cause relatively large changes in sediment transport capacity. The borrow pit causes a sudden expansion in channel cross section, reducing velocities and flow depths, and therefore reducing sediment transport capacity. This will result in sediment deposition in the borrow pit area and a relatively clear water discharge downstream of the borrow area with potentially high degradational ability (see Section 3.6).

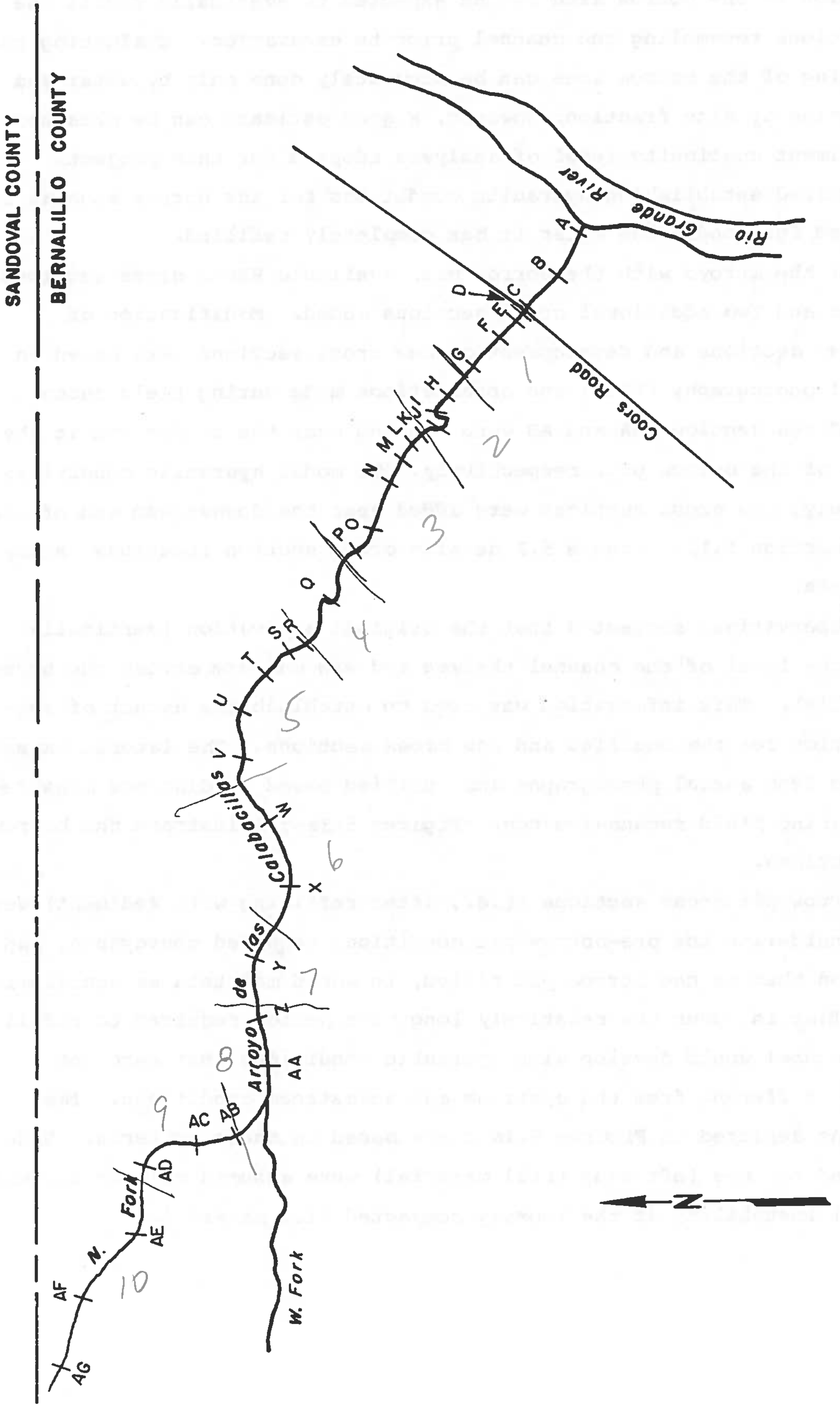


Figure 5.1. Approximate location of cross sections in study reach.

Deposition in the borrow area can be expected to eventually refill the pit to conditions resembling the channel prior to excavation. Evaluating the rate of filling of the borrow area can be accurately done only by water and sediment routing by size fraction; however, a good estimate can be obtained with the sediment continuity level of analysis adopted for this project. Analysis required establishing hydraulic conditions for the borrow area as it now exists and for conditions after it has completely refilled.

To model the arroyo with the borrow pit, available HEC-2 cross sections were modified and two additional cross sections added. Modification of existing cross sections and development of new cross sections were based on recent aerial photography (1980) and observations made during field reconnaissance. Cross sections AA and AB were located near the middle and at the upstream end of the borrow pit, respectively. To model hydraulic conditions more accurately, new cross sections were added near the downstream end of the borrow pit (Section I.1). Figure 5.2 details cross section locations in the borrow pit area.

Field observations suggested that the original excavation (vertically) was down to the level of the channel thalweg and was uniform across the borrow area (laterally). This information was used to establish the extent of vertical excavation for the modified and new cross sections. The lateral extent was evaluated from aerial phtoographs and verified based on distance measurements made during field reconnaissance. Figures 5.3a-c illustrate the borrow pit cross sections.

Post-borrow pit cross sections (i.e., after refilling with sediment) were evaluated considering the pre-borrow pit condition, required conveyance, and the assumption that as the borrow pit filled, it would maintain an equilibrium condition. That is, over the relatively long time period required to refill the pit, a channel would develop with hydraulic conditions that were not significantly different from the upstream and downstream conditions. The cross sections depicted in Figures 5.4a-c are based on these criteria. Side slopes adopted for the left bank (fill material) were assumed mild to account for potential instability of the loosely compacted fill material.

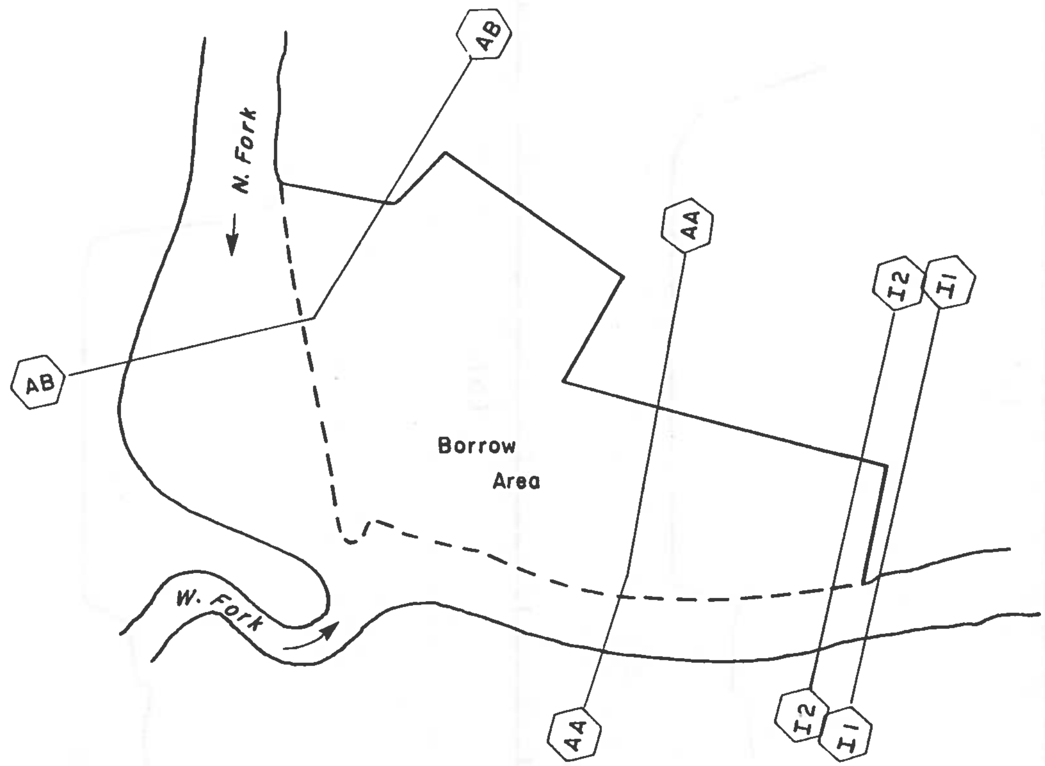


Figure 5.2. Approximate location of cross sections in borrow pit.

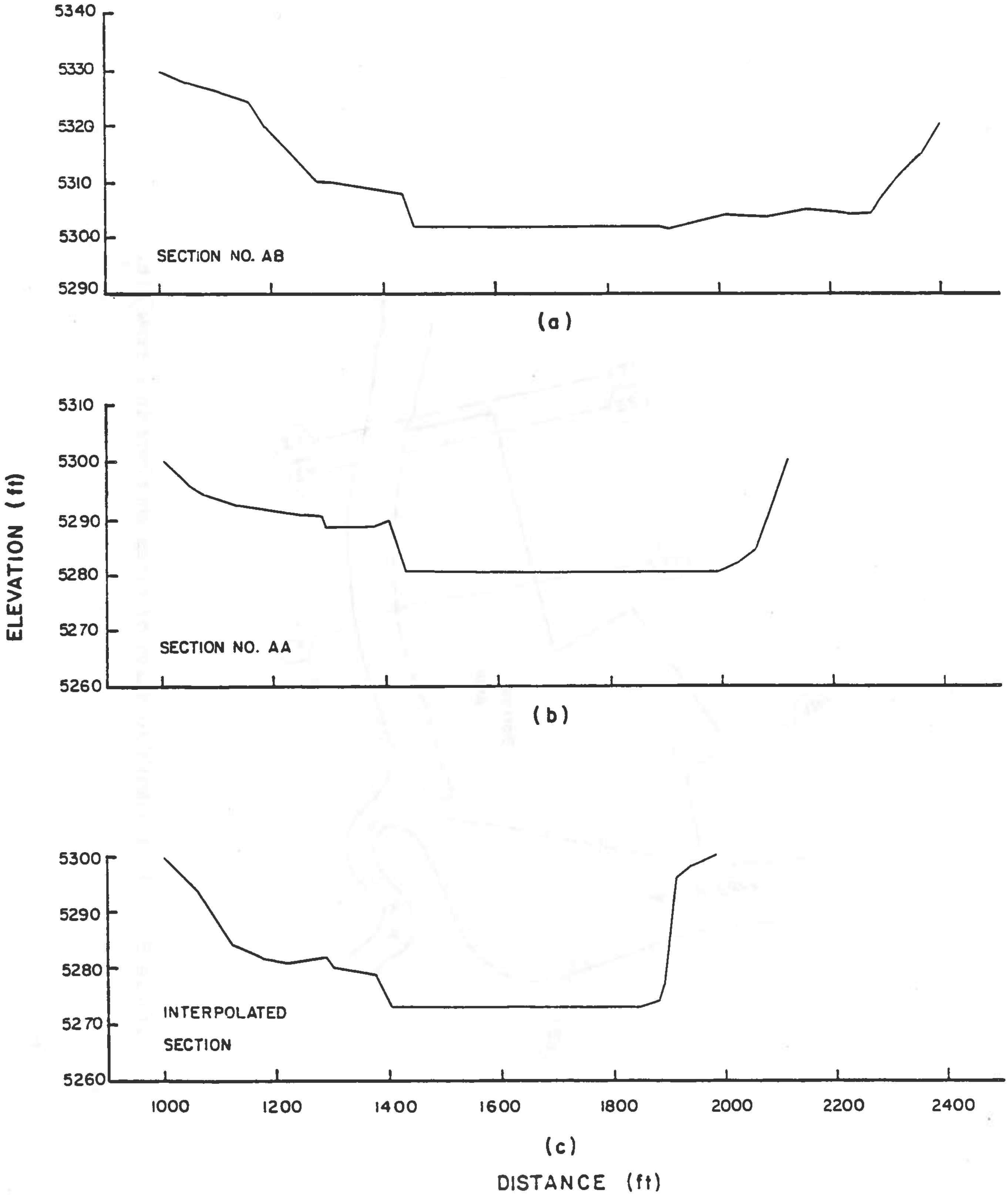


Figure 5.3. Borrow pit cross sections.

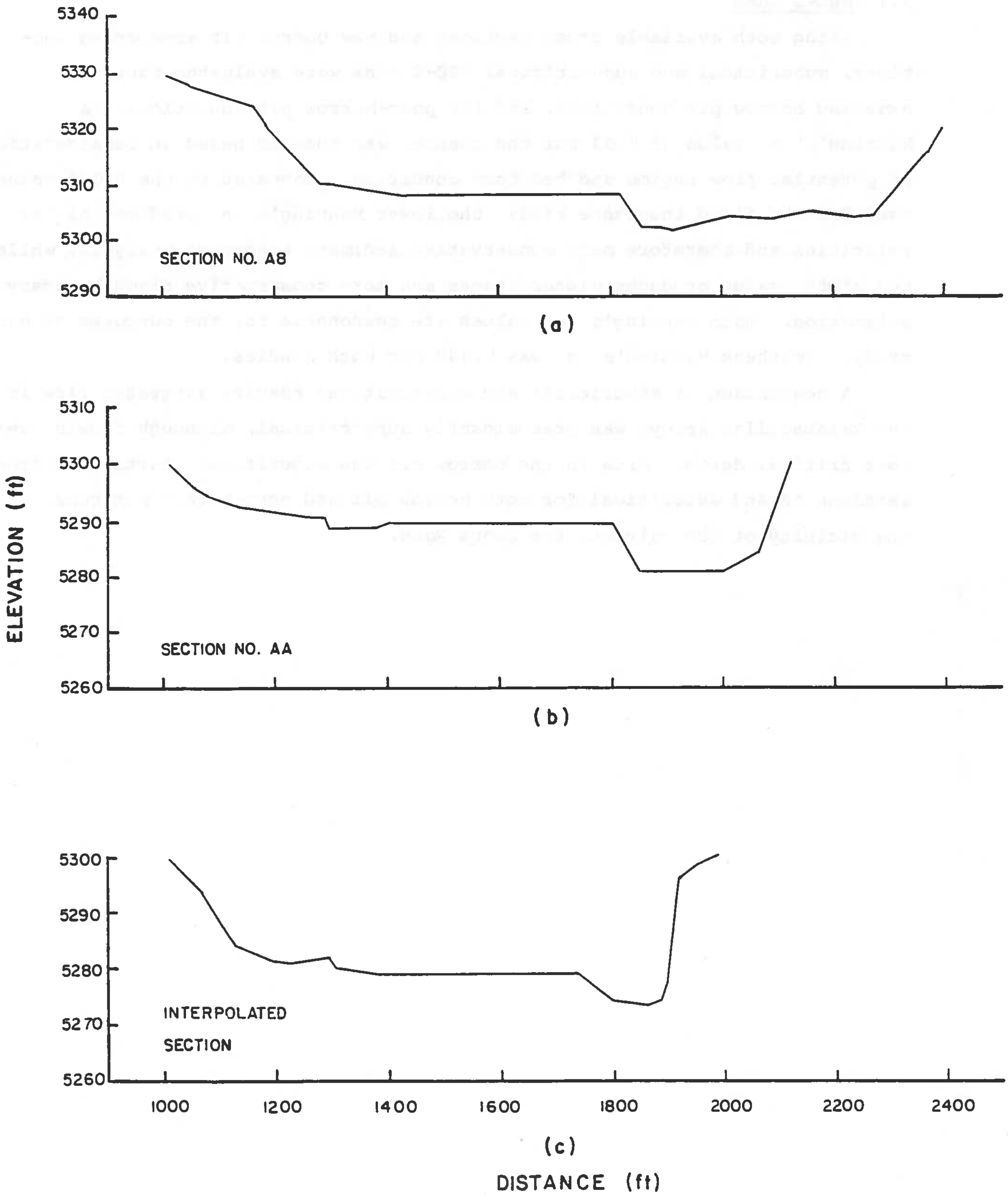


Figure 5.4. Assumed borrow pit cross sections after filling.

5.3 HEC-2 Runs

Using both available cross sections and new borrow pit area cross sections, subcritical and supercritical HEC-2 runs were evaluated for: (1) existing borrow pit conditions, and (2) post-borrow pit conditions. A Manning's n value of 0.03 for the channel was adopted based on consideration of potential flow regime and bed form condition. Compared to the 0.035 value used for the flood insurance study, the lower Manning's n produces higher velocities and therefore more conservative sediment transport analysis, while the higher value produces higher stages and more conservative flood boundary estimation. Both Manning's n values are reasonable for the purposes of each study. Overbank Manning's n was 0.040 for both studies.

A comparison of subcritical and supercritical results suggested flow in the Calabacillas Arroyo was predominantly supercritical, although flowing very near critical depth. Flow in the borrow pit was subcritical starting at cross sections AA and subcritical for both borrow pit and post-borrow pit runs in the vicinity of the culverts for Coors Road.

VI. EROSION, SEDIMENTATION, AND LATERAL MIGRATION ANALYSIS

6.1 Data Base

Erosion and sedimentation analysis includes development of a sediment transport relationship for Calabacillas Arroyo, aggradation-degradation analysis, and estimation of equilibrium slopes. These analyses are based on hydrologic data, hydraulic data and information characterizing the sediment. Sediment information represented the largest gap in the data base, consequently, observations were made and sediment samples collected during the field reconnaissance. The lateral migration analysis extends the results of aggradation, degradation, and equilibrium slope analysis into the lateral dimension.

6.2 Sediment Particle Size Analysis

A total of fifty sediment samples was collected consisting of 16 bed samples (taken at depths of 0-6"), 12 bank samples, 6 tributary samples, 13 watershed samples and 3 flood plain samples. Laboratory evaluation of these samples consisted of dry sieve analysis supplemented with hydrometer analysis where appreciable silt-clay percentages were encountered. Particle gradation curves were developed for the samples based on this analysis and are given in Appendix A. This characterization of the material available for transport was essential for subsequent sediment transport and aggradation/degradation analyses.

Considering bed particle size gradation curves representative of sediment characteristics in the surface layer, a noticeable shift towards finer material occurs downstream of Section Q. This can be attributed to the small drainage entering from the right bank at Section Q and to Black's Diversion Channel entering near Section M. A sample of alluvial fan material deposited by the small drainage (labeled Tributary 3 on page A.8 of Appendix A) and a sample of material depositing in Blacks Diversion Channel (page A.8) document these channels as sources of fine material. However, it is important to realize that these samples represent surface conditions (0-6 inches) and that at greater depths the alluvium is similar to that in upstream reaches. Consequently, for purposes of erosion and sedimentation analysis, particularly at the level of effort of this study, it is sufficient to adopt a single representative gradation for the bed material. The selected gradation (Figure 6.1) adequately represents the range and distribution of bed material in the

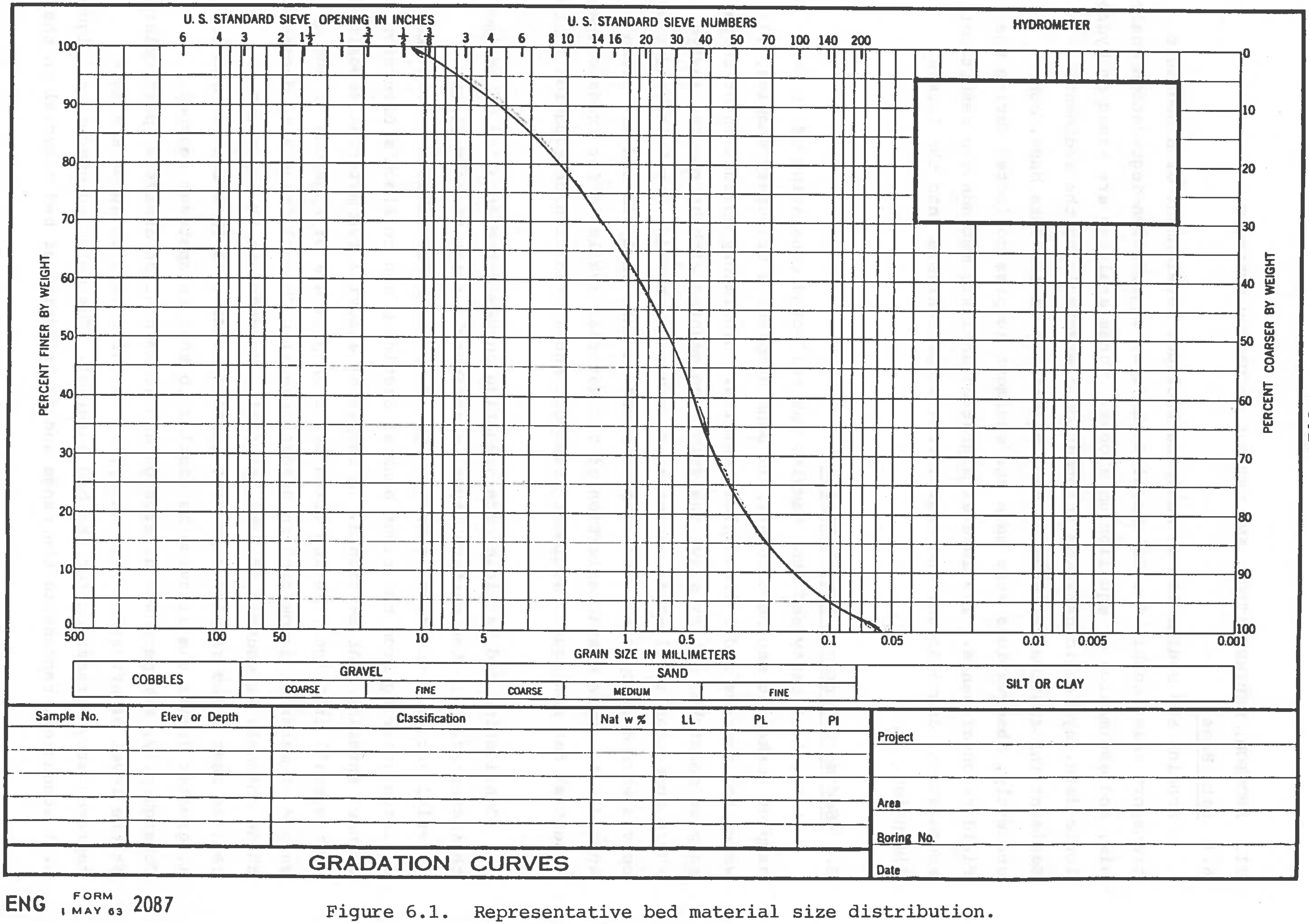


Figure 6.1. Representative bed material size distribution.

majority of the study reach and should provide conservative estimates of sediment transport capacity.

Considering bank sample gradation curves (pages A.5-A.7 of Appendix A), the material is fine and relatively consistent throughout the study reach. The only variations were a sample taken near Section AE, a sample taken near Section Q, and a sample near Section I. The sample near AE is combination bank/flood plain (i.e. there was no well defined bankline). The coarser sample from Section Q was taken from the inside of the bend near the bed and appeared to be a small lens or outcropping that may be contributing to the relative stability of the bend. The material was somewhat gravelly, cemented together by a more cohesive mixture. The material was reddish colored and was not present immediately upstream or downstream of this point on the bend. Figure 6.2 illustrates the bend configuration based on aerial photographs and topographic maps, and the location of the outcropping. The other sample at Q was taken upstream and higher on the bank from a thin very cohesive stratification of fine material. The sample at Section I, near the horseshoe shaped bend, was taken about 5 feet off the bed in the left bank. The bank was 40-60 feet in height and nearly vertical.

Watershed samples were typically as fine as the bank samples but with a much more uniform gradation. There was not a significant difference between the north and south watersheds. Flood plain samples were somewhat coarser but not significantly different from the bank samples. The sample near cross section X, where the flood plain is the largest (based on the flood insurance study), was significantly coarser than the other flood plain samples.

The only evidence of armoring was observed near the upstream study boundary at Section AG. The upper twelve inches appeared to have a somewhat coarser texture; however, results of the sieve analysis of surface and subsurface samples from this location indicate an insignificant difference (page A.13 of Appendix A.

6.3 Sediment Continuity

6.3.1 Representative Subreaches

For both short-term and long-term analysis, the study length of Calabacillas Arroyo was segmented into a series of ten representative subreaches. Figure 6.3 illustrates this delineation of the study area. For purposes of description, subreaches were numbered sequentially starting at the

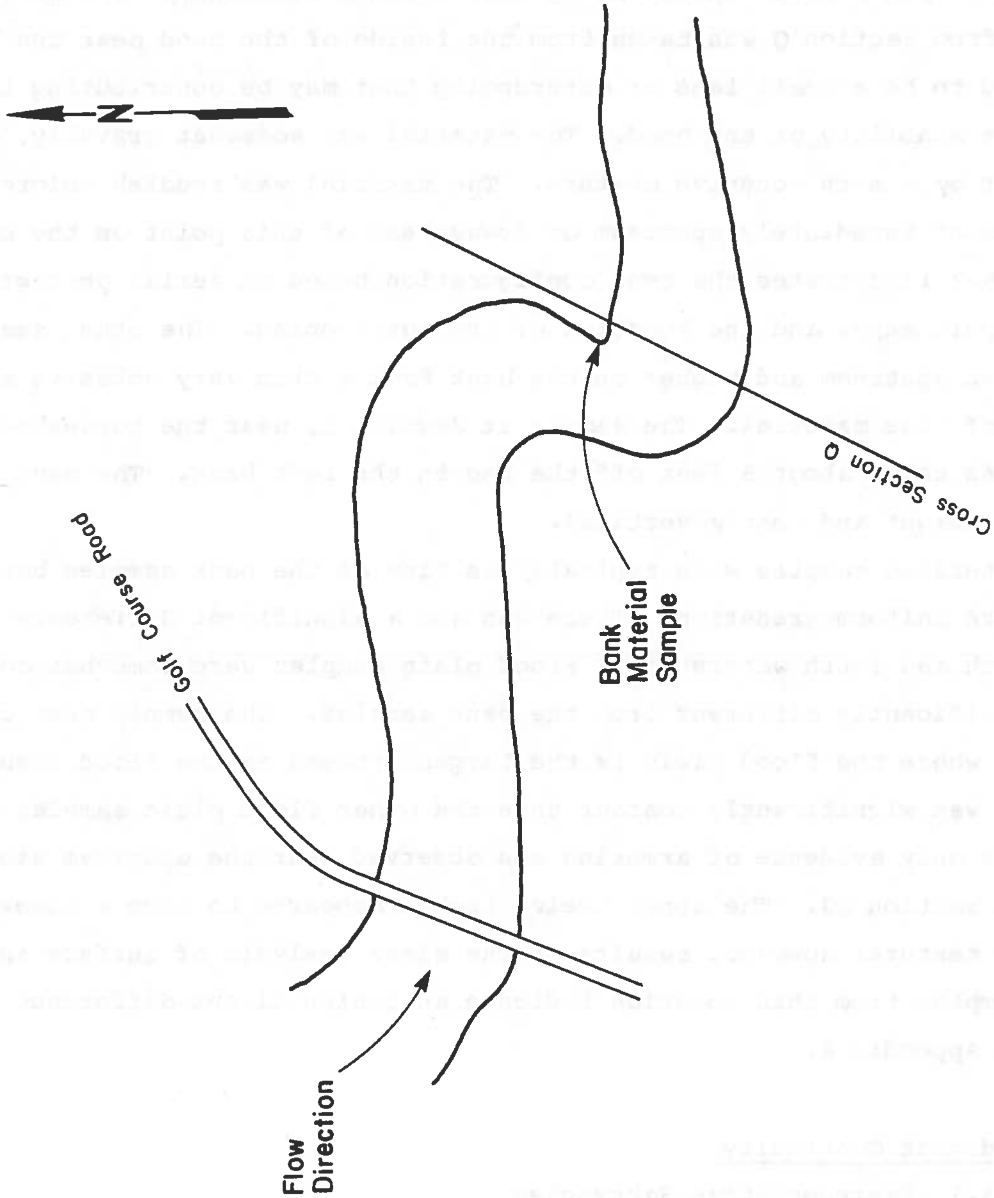


Figure 6.2. Channel bend configuration near section Q.

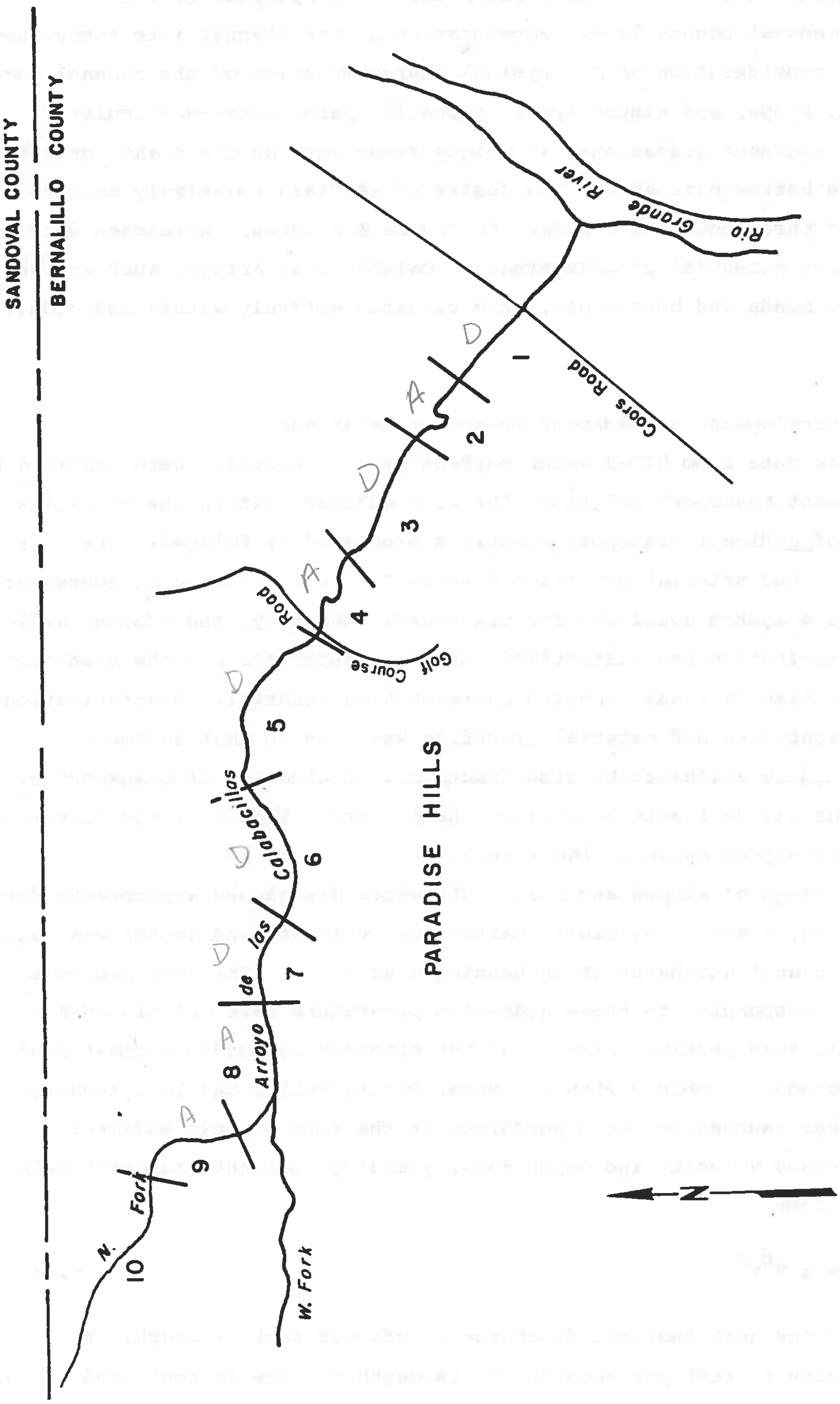


Figure 6.3. Definition of representative subreaches.

downstream study limit (Coors Road) and progressing upstream to the Bernalillo-Sandoval County line. Segmentation of the channel into subreaches was based on consideration of 1) physical characteristics of the channel such as top width, slope, and sinuosity; 2) hydraulic parameters--particularly velocity; 3) sediment gradations; 4) unique areas such as the S and horseshoe bends and the borrow pit; and 5) the desire to maintain relatively uniform reach lengths throughout the system. As Figure 6.3 shows, subreaches were defined so that potential problem areas in Calabacillas Arroyo, such as the S and horseshoe bends and borrow pit, were situated entirely within individual subreaches.

6.3.2 Development of Sediment Transport Relations

Hydraulic data from HEC-2 water surface profile modeling were utilized to develop sediment transport relations for each subreach within the study area. Development of sediment transport relations proceeded as follows. First, a characteristic bed material gradation (Figure 6.1) was selected to represent material in the system available for transport. Secondly, the adopted sediment size distribution was discretized into four intervals and the geometric mean particle size (D_g) was computed for each size interval. Discretization of the representative bed material gradation was done so that sediment transport could be evaluated by size fractions. Evaluation of transport by size fractions was desirable because of the potential impact of the borrow pit on sediment transport capacity (Section 5.2).

For the range of slopes and unit width water discharges appropriate for the study reach, a set of hydraulic parameters (velocity and depth) was calculated for each unit discharge using Manning's equation. The unit sediment discharges corresponding to these hydraulic parameters were calculated for each geometric mean particle size using the Einstein suspended bed-material transport procedure combined with the Meyer-Peter, Muller bed load equation. Multiple linear regressions were performed on the sets of unit sediment discharges versus velocity and depth data, yielding sediment transport relations of the form

$$q_s = a\,V^b Y^c \qquad (6.1)$$

where q_s is the unit sediment discharge in cfs per foot of width, V is average velocity in feet per second, Y is depth of flow in feet, and a, b, and c are derived coefficients. Values of a, b, and c for each geometric mean sediment size are given in Table 6.1. This transport relationship (Equation 6.1) is a function of the hydraulics of the study reach of Calabacillas and should not be applied to other systems unless they have similar slopes and bed material characteristics.

6.3.3 Storm Aggradation/Degradation Volumes from Continuity Analysis

Following derivation of sediment transport relations, a sediment continuity model was used to assess degradation/aggradation potential in each subreach. For a given storm event, the volume of sediment deposited or eroded within a subreach is simply the difference between the volume of sediment supplied and the volume of sediment transported. If supply is greater than transport the subreach is aggradational, whereas if transport is greater than supply degradation will occur. Sediment supplied to a subreach is equal to the sediment transported by the adjoining upstream subreach.

The volume of sediment being transported in a subreach was obtained by discretizing the flood hydrograph for a storm event into a set of constant discharges. Using HEC-2 depth and velocity data, discretized discharge values and relations defined in Table 6.1, unit sediment discharge (q_s) was computed for all cross sections contained in a given subreach. Total sediment discharge (Q_s) in a subreach was then calculated as the product of the average unit sediment discharge and average top width of the cross-sections in the subreach. Sediment volume transported was obtained by applying the relation,

$$\text{Volume of sediment transported} = \Sigma(Q_s \Delta T) \qquad (6.2)$$

where Q_s is calculated as described above and ΔT is the time interval corresponding to a constant discharge on the discretized hydrograph.

Results of sediment continuity analysis for the 2-year, 10-year, 25-year, and 100-year flood events are presented in Table 6.2.

6.4 Equilibrium Slope Analysis

Equilibrium slope analysis is based on the assertion that if over the long term there is no major change in channel geometry or sediment supply, then the channel will tend to develop a slope at which the transport capacity of the reach is equal to the supply of sediment entering the reach. Hence,

Table 6.1. Regression Coefficients for Sediment Transport Relations of the form $q_s = a V^b Y^c$.

Geometric Mean Size (D_g) mm	Coefficient a	Coefficient b	Coefficient c
0.15	34.0×10^{-5}	3.664	0.628
0.80	1.7×10^{-5}	4.638	-0.225
2.65	0.53×10^{-5}	4.723	-0.400
9.25	2.1×10^{-5}	3.904	-0.410

Table 6.2. Aggradation/Degradation Volumes (ft^3)[1].

Subreach	Recurrence Interval 2-yr	10-yr	25-yr	100-yr
10	------------------- Supply Subreach	-------------------		
9	0.014×10^5	1.0×10^5	1.4×10^5	15.0×10^5
8	0.19×10^5	4.2×10^5	5.0×10^5	47.0×10^5
7	-0.48×10^5	-7.3×10^5	-8.0×10^5	-78.0×10^5
6	-0.15×10^5	-5.5×10^5	-6.2×10^5	-28.0×10^5
5	0.18×10^5	2.1×10^5	1.5×10^5	-4.8×10^5
4	-0.25×10^5	1.0×10^5	2.0×10^5	2.6×10^5
3	-0.12×10^5	-4.3×10^5	-6.9×10^5	-46.0×10^5
2	0.047×10^5	3.4×10^5	5.9×10^5	48.0×10^5
1	-0.075×10^5	-2.7×10^5	-4.3×10^5	-29.0×10^5

[1] a "-" denotes degradation.

Deg Vol | Surface area | Depth

under these conditions, an equilibrium slope will be established, and there will be no aggradation or degradation within the reach, i.e.,

$$Q_{s_{in}} = Q_{s_{out}} \tag{6.3}$$

where Q_s is total sediment discharge.

The first step in an equilibrium slope analysis is to determine an overall sediment transport relation of the same form as utilized during sediment continuity analysis (Equation 6.1). Whereas four regression relations were applied during sediment continuity analysis (see Table 6.1), a single relation applicable to the entire system is more appropriate for evaluation of equilibrium slope. The single sediment transport relation derived for Calabacillas Arroyo was

$$q_s = 1.1 \times 10^{-4} V^{3.852} Y^{0.436} \tag{6.4}$$

where q_s is the unit sediment transport, V is the average flow velocity, and Y is depth.

Utilizing Manning's equation, the continuity assumption (Equation 6.3) and Equation 6.4, the following expression for equilibrium slope may be derived:

$$S_{eq} = S_{ex} \left(\frac{Q_s \text{ supply}}{Q_s \text{ capacity}}\right)^{\left(\frac{2}{b-x}\right)} \tag{6.5}$$

where

$$x = \frac{3}{5} \left(\frac{2}{3} b + c\right) \tag{6.6}$$

S_{eq} is the equilibrium slope towards which the reach is tending, S_{ex} is the existing slope, Q_s supply is the supply of sediment to the reach, Q_s capacity is the sediment transport capacity of the reach and values for b and c are defined in Equation 6.4 (coefficients of velocity and depth, respectively).

Equation 6.5 yields the following relationship for the study area:

$$S_{eq} = S_{ex} \left(\frac{Q_s \text{ supply}}{Q_s \text{ capacity}}\right)^{0.976} \tag{6.7}$$

If a reach is aggrading, its slope will tend to steepen, increasing velocities within the reach and hence sediment transport. If a reach is degrading, its slope will get flatter, decreasing velocities within the reach and decreasing sediment transport capacity. It should be noted that equilibrium slope analysis is time independent. It shows the change in the system assuming a constant supply of sediment, but does not consider the time required for change to take place.

In the equilibrium slope method aggradation or degradation is assumed to be non uniformly distributed longitudinally along the channel. Additionally, it is assumed that the existing slope changes to the equilibrium slope by pivoting about a fixed control point. The control point can be any location within the system at which the elevation is fixed, such as a grade control structure, culvert, or rock outcropping, or base level control at a tributary. Within Calabacillas Arroyo, three control points were identified for purposes of this study: the culverts at the Coors Road Crossing, the road surface at the dip crossing of Golf Course Road, and the Lyons Road crossing. Lyons Road was chosen as a control point with the expectation that an improved road crossing would be constructed at some future date, as shown in development plans.

Table 6.3 summarizes the computed equilibrium slopes for the subreaches of the study area. Equilibrium slopes are shown for the 100-year storm event which represents the short term, and the 2-year event which is representative of the long-term equilibrium slope. Generally, above Subreach 5 the existing slope is comparable to the computed equilibrium slope.

6.5 Definition of the Representative Storm

Evaluation of erosion potential corresponding to a given flood event provides information related to short-term response of the system. For purposes of this study, short-term is defined relative to the flood event with a return period of 100 years. Erosion can also be the cumulative result of numerous flood events occurring over a span of many years. The long-term period adopted for this study was 25 years, as discussed in Section 1.2. The approach used in this study to evaluate long-term erosion impacts was to define a representative storm event to be applied over the 25-year period.

Table 6.3. Equilibrium Slopes.

Subreach	Average Existing Slope	2-Year Equilibrium Slope (Long-Term)	100-Year Equilibrium Slope (Short-Term)
10	--------------Supply Subreach-------------		
9	0.01394	0.01443	0.01542
8	0.01450	0.02936	0.03830
7	0.01333	0.00442	0.00473
6	0.01337	0.01015	0.01085
5	0.01315	0.01536	0.01081
4	0.01540	0.01132	0.01478
3	0.01400	0.01170	0.01058
2	0.01325	0.01608	0.02171
1	0.01053	0.00794	0.00482

Sediment yield associated with the annual representative flood event was determined from a relationship which considers the annual probable occurrence of storms with various return periods. The probability weighting utilized was

$$(Vol_s)_r = 0.01(Vol_s)_{100} + 0.01(Vol_s)_{50} + 0.02(Vol_s)_{25} + 0.06(Vol)_{10} + 0.1(Vol\ )_5 + 0.3(Vol\ )_2 \quad (6.8)$$

where Vol_s denotes sediment yield, subscript r is for the representative storm, and subscripts 100, 50, 25, 10, 5, and 2 denote the recurrance interval of the storm event. Equation 6.8 basically defines the representative storm as a statistical mean annual storm which has a sediment volume equal to the expected values of the sediment volume averaged over all the storms with various annual occurrence probabilities.

Sediment volumes associated with the 100-, 25-, 10-, and 2-year storms were computed for the sediment continuity analysis. Values of sediment yield corresponding to the 50- and 5-year storm events were obtained by interpolation.

It may be noted that the sum of the weighting factors in Equation 6.8 is only 0.5. The remaining weighting factor of 0.5 applies to contributions of storms with recurrence intervals less than 2 years. SLA experience and results shown in Table 6.2 indicate that the sediment contributions from storms smaller than the 2-year event are minor and can be excluded.

Using Equation 6.8, sediment volumes corresponding to the representative flood event were computed for each subreach. Results are presented in Table 6.4. The long-term erosion volumes in column three are the cumulative aggradational/degradational potential of the representative storm event over a 25-year period.

6.6 Evaluation of Borrow Pit Filling Rate

Based on the short- and long-term sediment transport results an estimate of the time necessary to refill the borrow pit can be made. The computed equilibrium cross sections in the borrow pit region after filling (see Section 5.2) define the approximate volume of sediment necessary to fill the existing excavation. This volume is about $6x10^6$ cubic feet. Based on the computed short-term aggradation in Reach 8 (Table 6.2, 100-year event data), a single large event would fill approximately 75 percent of the excavation. The number

Table 6.4. Representative and Long-Term Erosion.

Subreach	Representative Annual Aggradation/Degradation[1] Volume (ft^3)	Long-Term (25-Year) Aggradation/Degradation[1] Volume (ft^3)
10	---------- Supply Subreach ----------	
9	0.038×10^6	0.95×10^6
8	0.14×10^6	3.5×10^6
7	-0.24×10^6	-6.0×10^6
6	-0.13×10^6	-3.3×10^6
5	0.028×10^6	0.70×10^6
4	0.013×10^6	0.33×10^6
3	-0.12×10^6	-3.0×10^6
2	0.13×10^6	3.3×10^6
1	-0.074×10^6	-1.8×10^6

[1] a "-" denotes degradation.

of years necessary to entirely fill the excavation can be estimated using the long-term, representative storm data (Table 6.4). Based on this analysis, more than 40 years are required to fill the excavation. Consequently, the analysis of this report assumes that the borrow pit influences sediment transport throughout the 25-year period defined for the long-term analysis.

6.7 Lateral Migration Analysis

6.7.1 General

Geometry changes in an alluvial channel occur due to aggradation/degradation (changes in the vertical direction) and lateral migration (changes in the horizontal direction). Lateral migration can be defined as bankline shifting due to the processes of bank erosion. Lateral migration tendencies of a channel are strongly influenced by the aggradation or degradation that occurrs in a given reach.

Most existing sediment routing models and analysis techniques are one-dimensional (aggradation/degradation only) and do not account directly for lateral migration, but lateral migration can be estimated after evaluating aggradation/degradation potential. The qualitative, geomorphic analysis of Chapter III provides valuable information for interpreting and evaluating aggradation/degradation results in terms of lateral migration potential. To supplement that qualitative assessment, the results of the aggradation/degradation analysis of this chapter support a quantitative evaluation of lateral migration tendencies of Calabacillas Arroyo.

6.7.2 Mechanisms of Lateral Migration

The two basic mechanisms of lateral migration can be related to aggradation/degradation trends in the arroyo. The first mechanism, associated with channel reaches of large w/d (width/depth) ratio, typically in an aggradational mode, promotes bank instability and lateral migration as a result of increased velocities and shear stresses along the banks as the local energy gradient increases. The second mechanism, associated with channel reaches of small w/d ratio, typically in a degradational mode, causes increased bank instability from bank failures as a result of development of a narrow, deep channel with steep banks.

There are several variations of the first mechanisms involving a typically aggradational reach of channel. If deposition occurs as isolated sand and gravel bars, local energy gradient increases due to higher flow velocities result from a reduction in effective channel area. Additionally, relatively stable sand and gravel bar deposits deflect the flow towards the more erodible banklines. Consequently, severe localized bank failures may occur. However, if deposition occurs more uniformly across the channel, local energy gradient downstream of the deposition increases due to higher velocities resulting from an increase in channel slope. The absence of current deflection and the more gradual increase in velocities results in less severe bank erosion, but erosion takes place over longer distances.

Similarly, there are variations of the second mechanism involving a typically degradational reach of the channel. The mode of bank failure as the channel deepens depends on bank material composition. In a channel with predominantly clay banks failure may be by sloughing due to undercutting by low flow discharges. In a stratified bank with lenses of erodible material, enough of this material may be removed that the block of bank material above tilts downward, opening a vertical tension crack. Ultimately the bank fails in large blocks of material. Piping can also promote bank failure in a stratified bank.

In both mechanisms of lateral migration, development of saturated banks above the water line can increase bank erosion through local mass wasting. Saturated banks may develop during the rising stage of a flood during which flow moves into the bank from the river, promoting increased bank stability. During the falling stage, this gradient reverses and decreases bank stability, particularly in the saturated condition. Flow may also occur from the bank to the river due to a groundwater table that is higher than the river stage. This condition could develop during a wet period as water draining from the watershed saturates the flood plain to a level higher than normal.

6.7.3 Analysis of Calabacillas Arroyo

Within the Calabacillas study reach, deposition generally occurs uniformly across the channel. This characterization is consistent with Schumm's (1977) description of a uniform mode of deposition in the Arroyo Calabasas, an arroyo in New Mexico draining coarse Tertiary alluvium similar to Calabacillas. As previously discussed, the occurrence of uniform deposition creates less potential for bank erosion than does deposition in the form of isolated sand and gravel bars. Thus for aggradational subreaches on Calabacillas Arroyo, historical evidence of planform changes or the 100-year floodway boundaries were assumed to be controlling factors for establishment of offset tangents.

Using results of the qualitative geomorphic analysis, sediment continuity analysis and equilibrium slope results, lateral migration in degradational subreaches was evaluated for both the long and short term. To provide a conservative estimate, the potential lateral migration distance was computed initially by assuming all sediment eroded must come from the channel banks. This is equivalent to stating that thalweg elevation will be constant in time, an assumption that was implicit in the sediment continuity analysis and is supported (in the upper half of the study area) by the equilibrium slope analysis (Table 6.3). Furthermore, since the direction of lateral migration is not known with certainty, the required volume of sediment was first assumed to come entirely from one bank, and then from the opposite bank, unless geologic or other control inhibited movement in a given direction. Results obtained from this analysis are presented in Table 6.5 as distances in the direction of the left or right bank over which the arroyo has potential to migrate. Lateral migration distances in Table 6.5 are given relative to the existing thalweg location. At some cross sections in the degradational subreaches lateral migration was deemed unlikely due to the existence of some form of control or impediment. For example, the right bank of the arroyo at cross section X in Subreach 6 abuts the steeply sloping edge of a mesa which has remained stable historically. As a result, lateral movement of the channel into the right bank is not considered likely at this location.

6.8 Slip Circle Analysis of Bank Stability

Stability of channel banks is an important consideration in any study concerned with evaluation of erosion/sedimentation and changes in channel morphology. The purpose of slope stability analysis is to relate channel base level changes (channel incision) to a change in factor of safety against bank failure.

Site visit observations indicated that consideration of bank slope stability was appropriate in Subreach 1 of the study area. In this subreach the banks exhibited characteristics which indicated stability could be evaluated

Table 6.5. Lateral Migration Potential.

Subreach	Cross Section	Distance from Existing Channel Thalweg (ft) Left Bank Short-Term	Left Bank Long-Term	Right Bank Short-Term	Right Bank Long-Term
	L	142	122	93	72
	M	NA	NA	119	93
3	N	145	97	134	110
	O	235	174	108	88
	P	135	111	216	166
	S	63	NA	123	NA
5	T	70	NA	91	NA
	U	47	NA	47	NA
	V	50	NA	97	NA
6	W	187	210	112	124
	X	233	219	NA	NA
7	Y	NA	NA	426	380
	Z	461	384	315	286

NA - Not Applicable

by the slip-circle methodology. Evaluation of bank stability in Subreach 1 was further justified by comparison of topographic descriptions provided in 1972 and 1980 maps. During this time period noticeable vertical incision of the channel occurred within Subreach 1 (see Section 3.5).

Results obtained from slip-circle bank stability analysis indicate that for slope geometry and soil characteristics typical of this subreach, maximum stable vertical bank height is approximately 40 feet. In a failure mode, bank instability will progress outward laterally (horizontally) a distance of approximately 60 feet. Appendix B summarizes the slip-circle analysis procedure. To apply this result to evaluate potential changes in Subreach 1, long- and short-term degradation volumes (Tables 6.2 and 6.4) were used to compute potential base level change. It was assumed that all eroded material would come from the channel bed.

Potential base-level change in Subreach 1 was computed as the volume of sediment degraded divided by the product of average channel bed width and subreach length. Potential base-level change is approximately 20 feet for the short-term and about 15 feet for the long-term analyses. Bank height in this subreach of the arroyo is presently on the order of 30 feet. As a result of the lowering of base level, maximum bank height will be exceeded and bank failure is expected to occur over both the long and short term. Consequently, the channel will widen laterally approximately 60 feet. The 60-foot lateral extent of potential bank failure is relative to conditions portrayed in the 1980 FEMA Flood Insurance Maps which serve as base maps for this study.

VII. OFFSET TANGENTS

7.1 General Procedure and Results

Offset tangents were established by consideration of both the short- and long-term erosion analysis presented in this report and the 100-year flood plain boundary determined for the FEMA flood insurance study. To comply with FEMA guidelines the 100-year flood plain boundary defined the minimum offset tangent. Development in the 100-year flood plain is allowed only when channel improvements are made creating a floodway channel as in accordance with FEMA regulations and/or local ordinances. The offset tangents based on erosion considered results of both the Level I qualitative geomorphic analysis (Chapter III) and the Level II engineering analysis (Chapter VI). The governing physical processes were considered in establishing the mode of lateral migration most applicable to a given section in each subreach.

The resulting offset tangents (see pocket in back cover) define the boundaries beyond which, without channel improvements, it is not considered prudent to develop. Legal descriptions of the offset tangents are indicated on these maps. The following discussion summarizes the decision-making factors involved in establishing the offset tangents in each subreach.

Sediment continuity analysis indicates that Subreach 1, above Coors Road, is degradational over both the long and short term. Between the years 1935 and 1980 aerial photographs indicate that the channel remained relatively straight, exhibiting little tendency for lateral migration. Topographic maps, on the other hand, indicate significant vertical incision of the channel between 1972 and 1980 (see Section 3.5). Thus, lateral instability in this portion of the arroyo is expected to result from bank failure that occurs as the channel incises.

The potential for channel incision over both the long and short term was evaluated by assuming that all material eroded would come from the channel bed. To evaluate the extent of bank failure associated with channel incision, slip circle analysis results were utilized. Offset tangents in Subreach 1 describe the extent to which the channel top width may increase as a result of continued channel entrenchment and associated failure of the banks.

Erosion offsets in Subreach 2 are controlled primarily by the existence of the horseshoe bend. Overall, the horseshoe bend configuration has been relatively stable during the recent past (since the 1935 aerial photography). However, there is some photographic evidence of an increase in the meander amplitude. It is also readily apparent from study of both aerial photographs and topographic maps that the low-flow channel in the horseshoe bend moved downstream between 1967 and 1980. Results of sediment continuity analysis indicate that this subreach is aggradational over both the long and short term. It should be noted, however, that sediment continuity analysis techniques rely on simplifications of the system and do not allow for quantitative consideration of abrupt changes in flow direction which can occur in highly sinuous channel reaches. Thus, although the subreach as a whole exhibits aggradational tendencies, there is potential for the flow to attack and erode channel banks within the horseshoe bend where abrupt changes in flow direction take place. Ultimately, given the right combination of flow conditions, a chute channel could form, cutting off the existing horseshoe bend. For these reasons, offsets delineate a potential meander zone for the horseshoe bend, within which development is not considered advisable.

Within Subreaches 3 and 4, major factors governing offset tangent delineation are short-term lateral migration potential (Table 6.5), historical evidence of significant changes on channel planform, and present conditions of channel sinuosity. As discussed in Section 3.3.3, appreciable changes in the meander pattern within these subreaches was noted from study of aerial photographs. Between 1935 and 1967, channel characteristics in Subreach 3 went from highly sinuous to generally straight. This type of change is also noticeable in the lower portion of Subreach 4; however, Subreach 4 still encompasses a highly sinuous portion of the channel, identified as the S bend in this study. In Subreaches 3 and 4 the offset tangents define a meander belt based on the more critical condition of either channel lateral migration tendencies associated with occurrence of the short-term (100-year) event, or the extent of present and past channel meandering.

The sediment continuity analysis indicates that Subreaches 5, 6 and 7 are highly degradational. This result reflects the significant erosional potential of nearly clear water releases from the borrow area as deposition of sediments occurs within the borrow pit. Both the long- and short-term lateral migration tendencies are significant factors for consideration in these subreaches. In Subreach 6, long-term lateral migration is slightly greater than short-term, whereas in Subreach 7, short-term response of the channel is more critical.

The borrow pit which exists at the confluence of the north and west forks of Calabacillas Arroyo is contained in Subreach 8. Sediment transport analysis identifies the borrow area as a depositional zone for sediment (sediment sink). Offsets on the left bank basically follow the existing limits of excavation in the pit. Offsets along the right side of the channel essentially follow the established flood plain boundary.

The remainder of the study area above Subreach 8 consists of relatively straight channel sections having generally aggradational tendencies. Within Subreach 9 a tributary enters the main channel from the north. Section 3.2 described the fan deposit observed at this location and the present erosion of this fan deposit by flows in the main channel. As a result, this area was considered potentially unstable and offset tangents bracket the tributary confluence and alluvial fan deposit. Aside from the tributary confluence, the offset tangents were defined based on consideration of established flood plain limits. Subreach 10 was defined as the supply reach for all sediment analyses of the study area. Implicit in this definition is the assumption of equilibrium conditions in this portion of the arroyo. Thus, as with the majority of Subreach 9, offset tangents in Subreach 10 are based on existing flood plain mapping.

Available information pertaining to platting in the study area was used to estimate impacts of the offset tangents on proposed development along the arroyo. As shown on available plat plans, erosion/sedimentation offset tangents encompass part or all of approximately 150 residential lots. However, about 35 percent of these lots are also located within established 100-year floodway boundaries defined on FEMA Flood Boundary and Floodway Maps. Adoption of FEMA guidelines prohibits all development within the floodway. An additional 12 percent of the total lots impacted by offset tangents are situated within the 100-year flood plain and can only be developed if a floodway is constructed.

7.2 Discussion of Results

Offset tangent locations have been determined based on methodologies structured to provide an acceptable factor of safety and yet not be overly conservative. Hydrologic and hydraulic conditions in the study area were modeled based on the best information available to SLA. The validity of model inputs such as Manning's resistance coefficient n, are substantiated by SLA experience with alluvial sand bed channels. It is recognized that some question may arise regarding the difference in Manning's n between the FEMA flood insurance study (n = 0.035) and the n value as used in this study (n = 0.030). As noted in Section 5.3, both Manning's n values are reasonable for the purposes of each study and neither value is overly conservative.

The methodology applied to define erosion offsets associates a factor of risk with their location. As discussed in Section 1.2, an operational definition of the term prudent is based on consideration of both the potential erosion resulting from the single 100-year storm (short-term) and the cumulative impacts of a representative annual storm taken over a 25-year period (long-term). Acceptance of these criteria for definition of offset tangents necessitates acceptance of a calculated risk of 22 percent that the short-term (100-year) event will occur during any 25-year period. Adoption of the 100-year storm event as one of the standards for evaluating erosion potential in Calabacillas Arroyo is consistent with FEMA regulations for floodway delineation. Although erosion potential in the study reach has been evaluated for both the long- and short-term, results obtained from these analyses have not been considered additive.

Quantitative analyses of erosion potential over both the long- and short-term were carried out in all subreaches having degradational tendencies as indicated by sediment continuity analysis. Results from these analyses were used in conjunction with qualitative geomorphic assessments (see Chapter III) to ultimately define offset tangent locations. In the absence of any control (geologic or man-made), it is impossible to determine apriori the direction an alluvial channel will migrate. Therefore, the analyses first assumed all erosion came from one bank and then from the other. This assumption is not unrealistic based on observations of lateral migration patterns in alluvial channels nor overly conservative based on the objectives of this analysis.

In many locations within the study reach the predominant factor controlling location of the offset tangent was evidence of significant historical planform changes or the existence of a geomorphically significant channel configuration. For example, subreach 4 was found to be aggradational by sediment continuity analysis. However, there was sufficient historical evidence of changes in meander characteristics in this subreach to warrant situating the erosion offsets outside the potential meander zone.

It is significant to note that erosional responses in Calabacillas Arroyo are hydrologically dependent. In other words, the absence of significant planform changes should not necessarily be construed as indicative of a stable channel configuration. Rather, the absence of change may result from a lack of occurrence of hydrologically significant events in the system. In a semi-arid environment, such as that existing in the study area, it may be many years between occurrence of storms causing significant erosion. This phenomenon may contribute to a false sense of security in the development of land along the arroyo, and could have serious consequences in the years to come. The recommended offset tangents have been established using the best information available and state-of-the-art analysis techniques in order to minimize this risk without being overly conservative.

APPENDIX B

SLIP CIRCLE ANALYSIS PROCEDURE

Slope stability analysis is utilized to relate a lowering of channel base level to a change in the factor of safety against bank failure for a given set of slope geometry and soil conditions (Ponce, 1978). Slope geometry defined by slope angle α along with soil characteristics of cohesion c, angle of friction ϕ, and unit weight γ_s were used to evaluate maximum slope height H for the condition of incipient bank failure; defined to occur as the factor of safety against failure (F) becomes equal to unity. Table B.1 shows the general values assumed for the slope geometry and soil characteristics in Calabacillas Arroyo. These values were used to determine slope height H from generalized charts developed by Ponce (1978). For the combination of properties described in Table B.1 the maximum bank slope height is approximately 40 feet based on extrapolation of Ponce's charts.

Table B.1. Parameters Describing Slope Geometry and Soil Characteristics.

Cohesion	C = 25
Unit Weight	γ_s = 100 lb/ft^3
Angle of Friction	ϕ = 30° - 40°
Slope Angle	α = 34°

DESCRIPTION

The following description is the boundary as determined by the "Erosin Study to Determine Boundaries for Adjacent Development - Calabacillas Arroyo, Bernalillo County, New Mexico" a report prepared by Simons, Li & Associates, Inc. for Albuquerque Metropolitan Arroyo Flood Control Authority.

The description is based on New Mexico State Plane Coordinate System.

Beginning at a point which bears N. 32°-17'-16" E., a distance of 969.65 feet from BM-NM448-N10 which has the following coordinates N. 1,524,161.52; E. 377,788.84;

Thence, N. 52°-26'-34" W., a distance of 1,190.58 feet;

Thence, N. 40°-59'-28" W., a distance of 525.96 feet;

Thence, N. 48°-18'-07" W., a distance of 368.31 feet;

Thence, N. 72°-43'-36" W., a distance of 889.10 feet;

Thence, N. 19°-34'-11" W., a distance of 686.67 feet;

Thence, N. 64°-04'-12" W., a distance of 564.87 feet;

Thence, N. 85°-36'-05" W., a distance of 273.81 feet;

Thence, N. 65°-00'-12" W., a distance of 1,372.57 feet;

Thence, N. 61°-19'-10" W., a distance of 1,175.18 feet;

Thence, N. 62°-37'-54" W., a distance of 95.71 feet;

Thence, N. 64°-32'-26" W., a distance of 649.03 feet;

Thence, N. 41°-59'-42" W., a distance of 539.56 feet;

Thence, N. 16°-06'-26" W., a distance of 389.28 feet;

Thence, N. 45°-06'-27" W., a distance of 376.89 feet;

Thence, N. 78°-05'-43" W., a distance of 1,643.35 feet;

Thence, N. 85°-14'-45" W., a distance of 506.74 feet;

Thence, S. 64°-49'-26" W., a distance of 608.84 feet;

Thence, S. 64°-08'-52" W., a distance of 1,114.54 feet;

Thence, S. 85°-48'-34" W., a distance of 738.99 feet;

Thence, N. 78°-17'-06" W., a distance of 1,137.70 feet;

Thence, N. 47°-17'-00" W., a distance of 443.71 feet;

Thence, N. 63°-49'-01" W., a distance of 335.42 feet;

Thence, N. 85°-50'-01" W., a distance of 302.80 feet;

Thence, S. 78°-36'-49" W., a distance of 440.67 feet;

Thence, S. 88°-56'-10" W., a distance of 1,454.25 feet;

Thence, N. 76°-52'-19" W., a distance of 611.99 feet;

Thence, N. 71°-33'-54" W., a distance of 126.49 feet;

Thence, N. 70°-11'-51" W., a distance of 596.26 feet;

Thence, N. 04°-07'-30" E., a distance of 1,155.98 feet;

Thence, N. 10°-49'-06" E., a distance of 868.43 feet;

Thence, N. 69°-55'-13" W., a distance of 760.21 feet;

Thence, S. 80°-07'-07" W., a distance of 314.67 feet;

Thence, S. 47°-40'-16" W., a distance of 348.98 feet;

Thence, S. 88°-18'-55" W., a distance of 272.12 feet;

Thence, N. 59°-38'-55" W., a distance of 1,171.57 feet;

Thence, N. 34°-47'-48" W., a distance of 1,105.72 feet;

Thence, N. 81°-46'-58" W., a distance of 650.68 feet;

Thence, N. 66°-35'-05" W., a distance of 520.90 feet;

Thence, N. 00°-00'-00" W., a distance of 388.00 feet;

Thence, S. 66°-43'-31" E., a distance of 1,184.39 feet;

Thence, S. 79°-52'-31" E., a distance of 511.97 feet;

Thence, S. 39°-01'-58" E., a distance of 911.45 feet;

Thence, S. 76°-48'-02" E., a distance of 398.53 feet;

Thence, S. 49°-50'-04" E., a distance of 142.64 feet;

Thence, S. 75°-35'-19" E., a distance of 666.99 feet;

Thence, N. 72°-27'-31" E., a distance of 182.49 feet;

Thence, S. 74°-24'-49" E., a distance of 789.01 feet;

Thence, S. 40°-10'-04" E., a distance of 587.57 feet;

Thence, S. 05°-30'-45" W., a distance of 978.53 feet;

Thence, S. 19°-21'-32" E., a distance of 117.65 feet;

Thence, S. 77°-14'-17" E., a distance of 239.93 feet;

Thence, N. 44°-35'-05" E., a distance of 195.17 feet;

Thence, S. 56°-15'-07" E., a distance of 547.21 feet;

Thence, S. 30°-57'-50" W., a distance of 320.70 feet;

Thence, S. 76°-42'-13" E., a distance of 882.66 feet;

Thence, N. 64°-49'-43" E., a distance of 514.90 feet;

Thence, N. 88°-45'-23" E., a distance of 737.17 feet;

Thence, S. 80°-18'-58" E., a distance of 1,147.35 feet;

Thence, S. 35°-10'-41" E., a distance of 833.16 feet;

Thence, S. 62°-55'-29" E., a distance of 351.52 feet;

Thence, N. 86°-46'-10" E., a distance of 816.30 feet;

Thence, N. 57°-44'-10" E., a distance of 1,972.57 feet;

Thence, S. 78°-51'-54" E., a distance of 1,092.57 feet;

Thence, S. 63°-10'-34" E., a distance of 890.86 feet;

Thence, S. 47°-17'-57" E., a distance of 757.92 feet;

Thence, S. 36°-18'-12" E., a distance of 748.24 feet;

Thence, S. 84°-43'-13" E., a distance of 608.58 feet;

Thence, S. 65°-32'-59" E., a distance of 751.38 feet;

Thence, S. 31°-09'-44" E., a distance of 396.16 feet;

Thence, S. 62°-11'-49" E., a distance of 1863.08 feet;

Thence, S. 68°-00'-32" E., a distance of 224.32 feet;

Thence, S. 59°-59'-25" E., a distance of 1,153.66 feet;

Thence, S. 41°-59'-35" E., a distance of 741.36 feet;

Thence, S. 46°-24'-37" E., a distance of 1,350.28 feet;

Thence, S. 54°-38'-08" E., a distance of 707.68 feet;

Thence, S. 40°-58'-18" W., a distance of 270.46 feet, to the Point of Beginning.