

SOIL EROSION STUDY

HUBBELL TRADING POST, NATIONAL HISTORIC SITE

Ganado, Arizona



EARTH TECHNOLOGY CORPORATION

SOIL EROSION STUDY
HUBBELL TRADING POST NATIONAL HISTORIC SITE
GANADO, ARIZONA
CX 702930008

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ABSTRACT

SOIL EROSION STUDY HUBBELL TRADING POST NATIONAL HISTORIC SITE GANADO, ARIZONA

Beginning in the 1970s and continuing to date, surface runoff in Pueblo Colorado Wash and its tributaries has resulted in erosion damage to two prehistoric archaeological sites and potentially threatens primary historic structures at the Hubbell Trading Post National Historic Site located one-half mile west of Ganado, Arizona.

The surficial geology exposed in the study area consists of the Late Triassic Chinle Formation and Quaternary alluvium. On-site, the Chinle Formation consists primarily of mudstone, claystone, siltstone, bentonitic claystone, and minor resistant sandstone ledges. The Quaternary alluvium consists mainly of unconsolidated clayey, silty, and fine sandy terrace deposits with some coarser sediments in the Pueblo Colorado Wash and its main tributaries.

Pueblo Colorado Wash, with headwaters on the Defiance Plateau, flows southwesterly and has a drainage basin area upstream from the Trading Post Site of about 250 square miles. Two tributary drainage basins near the east and west site boundaries are about 0.9 square miles and 1.7 square miles in area, respectively. Preliminary flood discharge (Q) analyses, using the Roeske (1979) method for the northeast Plateau Area, indicate that calculated 100-year and 500-year flood discharge of the main watershed is on the order of 22,000 cubic feet per second (cfs) and 40,500 cfs, respectively. Calculated discharges from the tributaries range from 1,500 cfs to 4,000 cfs.

Regional erosion and arroyo downcutting commenced around the 1880s; however, the most intense erosion occurred between 1920 and 1950 along the Pueblo Colorado Wash, with accelerated channel incision and bank undercutting continuing from the early 1970s to date. Headward erosion and bank cutting has been significant on the east on-site tributary since the early 1970s. Four factors appear to be responsible for the accelerated erosion:

- (1) increased rainfall and snow melt runoff;
- (2) anthropogenic influences, such as grazing, and increased stream discharges due to a halting of diversion of water into Ganado Lake;
- (3) channel modifications, such as introduced vegetation, gabion erosion control structures, a bridge, and pilings in the channel;
- (4) bedrock controls.

The design criteria for erosion control devices considered the 25-year event as the design flood because of the impracticality of protecting against greater events. The analyses completed indicate that scour for greater events would be limited if the recommended erosion control devices are constructed.

The recommended erosion control devices include:

- log-rock revetments;
- slope reinforcement matting;
- rail string-jack deflectors;
- erosion check dams; and
- a drop structure.

1.0 EXECUTIVE SUMMARY

The geomorphic evaluation focused on the evolution of the Pueblo Colorado Wash over the last 80 years. Field studies, historical and recent photographs, and 1977 and 1983 detailed topographic maps were utilized to complete this assessment.

Significant changes in the main channel have occurred, including incision, bank-cutting, and an estimated four feet of downcutting during the last six years at one location. Historical photographs indicate that, between 1920 and 1950, entrenchment and the development of a well defined, meandering thalweg occurred.

Based on historical photographs, a distinct, entrenched tributary channel developed between 1920 and 1950 in the eastern and upper portion of the study area. In response to the change in base level of the main Pueblo Colorado Wash; channel entrenchment, increased scour, lateral bankcutting and headcutting of the eastern tributary have occurred.

The causes of the increased erosion along the main wash include the following:

- ° increased rainfall/snow melt runoff;
- ° anthropogenic influences including watershed overgrazing, increased discharges due to a halting of diversion into Ganado Lake, introduced vegetation in the wash and the development of irrigation systems;
- ° channel modifications such as the construction of the Highway 264 bridge, and the construction of gabions in 1974; and
- ° bedrock controls in one portion of the channel.

Detailed analyses, including the results of several computer runs, have facilitated the design of engineering structures which should protect against the 25-year flood event and significantly decrease the amount of scour which could occur during greater flood events. The control measures recommended for the main channel should stabilize the base level and control the most serious erosion problems. The stabilized base level, accompanied by the measures recommended for the tributaries, should effectively control the major erosion problems on the tributary streams and halt the accelerated gully headcutting also occurring.



The establishment of a stream gaging station is recommended on the main channel near the confluence of the Upper Tributary. This would allow the calibration of the discharge analysis and design data with actual streamflow records.



2.0 INTRODUCTION

Hubbell Trading Post National Historic Site is on State Highway 264, one-half mile west of Ganado, Arizona (Figure 1). The study area is situated near the southeast margin of the Black Mesa within the Colorado Plateau Physiographic Province. Topographically, the area surrounding Hubbell consists of mesas and rounded badlands. The major drainage system through the site is Pueblo Colorado Wash which flows southwesterly. It is a tributary of the Little Colorado River. The Historic Site is located on alluvial terrace deposits of the Pueblo Colorado Wash. Ganado Lake, a man-made impoundment, is located about three miles upstream from the site. Maximum relief within a two-mile radius of the Trading Post is about 420 feet.

The surficial geology exposed in the study area consists of the Late Triassic Chinle Formation and Quaternary alluvium. The stratigraphy of the Chinle Formation is complex and consists of thick sequences of claystone, clayey sandstone, and ledge-forming sandstones. Soils within Pueblo Colorado Wash and its tributary drainage consists of deep loamy, sandy, clayey soils. Adjacent to the flood plains, shallow fine-grained soils are formed on the Chinle deposits.

The Trading Post site has been subjected to severe erosion that has damaged two prehistoric sites and is threatening the primary historic resources of the Park. If the erosion is not arrested, it ultimately will damage the site's historic buildings as well as the access road to the park.

2.1 Purpose

The purpose of this study was to assess the past and present erosional processes occurring within the 160 acre Hubbell Trading Post National Historic Site in order to develop a plan to minimize future erosion. Flood plain maps were also developed for the Historic Site.

In accordance with the basic scope of work items requested by the National Park Service, Ertec performed services that included:



- ° a geomorphic assessment of the erosional processes;
- ° development of a comprehensive design for erosion control measures;
- ° characterization of the watershed processes which influence surface runoff, channel hydraulics, and estimation of runoff rates for the 100- and 500-year flood events;
- ° preparation of construction drawings for recommended erosion control measures; and
- ° production of flood plain maps for the 100-year and 500-year flood events for the Historic Site.

During the course of the project the original scope of work was expanded to include:

- ° obtaining new 1:3,000 scale aerial photographs of the site;
- ° producing a new 1:600 scale topographic map of the Trading Post site with two-foot contour intervals, using the new aerial photography; and
- ° analyzing channel hydraulics and preparing construction drawings with fewer erosion control measures (to accommodate mitigation measures) at a portion of the archaeological sites.

Project work commenced on May 12, 1983 with the final report scheduled for submittal on December 23, 1983.

2.2 Historical Setting

Juan Lorenzo Hubbell purchased the Trading Post land and established the local trading enterprise in ca. 1876. The Trading Post, under his influence, became a vital social, economic and political center of the Navajo Reservation. The Hubbell family operated the post continuously until the 1950s. In 1965 the National Park Service acquired the 160 acre site and established it as a National Historic Site because of its rich and diverse heritage and collection of archives (Scurlock, 1978).



The following discussion prepared by The National Park Service (1983) describes the recent erosion problems found at the Trading Post Site.

"In the early 1970's the National Park Service installed gabions in Pueblo Colorado Wash to protect an important archaeological site known as Wide Reed Ruin. This may have accelerated bank cutting downstream from the site, particularly at another archaeological site where there is considerable bank sloughing.

At present, erosion is damaging two prehistoric sites and ultimately threatens the primary historic resources of the park. Erosion along Pueblo Colorado Wash is cutting into two archaeological sites and working its way toward the park entrance road. If not halted, erosion will eventually threaten the historic buildings which the park was established to preserve. The terraced farmlands and irrigation system have been impacted by sheet runoff. The main entrance road travels east-west, paralleling Pueblo Colorado Wash and within 30 yards of the wash. A portion of the road consists of a bridge which spans a tributary arroyo to Pueblo Colorado Wash. In August 1982, heavy rains caused erosion around the pilings of the bridge which required emergency backfilling and the placement of gabions to prevent loss of the bridge. The remainder of the entrance road is still threatened by the gradual encroachment of the Pueblo Colorado Wash."

2.3 Geographic Setting

Hubbell Trading Post National Historic Site is on State Highway 264 one-half mile west of Ganado, Arizona and within the Navajo Indian Reservation (Figure 1). The study area is located southeast of Black Mesa, and a short distance west of the Defiance Plateau, within the Colorado Plateau physiographic province. Mesas, buttes, eroded badlands and alluviated valleys comprise the Ganado vicinity. Maximum relief within a 2 mile radius of the site is about 420 feet.

The major drainage through the site is the Pueblo Colorado Wash, an intermittent stream which flows southwesterly and drains into the Little Colorado River. The

drainage area of the Pueblo Colorado Wash at the Highway 264 bridge is 260.4 square miles (sq. mi.). This area includes 8.2 sq. mi. which drains into Ganado Lake, a man-made impoundment, which is located three miles upstream from the site.

Below the Highway 264 bridge and through the study area, the Pueblo Colorado Wash is contained within a relatively narrow wash bordered by high alluvial terraces and the Trading Post to the south, and bedrock to the north. Even prior to the current channel incision, the channel sloped steeply in this reach, with a gradient of approximately 0.014 ft/ft.

The study site is also drained by two major, ephemeral channels which are tributary to the Pueblo Colorado Wash. These unnamed tributaries, which lie to the east and west of the Trading Post (Plate 1), have drainage areas of 0.89 and 1.65 sq. mi., respectively.

Downstream of the Trading Post the Pueblo Colorado Wash flows through a much broader valley. The channel slope decreases to 0.006 ft/ft, and the streambed is composed of sand and coarse material. Consequently, transmission losses are very high through this reach.

Average annual precipitation ranges from 12 to 14 inches with an August maximum of 1.85 inches and a January maximum of 0.88 inches. Average maximum temperatures range from 88° F in the summer to 54° F in the winter. Vegetation is strongly influenced by the amount of rainfall and available surface water. Riparian habitat dominates the Pueblo Colorado Wash and its tributaries. The riparian habitat consists of narrow zones of cottonwood, Tamarisk and introduced Russian Olive trees. Desert Scrub and Juniper Grove habitat is present on the higher lands. The vegetation of the site area has been attended by overgrazing and farming activities (Scurlock, 1978).

2.4 Archaeological Resources

In part, an indirect outcome of this study will be to determine methods to protect the known archaeological resources at Hubbell Trading Post National Historic Site from erosion. In the archaeological assessment (Scurlock, 1979) conducted



in 1978, Scurlock identifies and describes seventeen (17) archaeological sites within or adjacent to the Trading Post property (Figure 2). The resources range in cultural affiliation from Historic Anglo-American and Navajo to Anasazi-Basketmaker II (A.D. 200-500). The most significant sites which are potentially threatened by erosion include the following, as described by Scurlock (1979):

<u>Site No.</u>	<u>Description</u>	<u>Cultural Affiliation</u>
HUTR-1	Trading Post Building Complex (10 structures) - contains fairly extensive historic material, 1870-1940. Access to the complex is threatened by erosion.	Historic Anglo-American, Navajo
HUTR-4	Big Dune Site Cist - contains sherds, lithics, and charcoal. This site is highly threatened by bank collapse along Pueblo Colorado Wash, and runoff in a drainage trench.	Prehistoric Pueblo - Historic Navajo
HUTR-5	Wide Reed Ruin - large ruin with plazas and kivas. Highly threatened by bank collapse along Pueblo Colorado Wash.	Pueblo III
HUTR-10	Contains two cists and "paved" stone floors and two burials. Sherds, vessels, shell beads. Threatened by continuing slope wash erosion.	Basketmaker III - Pueblo I
HUTR-11	Concentrated scatter of surface sherds and lithics. Accelerated slope erosion occurring on portion outside NPS boundary.	Pueblo III
HUTR-12	Sparse scatter of sherds along boundary fence. Minor slope erosion occurring.	Pueblo I - 18th or 19th Century Navajo Component

2.5 Acknowledgements

The Erosional Study at the Hubbell Trading Post National Historic Site was performed by the Earth Technology Corporation of Phoenix, Arizona under contract to the National Park Service (NPS Contract No. CX 702930008).

Managing Principal Investigator, Kenneth M. Euge, R.G., Senior Engineering Geologist, was responsible for the overall project direction and management.

The engineering design management was executed by Joseph J. Kulikowski, P.E., with support from Gerald Bickel, P.E., and Steve Haire, P.E. Trevor Hart, Ph.D. was responsible for the geomorphic analysis and hydrologic assessment. Dr. Larry Agenbroad, consultant and Northern Arizona University Geology Professor, was the geomorphic co-investigator.

Ertec Airborne Systems of Cypress, California produced the 1:600 scale site topographic maps and 1:3,000 scale aerial photographs of the site under a sub-contract agreement with Ertec Western.

Assistance rendered by the National Park Service personnel during the Project is greatly appreciated and acknowledged. Special thanks to the Contracting Officer and the Contracting Officer's Representatives, Mrs. Erlinda Lopez and Mr. Ron Ice, for their continuous cooperation and contractual support. Mr. James Ebert, Branch of Remote Sensing, Albuquerque, New Mexico, expeditiously provided much needed data, maps and photographs of the site. Mr. Ed Gastellum, Park Superintendent, provided assistance numerous times while the field work was being performed. Appreciation is also offered to Elizabeth Bauer, Park Curator, who diligently searched for and provided historical photographs for the erosional assessment.

3.0 GEOLOGY

3.1 Geologic Setting

Hubbell Trading Post National Historic Site is located in the south-central portion of the Colorado Plateau. This area is typified by:

- (1) broad, irregular sedimentary mesas, and small plateaus which are separated by irregular and elongated valleys;
- (2) alternating buttes, rounded mesas, monoliths and valleys; and
- (3) flat uplands dissected by steep-walled canyons.

Deeply incised Canyon DeChelly, 28 miles to the north, and the Defiance Uplift, 18 miles to the east, are two of the major landforms near the historic site.

3.2 Stratigraphy and Depositional History

The Upper Triassic Chinle Formation and Quaternary Alluvium comprise the surficial geology (Plate 1). Within a four-mile radius of the Trading Post, the Chinle Formation unconformably overlies the Middle Permian (Lower Leonard Stage) DeChelly Sandstone and the Chinle Formation underlies the Lower Jurassic (?) Wingate Sandstone. Just south of Ganado, the Tertiary Bidahochi Formation unconformably outcrops above the Chinle Formation (Figure 3).

3.2.1 Permian Rocks - DeChelly Sandstone

Continental deposition during the Middle Permian Period prevailed. Large-scale, high angle cross-stratification of the DeChelly sandstone, which outcrops three miles northeast of Hubbell, suggest that a predominantly eolian depositional environment occurred. The cross stratification, reddish orange color, and hematitic cement indicate that the source area for these wind-blown sands was to the northeast from the Cutler Formation Arkosic sediments, adjacent to the Uncompahge Uplift area (Figure 4, Repenning, 1969). Further to the south, some of the DeChelly sediments appear to be water-laid deposits.

Additional eolian, lagoonal, and marine conditions encroached from the northeast and northwest during the mid to late Permian. Since the Pennsylvanian Period, the Defiance Uplift area prevailed as a positive area near Hubbell. The late Permian stratigraphic record is not as diverse in the Hubbell area as it is in the western portion of the Navajo Reservation due to:

- (1) a lack of marine encroachment upon the Defiance Uplift area;
- (2) a prevalence of eolian type deposition; and
- (3) possible erosion on the slopes of the Defiance Uplift.

A major unconformity is present between the mid-Permian DeChelly sandstone and the overlying Upper Triassic Chinle Formation.

3.2.2 Triassic Rocks - Chinle Formation

The Chinle Formation was deposited during the Late Triassic Period. Several members (subdivisions) within the Chinle Formation have been designated. One is the basal multicolored Shinarump Conglomerate Member which consists primarily of well-rounded pebbles and cobbles with a cemented sand matrix, and some sandstone and mudstone horizons. The other Chinle members consist of mudstone, claystone, siltstone, fine sandstone, bentonitic claystone, thin limestones, and some conglomerate horizons. The Chinle deposits are various colors (often banded) including brown, purple, gray, light green, red, and blue.

The Petrified Forest Member, the most widespread Chinle member, which is usually stratigraphically above the Chinle type deposits present at Hubbell, is well known for its large, abundant agatized wood specimens such as those present at the Petrified Forest National Park.

In the Trading Post area, the Chinle Formation consists of the Monitor Butte Member. This member is exposed in three primary areas - Monument Valley, the Defiance Plateau Region, and the Zuni Mountains (Repenning, 1969). On-site the Chinle Formation is described as follows:



Dark brown and purplish brown claystone, mudstone, and clayey siltstone; light green bentonite; white to light pink resistant, low angle (3-10°) cross-stratified, fine, sandstone; dark brown, finely laminated to climbing ripple laminated fine sandstone; and thin, massive silty sandstones, and sandy siltstones. The claystones, mudstones, and clayey siltstones are the loose, non-resistant, nearly level deposits which weather to the rounded buttes and smooth slopes common in the Ganado area. The sandstones, and silty sandstones are thin, resistant cap rocks near the top of Hubbell Hill and at one location in Pueblo Colorado Wash.

Throughout northeast Arizona an erosional surface of low relief overlies the Permian rocks (Repenning, 1969). As Early Triassic seas encroached upon the region, regional upwarping terminated the marine deposition and initiated a shift to degradational processes, followed by continental type deposition.

Primary source areas were in the Mogollon Highlands to the south and the Uncompahgre Uplift to the northeast, as a generally northwest trending drainage system deposited the relatively coarse Shinarump Conglomerate Member at the base of the Chinle Formation. The majority of the Chinle Formation above the Shinarump consists of claystone, mudstone, siltstone, and fine sandstone. These sediments were deposited in streams, on flood plains, and in lakes during a relatively wet climatic period. Bentonitic clays in the Chinle were derived from volcanic ash deposits from eruptions in southern Arizona. Reptile and fish remains have been found in the uppermost Chinle strata in the region (MacLachlan, 1972).

The fine claystone, and mudstone deposits at Hubbell were deposited in lakes and on flood plains. The sandstone cap to Hubbell Hill is probably a stream channel deposit (Plate 1). The climbing ripple laminations in the sandstone, a short distance below the top of Hubbell Hill, indicate a flood plain environment.

3.2.3 Jurassic Rocks - Wingate Sandstone

Above the Chinle Formation, during the Early Jurassic Period, continental deposition including water-laid and eolian sedimentation prevailed in the region as is evidenced by the Wingate Sandstone outcrops. In the Hubbell vicinity the Wingate sandstone consists of reddish brown cross-stratified sandstone, siltstone, and some mudstone (Repenning et al, 1969). Continental and marine deposition occurred in the region in the remainder of the Mesozoic Era, but erosion on the western slope of the Defiance Uplift has removed the stratigraphic record of this deposition at Hubbell.

3.2.4 Tertiary Rocks - Bidahochi Formation

The Late Tertiary Bidahochi Formation unconformably overlies the Chinle Formation, due to a major period of erosion which locally removed most of the late Triassic through early Cenozoic deposits. Pliocene lake beds and overlying fluvial deposits which alternate with layers of volcanic ash comprise the Bidahochi Formation which outcrops just south and north of Ganado. Lake Bidahochi, or Hopi Lake, apparently was over 100 miles in diameter during the late Tertiary Period (Chronic, 1983). During that time, the Little Colorado River apparently emptied into Lake Bidahochi. About a mile south of Ganado in a road cut along State Highway 63, an exposure of the Bidahochi Formation consists of light tan, well stratified, poorly consolidated, stream channel sands which overlie and truncate a dark colored volcanic ash bed. Bidahochi deposits which consist of sandstone, claystone, some siltstone, tuff, and volcanic flow detritus material also cap Ganado Mesa one mile north of Hubbell, and are the primary surficial deposits for several miles south of Ganado along Highway 63.

3.2.5 Quaternary Sediments

Quaternary alluvium, the most prevalent surface deposit at Hubbell, consists of sand, silt, clay and some gravel. Unconsolidated Quaternary deposits along Pueblo Colorado Wash within the Historic Site total a maximum thickness of at least 25 feet. Bank exposures of the alluvial sedi-



ments consist primarily of clayey sands, silts, and clays, with sand, silt and some gravel in the active channel.

The alluvium occurs as stream terrace deposits, colluvium and minor alluvial fan deposits on-site. Several levels of small, terrace deposits flank Pueblo Colorado Wash (Plate 1). The terrace designations (Qt1 to Qt6) indicate their relative position above the active channel, but the designations do not necessarily imply that correlative surfaces or paired terrace treads are present. The various terraces indicate a depositional history of valley filling followed more recently by episodes of stream downcutting. The oldest terraces consist of sandy clays and clayey sands which abut against Hubbell Hill on the northwest, as well as cultivated land below Red Point on the southeast. Small active eolian dune-type deposits and deflation surfaces are present in and adjacent to the Pueblo Colorado Wash flood plain and also in the two main tributary drainages on-site. Wind action has locally removed sediment from the flood plain area and has reworked some of the terrace deposits.

Cooley (1969) discusses three major periods of stream deposition and two major episodes of stream erosion which have probably occurred in the region. During late Pleistocene and early Recent time, valley cutting occurred followed by the deposition of alluvial sediments between 2000 B.C. and A.D. 900-1200. According to Cooley (1969), the basal portion of this alluvium is relatively coarse-grained, but the uppermost sediments consist of thin-bedded mud and silt layers. Terrace deposits Qt6, Qt5, and portions of the Qoal (Plate 1) were probably deposited during this early aggradational period. Although deposit Qt6 is primarily an erosional terrace on Chinle bedrock and older colluvium, stream action shaped the terrace and deposited some of the tread material during this period.

Portions of the lower alluvial unit have been removed by an episode of erosion and arroyo cutting about A.D. 1100-1300. At the Hubbell site, incision during this period probably extended down to the top of the Chinle Formation in the deeper channel(s). Low energy deposition in ponds and sluggish fluvial deposition occurred from about A.D. 1300 to until the

late 1800s. Sediments in the existing cut banks below the Dune Archaeological site and Wide Reed Ruin (Qoal), as well as deposit Qt4, are probably representative of this depositional sequence.

Increased regional erosion and arroyo downcutting proceeded beginning in roughly A.D. 1880-1890 (Cooley, 1969). Studies by Antevs (1955) and Eddy (1968) further substantiate this degradational episode. Grazing activities and drought-weakened vegetation followed by erosive summer-dominant rainfall probably induced the erosion (Antevs, 1955). Early photos of the Hubbell site (Section 4.0) indicate that, prior to 1920, deposition on a relatively broad flood plain predominated rather than downcutting. Two possible reasons why the geomorphic processes at the Hubbell site apparently did not coincide with this regional erosional trend at that period are: (1) arroyo downcutting may have occurred in the upstream reaches of Pueblo Colorado Wash with deposition occurring at the middle reaches near the Hubbell site; and (2) during that period, winter rainfall of lower intensity, rather than intense summer precipitation, may have dominated in the Pueblo Colorado Wash watershed.

More recently, sediments of Qt1, Qt2, Qt3, Qal and Qe have accumulated in the Pueblo Colorado Wash flood plain. Historical photos indicate that these deposits postdate 1920. The modern erosional period which includes at least 15 feet of stream downcutting adjacent to the Dune Archaeological Site, commenced after 1920, but prior to 1950, with substantial erosion occurring since the early 1970s. Ongoing erosion has removed all of the previous alluvium in portions of the Pueblo Colorado Wash channel bottom and exposed Chinle Formation deposits (Plate 1). The exposed Chinle deposits in the channel consist of claystone and mudstone with a lens of resistant fine sandstone and siltstone. Downstream from the resistant Chinle Formation lens, for roughly 650 lateral feet, non-resistant Chinle mudstones and claystones are exposed or covered by less than 2 feet of recent alluvium in the channel (Plate 1). Similar Chinle mudstone and claystone deposits are probably present at depths of 2 to 10 feet below Quaternary alluvium further downstream within the site boundary, but no subsurface exploration was performed to verify this.

3.3 Soils

Soils at the Historic Site occur on alluvial terraces, in alluvial channels, and on hill slopes. These deposits consist of clay, clay loam, sandy clay loam, sandy loam, and gravelly sandy clay (U.S.D.A. classification system) (Lopez, et al 1978). Based on the Unified Soil Classification System (Figure 5) developed for engineering purposes, the following general soil categories are present at the site:

- ° active stream alluvium - silty sand (SM), sandy silt (ML), sand (SP-SM), clayey silt (ML), clay (CL) and sandy gravel (GP-GM);
- ° eolean deposits and deflation areas - silty sand (SM), sand (SP and SP-SM), and sandy gravel (GP);
- ° colluvium and minor alluvial fan deposits - clayey sand (SC), sandy clay (CL), silty sand (SM), and clayey, gravelly sand (SC); and
- ° terrace deposits - silty sand (SM), clayey sand (SC), silt (ML), sandy clay and silty clay (CL).

3.4 Structural Geology

Monoclinial flexures which typify the mildly deformed Colorado Plateau and broad anticlinal and synclinal folds comprise the major structural elements in the Ganado region. The Defiance Anticline and the West Defiance Monocline are two of the most significant local structural features.

The over 100-mile long Defiance Anticline crests about 20 miles east of Hubbell. Elevations exceed 8,000 feet at the high points of the anticline which extends from near Route 66 on the south to near the Arizona-Utah border on the north. Ganado is situated on the lowermost western slopes of this broad arch-like flexure. Deposition and erosion has been influenced by a positive area, partially coinciding with the present location of the Defiance Anticline, throughout the majority of the Paleozoic through Cenozoic Eras, except during the encroachment of the Upper Cretaceous seaway.



The westward and northwestward dipping West Defiance Monocline inclines roughly 7-10°, about 3 miles west of the Historic Site. Although the Defiance Anticline is the most significant structural feature in the area, step-like monoclinal folds are more common deformational features on the Colorado Plateau. Smaller synclines, anticlines and normal faults are also present in the Hubbell region.



4.0 GEOMORPHIC HISTORY OF THE PUEBLO COLORADO WASH

This investigation has focused on the evolution of the Pueblo Colorado Wash at the Hubbell Trading Post over the last 100 years and particularly on the changes associated with the erosion control measures implemented in the mid-1970s. This analysis has included an assessment of changes in the main channel of the wash and the two unnamed tributaries to the east and west of the Trading Post, as well as an evaluation of watershed processes, notably gully development, which have also affected the site.

Such small-scale adjustments in the fluvial system are the best documented, being recorded in historical photographs and reports, published literature, and field evidence. They also provide a direct insight into the erosional history of the Trading Post site, and information to assist in the design of an effective erosion control system. The long-term geomorphic history of the Pueblo Colorado and its associated alluvial stratigraphy are briefly discussed in Section 3.2.5, above.

Geomorphic research throughout the American Southwest is generally hindered by a lack of evidence as to the nature, timing, and causes of adjustments in alluvial valley systems. In this investigation, however, information on historical changes in Pueblo Colorado Wash was available from published reports and a sequence of photographs of the Trading Post taken over a period of 75 years. These photos, from several sources, were available from the National Park Service files at the Trading Post. This review of historic photographs was supplemented by an analysis of recent air photos dated from 1952, 1977 and 1983 (a sequence flown for this project); by a field investigation, including interviews with Park Service personnel; and by a review of the published literature.

4.1 Historic Changes in the Pueblo Colorado Wash (1850-1975)

4.1.1 Evolution of the Main Channel

Diaries of nineteenth century explorers indicate that before the present cycle of incision and arroyo cutting began in the 1880's, stream valleys in the American Southwest consisted of either severely incised profiles or

relatively broad, unincised profiles (Cooke and Reeves, 1976). This also appears to have been the situation which existed in the Pueblo Colorado Valley. The earliest available description of the Pueblo Colorado, at the location of Hubbell Trading Post, is provided by J. C. Ives (1861) whose expedition crossed the wash in May 1859. He described a broad wash flowing between well defined cut-banks formed in the old terrace surfaces:

"We found a pretty creek running between steep earth banks ten or twelve feet high. The water is good though warm . . . The crest of a plateau a few miles from the creek overlooked an extensive and lovely valley, a brilliant sheet of verdure dotted with clumps of cedars, and extending far to the north and south."

(Ives, 1961, p. 1-128; Pueblo Creek, May 20, 1859)

In contrast to many of the valleys throughout the southwest, however, the Pueblo Colorado remained unincised through the early decades of the twentieth century. This is documented by a series of historic photographs dating from circa. 1910, which match the description of Ives (Photos 1 through 6). These photographs show the Pueblo Colorado as a broad, sandy wash, with little evidence of channel incision, bounded by cut banks ten to fifteen feet high (Photos 3 and 6).

Within its banks, the entire unincised wash appears to have been subject to reworking during periods of flow. This suggestion is supported by Gregory (1916, p. 102) who reported that a gaging station was established on the Pueblo Colorado in 1910, but had to be abandoned because of the problems in measuring stage and discharge within such a shifting channel. The interior, active channel appears to reflect, in a muted way, the sinuosity of the meandering reaches of the wash (Photos 1 and 5). This meandering channel was able to freely migrate and laterally undercut the cut-banks on the margins of the floodplain. In the straighter reaches of the wash, the channel is braided (Photo 1), possibly reflecting the sandy bedload transported by the stream. At certain times of year, it even appears that standing water remained on the wash bed (Photo 8).

A striking feature of all the historic photographs, particularly in comparison with existing conditions (cf. Photo 18) is the lack of vegetation inside the banks of the wash. Photo 2 shows the limited scrub vegetation characteristic of the wash at this time. These photographs also demonstrate that the inner terraces (Units Qa₁, and Qt₁ to Qe₄) mapped on Plate 1 are recent geomorphic features that postdate 1920. Older upper terrace units are apparent above the banks of the wash (Photos 3, 5, 6, and 7), and correspond to units Qt₅, Qt₆, and Qoal on Plate 1. These upper units, based on the description of Ives (1861) and the photographic evidence (Photos 2, 8), were extensively grazed during this period. Furthermore, Gregory (1917, p. 89) reported that:

"(These) terraces along the canyon in the upper portion (of the Pueblo Colorado) and the wide flats below the mouth of the canyon have been cultivated by means of irrigation since the days of the cliff dwellers."

Less evidence is available on changes in channel morphology upstream of the Trading Post. Gregory (1916, p.131), however, commented (without any supporting documentation) that "terraces on the Pueblo Colorado Wash at Ganado date from about 1890". This would suggest that there was considerable spatial variability in the degree and extent of incision within the drainage basin. Such variability is anticipated based on recent, detailed studies of the channels in the region (e.g. Patton and Schumm, 1981), and will be discussed in more detail in Section 4.1.2.4 (Complex Response).

An analysis of aerial photographs flown in 1951 has shown that by this date the channel had incised, and the inner terraces (Qt₂ - Qt₄) mapped on Plate 1 had formed within the floodplain but were not heavily vegetated. Despite such incision, the channel was not well defined and appeared to have been free to migrate over the inner terraces at high floods. This was possible because the channel was not yet constricted by the Highway 264 bridge (constructed during the 1960s) or extensive vegetative growth on the lower terraces. During this period the floodplain (and inner terraces) maintained a high sinuosity, but the channel itself was braided

in many reaches. This channel morphology reflects many factors including a high base sedimentation load and irregular peak flows resulting from snow melt and storm runoff (Tricart and Vogt, 1967).

The aerial photographs indicate that during the early 1950s, bank erosion was focused at the Wide Reed Ruin site, at the outer bend of a meander at the upstream edge of the Trading Post, and to a lesser extent at the Sand Dune site. Downstream of the Sand Dune site, point bar deposition was occurring in a reach (adjacent to the proposed car parking lot) which is currently (1983) being undercut by bank erosion.

Channel conditions in 1975, prior to the most recent episode of accelerated erosion, have been established from aerial photographs (circa 1977) and field observations. A composite photograph (Photo 18) was taken in June 1983, to document the existing characteristics of the channel, and to provide a contrast with the historic photographs.

This analysis indicates that by the early 1970s, a more clearly defined channel had developed, with an increased sinuosity and narrower width. The causes of this channelization appear to include the construction of the Highway 264 bridge and its associated structures, and the stabilization of the inner terraces by the growth of dense communities of shrubby and woody vegetation, including Russian Olive. As a consequence of the stabilization of the inner terraces, the former banks of the wash are separated from all but the higher magnitude flow events (compare Photos 7 and 18). These slopes, particularly downstream from the Trading Post, are now primarily eroded by slope processes, including the formation of discontinuous gullies.

Within the active channel, vegetative growth has prevented significant lateral cutting to the north. This appears to have led to increased incision and undercutting of the banks to the south of the wash, including the Wide Reed Ruin and Sand Dune archaeological sites. Only limited aggradation, on point bars in meander bends (Photo 11), and in areas of dense vegetative growth, has occurred within the wash during this period of incision.

Although its timing cannot be precisely defined, it appears that between 1920 and 1950, a period of alluviation in Pueblo Colorado Wash adjacent to the Trading Post was followed by the incision of the inner terraces and active channel. This incision appears to have been accompanied by an increase in channel sinuosity, reflecting the adjustment of the channel to an increase in slope and sediment load.

4.1.2 Causal Analysis of Incision in the Pueblo Colorado Wash

Love (1979) and Schumm (1981), among others, have suggested that incision may be a response to a number of variables including:

1. variations in precipitation and runoff;
2. overgrazing of a water shed;
3. localized variations in runoff, such as those associated with the characterization of flow;
4. the complex response (Schumm 1981) of one part of a drainage basin to changes in another;
5. intrinsic fluvial adjustments or geomorphic thresholds (Schumm 1981).

Cook and Reeves (1976) in a comprehensive review of arroyo development throughout the southwest, concluded that small scale adjustments are often the result of a combination of such factors. Hodges (1975), furthermore, has stressed that the initiating cause of channel incision or aggradation may not necessarily be the same for all reaches of a wash. Recognizing that such a complex range of possibilities may lead to entrenchment, historical evidence may be used to reduce the extent of speculation and uncertainty. In this study, the causal factors listed above have been examined in the light of the available historical data.



4.1.2.1 Variations in Precipitation

Many authors (e.g. Leopold, 1977) have suggested hypotheses in which climate change is seen as the ultimate cause of entrenchment. In order to test those related hypotheses for the study area, precipitation records from 1857 to 1960 for the St. Michaels - Window Rock Station (approximately at the same elevation and 25 miles east of the Trading Post) have been collected and analyzed. The records prior to 1890 were obtained from Gregory (1917); after 1891 the data were taken from U. S. Weather Bureau records.

There are several problems in analyzing these data. First, there are a number of gaps in the record, notably from 1860 to 1897 and 1924 to 1929, which limit the effectiveness of the analysis. Secondly, the location of the station has changed four times during the period of record (Table 1). The records have been combined into a single series because the known changes are within a relatively small area. Finally, it is necessary to assume that the recorded data are accurate. This assumption seems to be justified by the precise nature of the data and notes. Nevertheless, there could have been differences in recording procedures during the last 100 years that significantly influenced the data, and have not been recorded.

A correlation and regression analysis of the precipitation data has shown that there has been no clear secular trend in precipitation over the period of record.

ANNUAL RAINFALL TOTALS CORRELATION AND REGRESSION SUMMARY

Station	b	r	N	Period
St. Michael- Window Rock	-0.028	-0.233	56	1857-1960

These observations agree with those of Leopold (1951) in New Mexico and Cooke (1971) in Southern Arizona.



TABLE 1

PRECIPITATION STATION HISTORY

ST. MICHAELS-WINDOW ROCK

Observers	Dates	Direction and Distance of Station from Post Office	Elevation (ft)	Station Known As
C. C. Manning	June 1897 - Dec. 1905	50 ft. E. of Ft. Defiance	6900	Ft. Defiance
Rev. Anselo Weber	Jan. 1906 - Feb. 1921	At St. Michaels	6950	St. Michaels
Felix Bruening	Mar. 1921 - Aug. 1924	At St. Michaels	6950	St. Michaels
Leopold Ostermann	Sep. 24 - Nov. 1927	At St. Michaels	6950	St. Michaels
U.S. Indian Service	Sep. 1929 - Dec. 1936	0.1 mi. N of Ft. Defiance	6900	Ft. Defiance
U.S. Indian Service*	Apr. 1937 -	0.3 mi. SE of Window Rock	6750	Ft. Defiance**

*Observer's name published as "U.S. Off. Indian Affairs" beginning Aug. 1952, and as "Bur. Indian Affairs" beginning Jan. 1958.

**Name changed to "Window Rock" 6-1-49.

Within this time series there is considerable year-to-year variation (Figure 12). Drought or wet periods have been arbitrarily chosen as two or more successive positive or negative regression residuals, and an analysis of these short-term trends has highlighted a number of significant features. First, spells of wet or dry years are fairly common. Secondly, drought periods are, at times, terminated by wet years. For example, the drought of 1889 to 1902 was terminated by the wet years of 1903 and 1905. Under such conditions it would be anticipated that the vegetation cover (especially the perennial grasses) would be depleted during such a drought, would not recover immediately, and the higher rainfall terminating the drought would probably fall on surfaces relatively vulnerable to runoff and erosion. However, while such a mechanism may be an important, secondary cause of entrenchment, the annual precipitation record shows no clear trend (at least partially as a consequence of the incomplete records), during the period the Pueblo Colorado was undergoing active incision. Consequently, an analysis was made of seasonal precipitation in order to identify potential mechanisms which provide a better correlation with the historical record of channel evolution.

Winter (October to March) and summer (April to September) precipitation totals were compared over the period of record (Figure 13). This analysis indicates that a period of minimum winter precipitation prior to 1904, was followed by a period of significant winter precipitation from 1905 to 1932. This was then followed by another period of generally low winter precipitation until 1960. This period of high winter precipitation does correspond with channel entrenchment in the Pueblo Colorado. Furthermore, Lockam (1981) has suggested that such an increase in the relative amount of snowmelt runoff, compared to that derived from summer storm events, could induce channel entrenchment because of the different sediment loads associated with runoff from each source. The sediment loading of snowmelt runoff is generally less than that of rainstorm runoff because, for example, a more erosion-resistant vegetation cover tends to exist in upland areas where snow accumulates. A reduction in the sediment loading of flow into the wash could increase its erosive capacity, and hence lead to erosion and incision.



In concluding this analysis, a number of reservations need to be stated. First, it is not certain that a single station can adequately reflect conditions throughout the Pueblo Colorado drainage, in a region where the variability in precipitation totals, duration and intensity is very high. Secondly, the recorded trends in precipitation totals may be offset by other climatic variables (for example, temperature) which were not analyzed. Finally, other trends in precipitation (such as changes in precipitation intensity) may be identified through a more sophisticated analysis of the daily rainfall records.

While changes in precipitation and runoff can be recognized as a primary cause of incision in the Pueblo Colorado, a number of secondary factors may have played a significant role in determining the location and timing of incision. Few of these variables, however, are amenable to quantitative analysis, and must be assessed in more general terms than was possible in the evaluation of precipitation trends.

4.1.2.2 Overgrazing

A number of the historic sources reviewed in this study have documented the importance of grazing in the Pueblo Colorado Valley, J. S. Newberry, the geologist attached to the Ives expedition of 1859, described the Pueblo Colorado as follows:

" . . . we reached the brink of the wall limiting a larger, richer, and more beautiful valley than that last described. This is one of the favorite grazing grounds of the Navajos, the green plain below us as far toward the north as the eye could reach was dotted with their herds and flocks."

(Ives, 1861, Chapter 2: pg. 90)

A number of the historic photographs (e.g. Photo 2) also suggest that sheep and goats continued to graze around the Trading Post during the early decades of the twentieth century. Overgrazing of the valley floor could have led to a depletion of the limited vegetation cover. This, in

turn, could result in higher peak flows and, potentially, gullying on the upper terraces and wash floor.

4.1.2.3 Characterization of Flows

The irrigation system developed by Lorenzo Hubbell may also have resulted in a concentration of flows around the Trading Post during the early part of this century. This hypothesis is supported by the presence, primarily to the north of the Trading Post, of a number of small gully systems which are associated with abandoned irrigation canals.

Over the last fifty years, perhaps the most significant anthropogenic influence on entrenchment has been the extensive planting which has occurred in the wash. Shrubs and woody vegetation were introduced into the wash during the 1930s as part of a federal program to prevent bank erosion. Russian Olive, in particular, which was planted in the Ganado College area, has spread down stream along Pueblo Colorado wash (Scurlock, 1979) around the Trading Post. The effect of this increased vegetation cover, particularly after 1952, was to stabilize large areas of the flood plain and prevent any significant lateral movement by the channel. As a consequence, the channel adjusted by downcutting within a more clearly defined active channel.

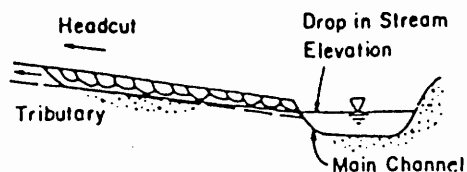
4.1.2.4 Complex Response

The nature of a response in the channel geometry to a change, such as increased snowmelt runoff, is made more complex through the adjustment of one part of a drainage to changes in another section (Complex Response). Tributary incision following base level lowering in the main channel, for example, may have resulted in increased sediment loading to the Pueblo Colorado and localized deposition. Furthermore, the historical record suggests that incision was not contemporaneous throughout the main channel. If the report by Gregory (1916) is correct, incision may have occurred upstream of Ganado as early as 1890, resulting in sediment deposition near the Trading Post, prior to a renewed cycle of incision between 1910 and 1950.

The causal analysis presented above also does not take into consideration intrinsic adjustments which may have occurred within the fluvial system (Schumm, 1977), such that only a small event (such as a storm) may have triggered incision in the channel, which had become inherently unstable. Such considerations may be important in evaluating the detailed timing and sequence of entrenchment in the Pueblo Colorado, but are not readily amenable to analysis over the historic period, with only limited data.

4.1.3 Evolution of the Tributary Channels

The historical photographs reviewed above do not show the distinct entrenched tributary channel to the Pueblo Colorado Wash, which currently runs to the east of the Trading Post site (Photos 1 & 3). This would suggest that the tributary channel, at least in its present incised form, is also a recent geomorphic feature postdating 1920. It appears likely that the incised channel developed in response to a lowering of base level in the main channel of the Pueblo Colorado Wash. Figure 6 schematically illustrates the confluence of the tributary with the main channel. As the main channel becomes entrenched, the base level for the tributary is lowered, and the local gradient of this stream is significantly increased. This increased energy gradient would induce headcutting and cause a significant increase in water velocities in the tributary stream. The result would be bank instability, possible major changes in the geomorphic characteristics of the tributary, and increased local and general scour. The results of this change in base level may be seen in the present, deeply incised nature of the tributary. Headcutting may also have extended back to the headwater of the tributary, resulting in an extensive system of continuous gullies observed in the field and on recent aerial photographs.



Local Effects	Upstream Effects	Downstream Effects
1. Headcutting	1. Increased velocity	1. Increased transport to main channel
2. General scour	2. Increased bed material transport	2. Aggradation
3. Local scour	3. Unstable channel	3. Increased flood stage
4. Bank instability	4. Possible change of form of river	4. Possible change of form of river
5. High velocities		

Figure 6 - Lowering of base level for tributary stream
(Simons et al, 1975).

Evidence from the recent aerial photographs also suggest that runoff may have been concentrated into this tributary stream as a result of the irrigation system developed around the Trading Post. Flows may have been channelized into this wash at the margins of the irrigated lands. This could have occurred deliberately, to carry off excess water and to prevent the washing out of the irrigation canals during storm events, or have been



the result of the disruption of the irrigation system during peak flow events. Whatever the cause, increased flows within the stream would also have increased scour and further modified the geomorphic characteristics of the channel.

4.2 Recent Changes in the Pueblo Colorado Wash

This discussion will evaluate the changes which have occurred in the Pueblo Colorado Wash and the major tributaries in the study area since the early 1970s. In particular, the effects of the erosion control measures, constructed by the National Park Service in 1974, on the main stream and tributary streams will be assessed.

4.2.1 Changes in the Main Channel

By the early 1970s, the historic cycle of entrenchment had resulted in the formation of a well-defined, active channel and a sequence of inner terraces within the former flood plain of Pueblo Colorado Wash. During flood events, active bank erosion was occurring, notably on the downstream outside segments of meander bends. Photo 10, taken during the spring of 1983, documents the continued erosion of the Wide Reed Ruin site on the south bank of the wash. This photo suggests that this bank erosion was increased by the channelized flow under the Highway 264 bridge.

To prevent the continued erosion of the Wide Reed Ruin archaeological site, the National Park Service constructed gabions on the south bank of the channel in 1974 (Photo 11). Photos 11 and 12 show that, at this time, while the active channel in the wash is clearly defined, the bed of the wash is not deeply incised. These photographs also document the stabilization of the wash banks by dense communities of shrubs and trees, including Russian Olive.

Three photographs (Photos 13, 14, and 15) dated from early summer, 1974, document flooding in Pueblo Colorado Wash and the beginning of the failure of the engineering structures.

Photo 13, a view upstream from the sand dune site, and Photo 14 show flood flows undercutting and eroding behind the gabions. The intensive turbu-



lence and scour at the confluence with the tributary (lower right foreground) is also notable. Photo 14 shows, in detail, the slumping and separation of the gabion baskets from the bank due to undercutting.

Two additional photographs from July 1978 document the impact of a later flood event. Photo 16 dramatically illustrates the channelized nature of flow above the Sand Dune site. Streamflow is restricted to within the channel by both the gabion structures and the vegetated banks to the north. Photo 17, looking downstream at the Sand Dune site, documents the accelerated undercutting of this bank, located on the downstream, outside edge of the meander bend, during flood events. Measurements made by the National Park Service personnel indicate that this cutbank was eroded by approximately six feet between 1978 and 1983.

Photo 17 also shows the depositional fan created at the mouth of the ephemeral tributary. Flows within the main channel are eroding this deposit and the cutbank is evidence of the continued incision in the main channel. This continued reduction in the base level provided by Pueblo Colorado Wash has resulted in renewed headcutting and bank erosion within the tributary streams (Photo 19).

During field studies conducted by Earth Technology Corporation, a number of additional photographs were taken to document the geomorphology of the Trading Post, supplement the surveyed channel cross sections, and to contrast with the historic photographs. A composite photograph, Figure 19, provides an overview of the study area and Pueblo Colorado Wash in May of 1983.

Photos 20 and 21 document the recent incision of the wash floor and the continued failure of the engineering control structures. In comparison with the wash in 1974 (Photo 11), the present bed (Photo 20) is deeply incised downstream of the knickpoint in the channel. Upstream of the knickpoint, channel entrenchment has been minimized by the presence of a sandstone cap rock which has also helped to maintain the integrity of the gabion structure (Photo 21). Downstream the stream has also eroded

through the alluvial deposits and into the nonresistant mudstone bedrock underlying the channel. This has allowed continued incision and bank erosion resulting in the almost complete failure of the gabion below the knickpoint.

The extent of incision over the past six years can be quantified by a comparison of the land profiles surveyed at cross sections 8 and 9 on the Pueblo Colorado Wash (Plate 3), with cross sections plotted from 1977 topographic maps (reference), which are also plotted on Plate 3. At cross section 9 on the sandstone cap rock, the channel has incised by significantly less than a foot between 1977 and 1983. At cross section 8 (Plate 3), below the knickpoint, the channel appears to have incised by approximately four feet.

Photo 22 documents the current bank erosion which is continuing at the Sand Dune site and the stream incision which continues downstream from the Trading Post. It also shows the limited aggradation which is occurring on the vegetated point bar at this meander bend. This trend is also supported by a cross section through this reach. A comparison of the 1977 and 1983 land surfaces indicates that channel incision and bank undercutting has been active on the outer bend of the meander. On the point bar, however, some deposition has occurred, particularly in the vegetated areas.

Erosion and incision in the bed of Pueblo Colorado Wash throughout the study area is also indicated by the long profile of the channel surveyed during the field program (Plate 3). Most noticeable is the pattern of the moderately sloping channel (0.004 ft/ft) above the knickpoint, where bedrock controls the channel form, followed by a rigid drop in the channel at the edge of this cap rock. Downstream of the knickpoint, gradient of the channel remains high, resulting in high energy gradients, stream velocities, and increased local scour adjacent to the Sand Dune site (cross section 7) and wash banks. At cross section 5 considerable scour and fill has resulted from the disruption of streamflow by the pilings from a bridge onto the Trading Post which was dismantled in 1979.

Both the photographic evidence and field observations have strongly indicated that accelerated stream incision and bank erosion have occurred at the site since the early 1970s. The causes of this increased scour appear to be complex and interrelated, but may be summarized under four headings:

- ° increased rainfall/runoff,
- ° anthropogenic influence on stream discharge,
- ° channel modifications, and
- ° bedrock controls.

No nearby precipitation records are available to quantitatively assess recent changes in precipitation and runoff within the Pueblo Colorado Wash drainage. The records of the Window Rock Station and the National Park Service personnel, however, have indicated that winter snowfall in the headwaters of the basin has been above average since the late 1970s. This has resulted in higher snow melt discharges and peak floods in late spring and early summer. Hubbell Trading Post personnel (Ed Gastellum, Personal Communication, 1983) has indicated that the early summer flood events have been among the most destructive.

In addition to any changes in precipitation and runoff, discharges in the Pueblo Colorado Wash have also been increased by the halting of diversions into the Ganado Reservoir. In 1978, the safety of Ganado Dam was questioned by the U. S. Army Corps of Engineers during a dam safety inspection. Since that time, flows in the Pueblo Colorado Wash which were previously directed to the reservoir are now allowed to continue downstream. This has resulted in higher flows at the Trading Post, particularly during early summer snow melt.

Field observations during May 1983 indicated that channel incision and bank undercutting is occurring in the Pueblo Colorado Wash from the diversion point to Ganado Reservoir to below the Trading Post. Scour is not restricted to the Trading Post area but appears to be a result of more

basinwide factors, including natural and anthropogenic increases in discharge.

A number of factors, however, have increased localized scour near the Hubbell Trading Post. The presence of the Highway 264 bridge, the heavily vegetated banks of the wash, and the gabion structures built in 1974 have all tended to further restrict flow in this narrow reach of the wash. This has increased energy gradients and velocities within the stream resulting in incision and bank erosion.

This pattern has been further complicated by the resistant sandstone cap rock which has prevented channel entrenchment downstream from the highway bridge. Under these conditions, the channel has acted as a lined chute, increasing the energy and erosive capacity of the stream at the meander bend bounded by the Sand Dune site and downstream of the knickpoint.

4.2.2 Recent Changes in the Tributary Channels

A review of historic photographs, aerial photographs and field observations has indicated that several cycles of headcutting, entrenchment, and bank erosion can be observed in the major tributary channels to the Pueblo Colorado Wash. Both a field inspection and an analysis of recent aerial photographs show that, in both tributaries, a reach characterized by an active channel incised two to three feet into the wash floor and increased bank undercutting, extends approximately one mile upstream from the confluence with the main stream. In the Upper Tributary this entrenchment extends into the badland/gully network in the headwater area of the wash, upstream of the road crossing, south of the Trading Post boundary. No clearly defined knickpoint exists in either tributary wash because of the sandy character of the streambed.

Photographs taken since the mid-1970s (e.g. Photo 19) have documented a recent cycle of headcutting at the mouth of the Upper Tributary. This has resulted in the undermining of the pilings which support the bridge providing access into the Trading Post. National Park Service personnel reported that this headcut was repaired with temporary fill in 1982. This



unstable reach, however, has rapidly eroded and the headcutting is again undermining the access road bridge.

Each of the cycles of headcutting and entrenchment are related to changes in the base level of the Pueblo Colorado Wash. At the Trading Post, where Pueblo Colorado Wash has undergone continued, rapid entrenchment, energy gradients in the Upper Tributary have been significantly increased. This, in turn, has caused an increase in flow velocities, headcutting and increased local and general scour. Below the Trading Post, in the Lower Tributary, there is no evidence of a recent cycle of rapid headcutting. This is because the base level of this tributary stream is controlled by a more stable reach of the Pueblo Colorado Wash. This broad, sandy reach is characterized by high transmission losses and lower flow velocities. The active channel is less defined through this reach and has not undergone as rapid or as intensive entrenchment.

4.2.3 Geomorphic Changes Within the Study Area

In addition to the lowering of the local base level and channel scour which has occurred throughout the study area, another consequence of the adjustment with the Pueblo Colorado Wash has been the insulation of the former wash bank from all but the highest flow events. This is particularly noticeable to the north of the wash and downstream of the Trading Post. At these locations, banks which were formally undercut by a shifting channel within a broad wash, are now isolated behind a heavily vegetated sequence of inner terraces.

A field inspection and analysis of aerial photographs indicated that many of these banks, including several containing archaeological sites, are undergoing erosion by discontinuous gullies. These gullies are not related to the base level of the major streams, nor do they form an integrated network. Most result from the localized concentration of runoff from roadways or from remnants of the irrigation network. Many of these gullies do appear to be healing where flow has been diverted away from them or some form of check dam (such as a fallen fence post) has led to silting and revegetation.



No additional, significant erosion problems have been identified in the interior of the park site. Away from the major drainageways, runoff is minimized both through the gentle slopes of the upper terrace surfaces and the increased infiltration behind the irrigation terraces which remain in the park. These localized depressions also provide an effective means of reducing the velocity of surface flows, holding runoff and promoting plant growth. All of these functions will tend to reduce erosion at the site.

The only additional area which appears to be undergoing accelerated soil erosion is in the northwest part of the site. This area was also identified by Earth Environmental Consultants (1978) as being environmentally sensitive because of the high clay content of the soils and the steep slopes found in this section.

On a more localized scale, the Sand Dune site is currently undergoing accelerated soil erosion, partly as a consequence of the diversion of flow toward the Pueblo Colorado. However, as this problem is so closely connected with the undercutting of this site by the Pueblo Colorado, the proposed mitigation measures have been included in the large program (see Sections 6.0 and 7.0).



Photo 1: Hubbell Trading Post (ca. 1906) showing the post situated on a rather narrow point of land on the inside of a meander in the Pueblo Colorado Wash. At this time there is little evidence of channel incision within the flood plain, particularly upstream from the Trading Post (view from Hubbell Hill looking southeast).



Photo 2: A view (ca. 1910) looking southeast from across the Pueblo Colorado Wash. The streambed is unvegetated and cut banks are shown on the south bank west of the Trading Post.



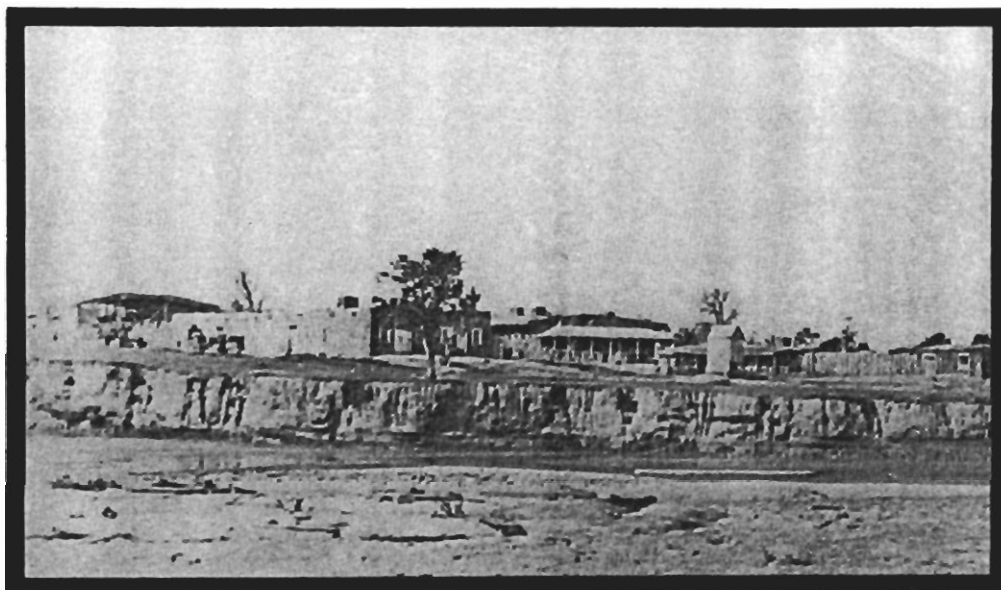


Photo 3: A view from the floor of the wash (ca. 1910) showing the cut bank forming the south bank of Pueblo Colorado Wash (view to the south-southwest).

Three additional photographs (ca. 1913) document the wash and its geomorphology near the Trading Post.

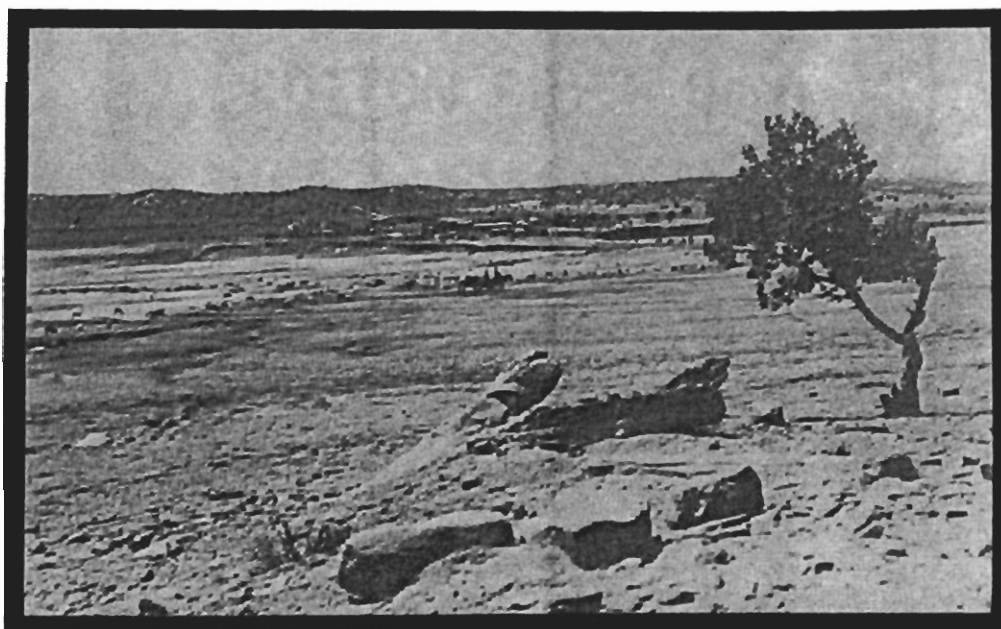


Photo 4: A view of the Trading Post from low ground northeast of the Trading Post (ca. 1913, view to the southwest). Note the lack of vegetation and the flat, unincised channel.



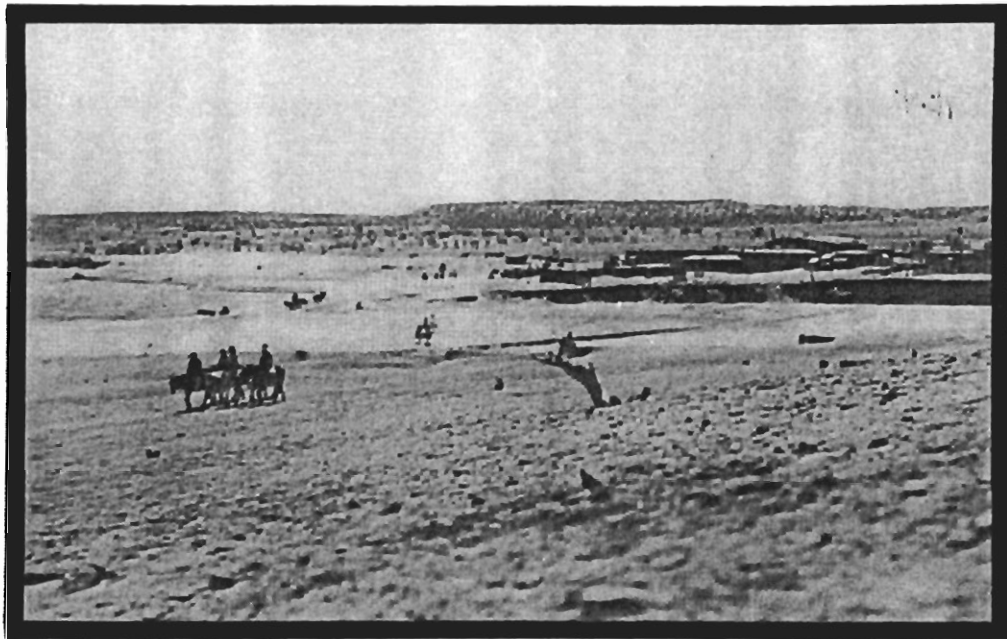


Photo 5: A view from Hubbell Hill (ca. 1913, looking southeast) showing an unincised channel and the establishment of a road crossing the wash.

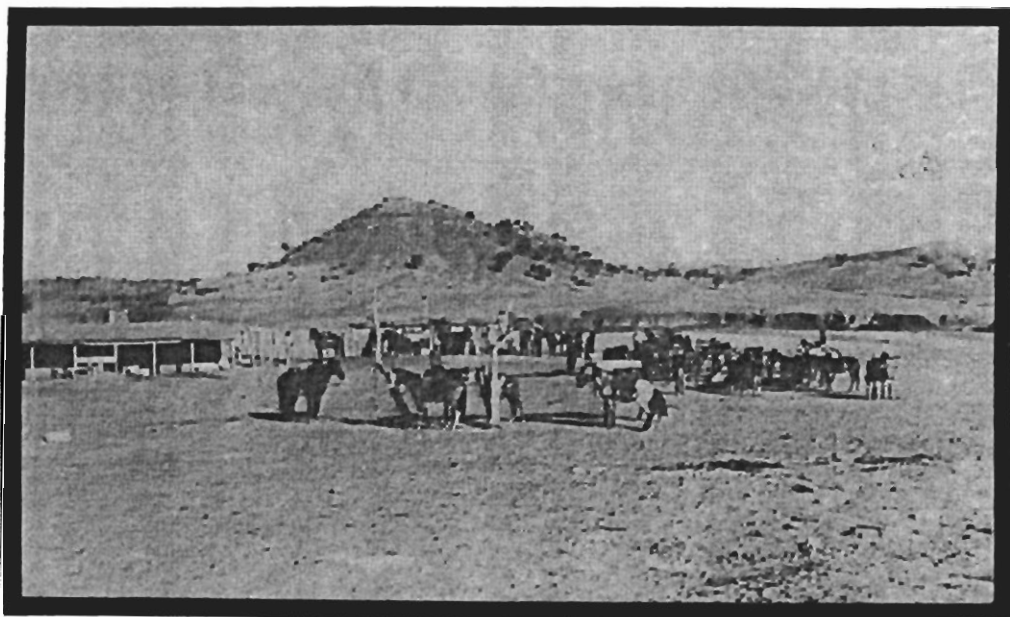


Photo 6: A view from the Trading Post (ca. 1913) toward Hubbell Hill. Moderate banks are noted on the north bank of the wash; these were undetected in previous photos taken from the north side of the wash.



Two views, (ca. 1915) indicate an even wider, non-incised wash floor.

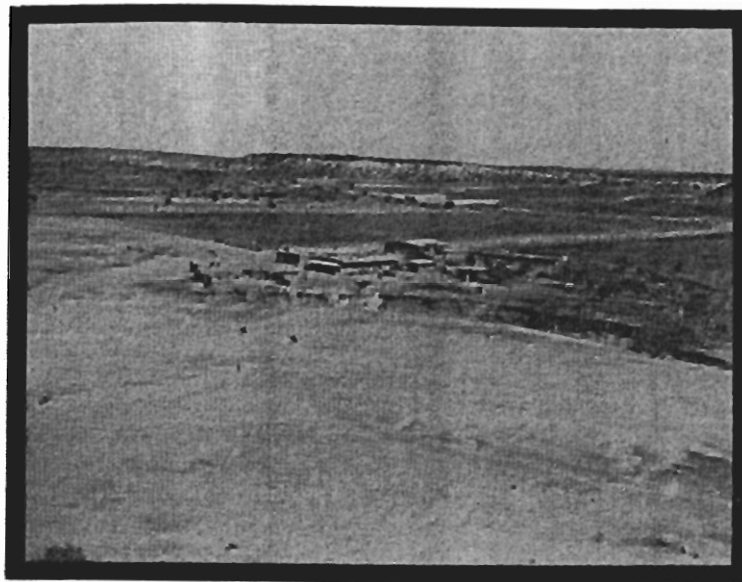


Photo 7: View from Hubbell Hill (ca. 1915) showing a flat, sandy wash floor (view to the south-east).

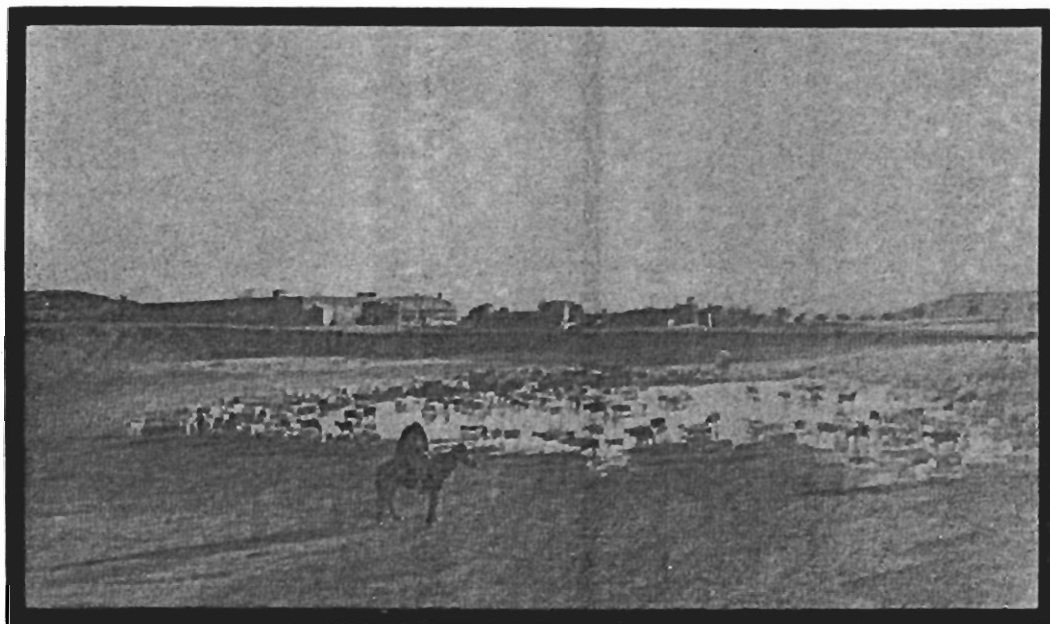


Photo 8: A view to the west-southwest from upstream of the Trading Post (ca. 1915). Cut bank walls of the inside of the meander on which the post is located are evident. The wash floor is flat, broad, and unincised.



One photo (ca. 1920) indicates a broad, unvegetated, unincised arroyo floor.



Photo 9: Hubbell Trading Post (view to the south, ca. 1920).

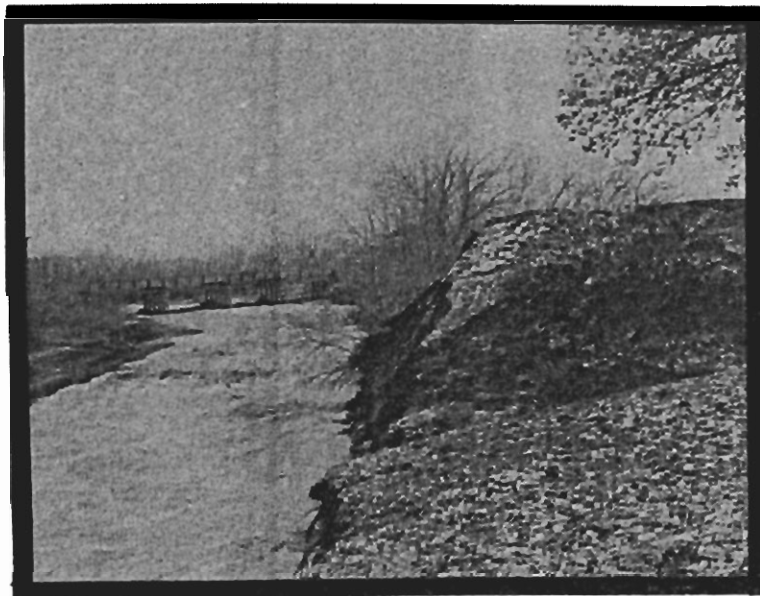


Photo 10: Documentation of the erosion of Wide Reed Ruins. Highway bridge upstream, viewing northeast (April, 1973).





Photo 11: Construction of a gabion to provide bank stabilization at Wide Reed Ruins (20 July 1974), view to the northeast, highway bridge upstream.

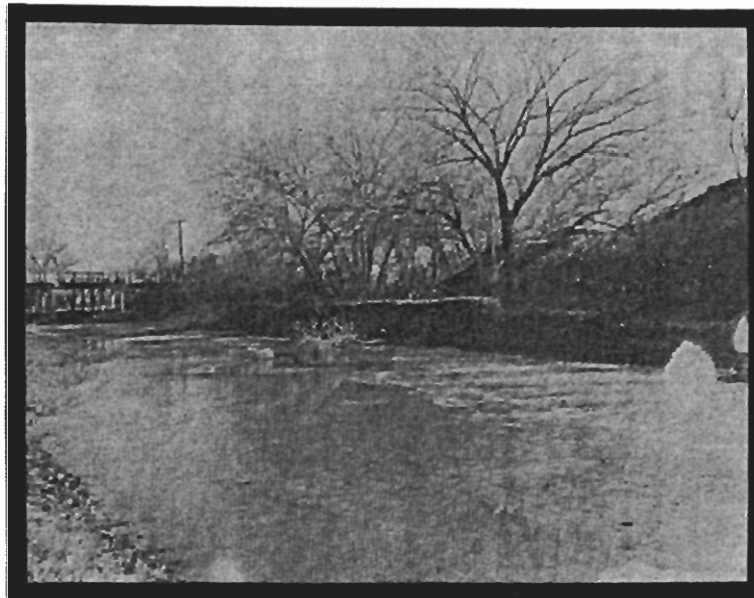


Photo 12: Completed stabilization (ca. fall, 1974); broad, unincised wash floor.

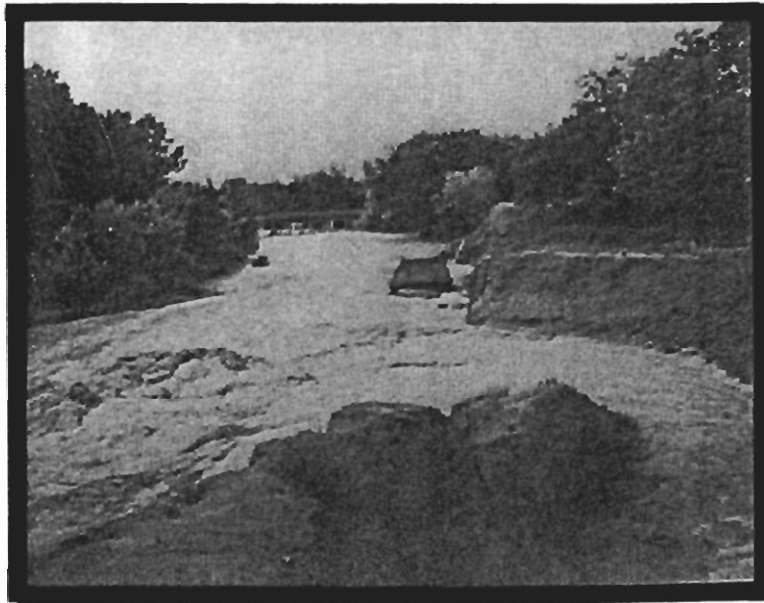


Photo 13: View upstream (northeast) showing flood crest, standing waves, and bankcutting near Wide Reed Ruins.

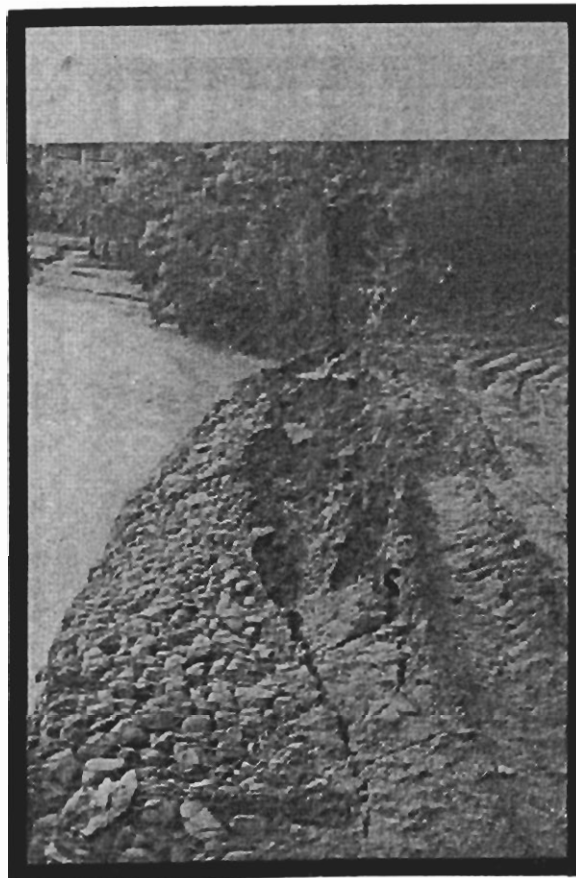


Photo 14: Close-up of failure of gabion wall after partial subsidence of the flow.





Photo 15: Close-up of subsidence of the engineering structure, due to undercutting, and the pulling away from the bank.

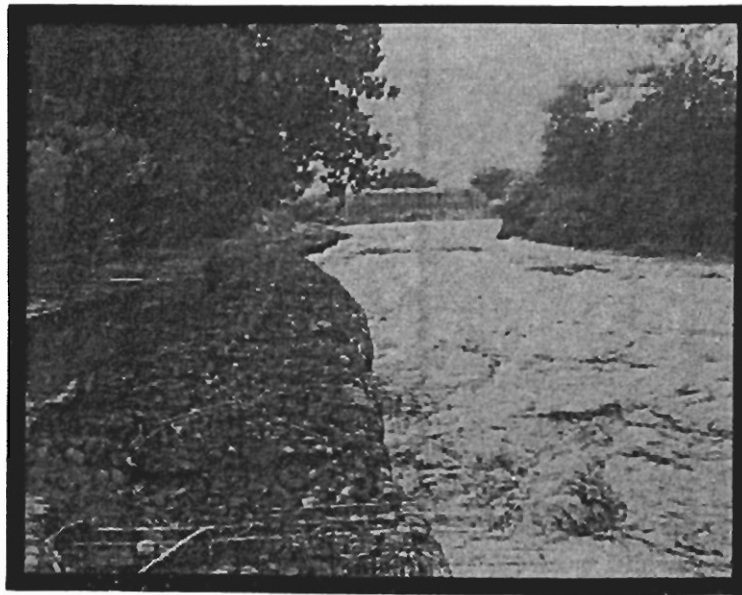


Photo 16: A view downstream (29 July 1976, looking southwest) from the gabion toward the Sand Dune Archaeological Site.



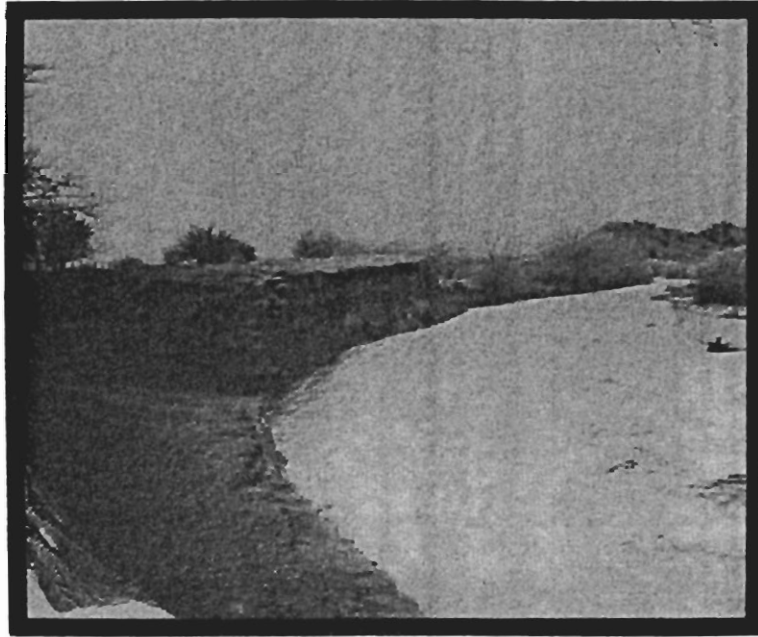


Photo 17: The cutbank caused by erosion at the Sand Dune Site (Dec. 1978).



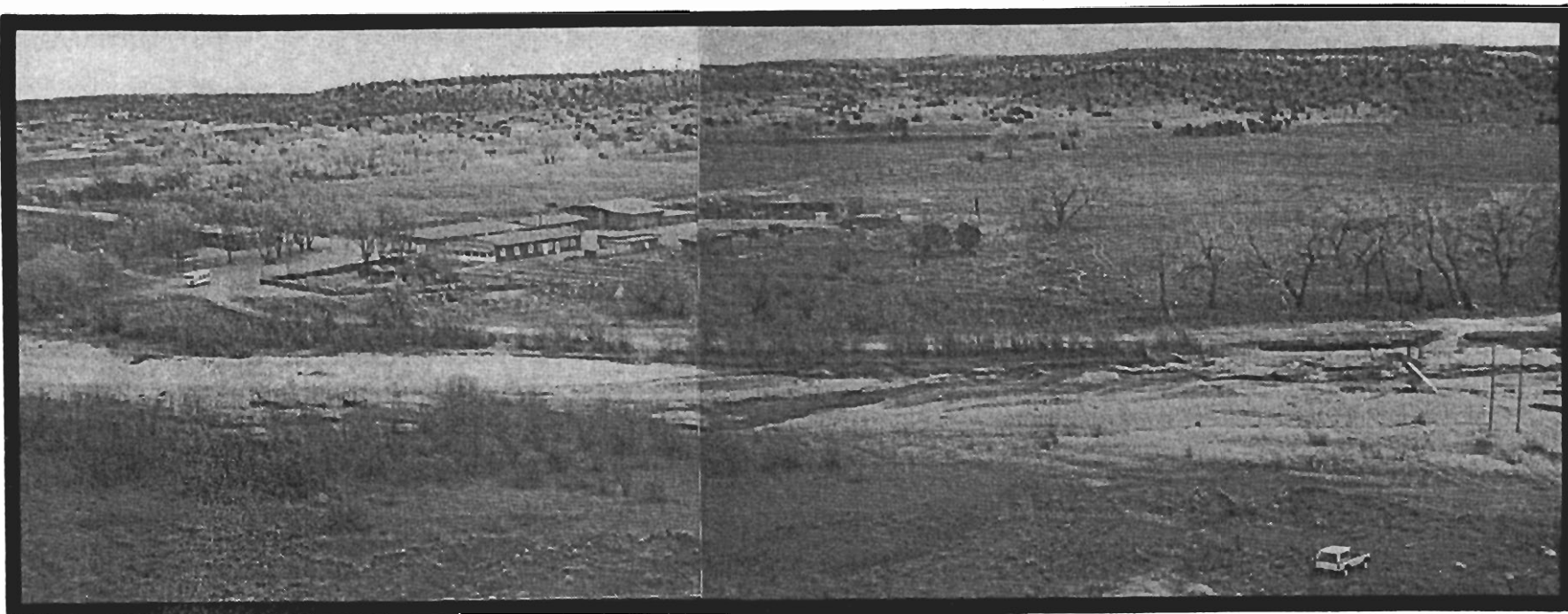


Photo 18: A composite photo (1983) of the Pueblo Colorado Wash and the Hubbell Trading Post from the top of Hubbell Hill, view to the southeast.



Photo 19: Headcutting (including undercutting of a utility line) in the Upper Tributary beneath the access bridge (November 1974).



Photo 20: A view upstream from the Sand Dune Site showing the failing gabion, the highway bridge, and channel incision (May, 1983).





Photo 21: Continued failure of the gabion and channel incision, view downstream (May 1983), southwest.

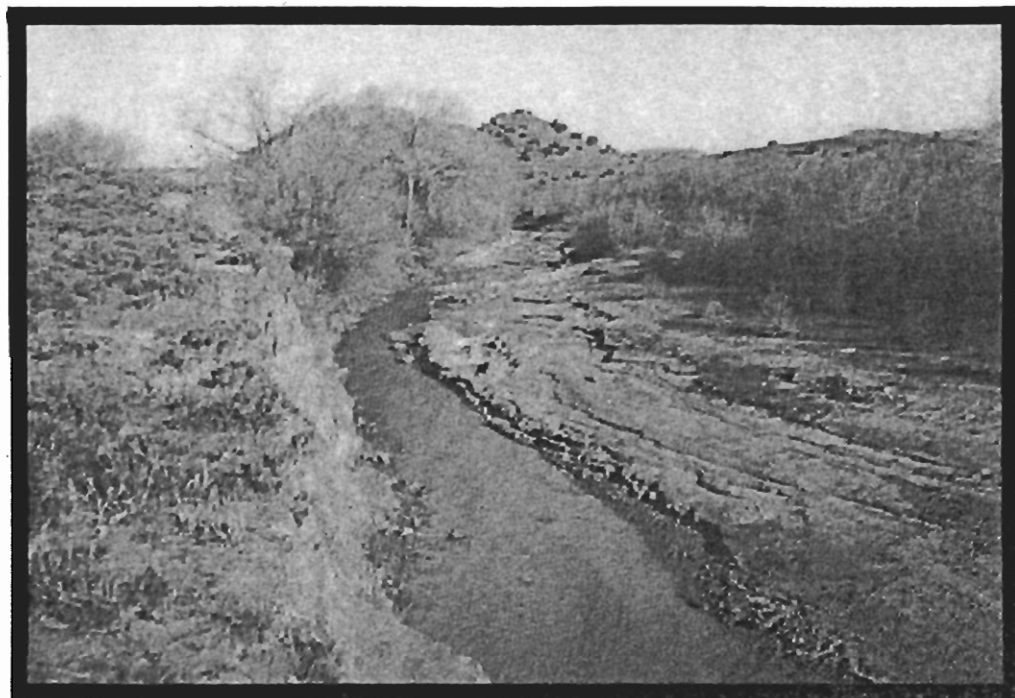


Photo 22: A view downstream from the Sand Dune Site (May 1983); note channel incision.



5.0 CHANNEL HYDRAULIC ANALYSIS

An evaluation was made of the channel hydraulics of the Pueblo Colorado Wash and its two major tributaries within the study area. The objectives of this evaluation were:

- (1) to establish discharge values and velocities for flows of known recurrence intervals which could be used in the design of erosion control measures in the channels;
- (2) to evaluate the effect of any control structures on flow velocities, and the depth and distribution of discharge in the channels;
- (3) to provide a basis for the aggradation/degradation analyses necessary to evaluate the effects of installing erosion control structures in the channels; and
- (4) to establish water surface elevations, and hence the extent of flooding (Figure 15), for the 100-year and 500-year recurrence - interval storm events.

5.1 Flood Discharge Calculations

No storm records are available for the Pueblo Colorado Wash or the tributary streams in the study area. Consequently, peak discharges corresponding to flow events of given recurrence intervals were calculated using regression equations developed by Roeske (1978). These relationships, which relate flood magnitudes to the statistically independent variables of drainage basin area and near basin elevation, are based on annual peak discharge data collected at 21 gaging stations in the northeast plateau area of Arizona. Two of the stations used in this analysis were established on tributary streams near Ganado. The basin characteristics and flood-frequency data of these stations are summarized in Table 2.

Flood magnitudes were computed for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years at the following sites in the study area:



TABLE 2
BASIN CHARACTERISTICS AND FLOOD FREQUENCY DATA
FOR
STATIONS NEAR STUDY AREA

<u>Station Number</u>	<u>Station Name</u>	<u>Region</u>	<u>Year</u>	<u>Basin Characteristics</u>			<u>Flood Discharges</u>						
				<u>DA</u>	<u>EL</u>	<u>PR</u>	<u>02</u>	<u>05</u>	<u>010</u>	<u>025</u>	<u>050</u>	<u>0100</u>	<u>0500</u>
09400100	Ganado Wash Tributary Near Ganado, AZ	4	13	11.10	6770	11.8	223	535	845	1380	1890	2510	4450
				Calculated Discharges			243	639	1080	1860	2620	3620	6840
09400200	Steamboat Wash Tributary Near Ganado, AZ	4	13	0.32	6750	12.1	30	171	426	1130	2110	3710	11600
				Calculated Discharges			35	175	392	941	1630	2760	7810

- (1) Pueblo Colorado Wash at Highway 264 bridge (cross section 12),
- (2) Upper Tributary at its confluence with the Pueblo Colorado Wash,
- (3) Lower Tributary at its confluence with the Pueblo Colorado Wash,
and
- (4) Pueblo Colorado Wash downstream of the study site and the Lower
Tributary (cross section 1).

The methods outlined by Roeske (1978) were followed to determine the drainage basin characteristics used as independent variables in the regression analysis. Drainage area (A), in square miles, was digitized from 1:24,000 scale topographic base maps. Mean basin elevation (E), in thousands of feet above mean sea level, was obtained from topographic maps by placing a transparent grid over the area of the drainage basin, determining the elevation at each grid intersection, averaging the elevations and dividing by 1,000. The grid size was chosen to ensure that at least 20 elevation points were sampled in each basin (Roeske, 1978).

The peak discharges of given recurrence intervals calculated for each site are summarized in Table 3. For flood events with recurrence intervals up to 100 years, it was assumed that flows into Ganado Lake would be obtained. For the 500-year event, it was assumed that Ganado Dam would fail, and that discharge from this tributary drainage would be added to the main channel.

The rating curve for overtopping of Ganado Dam developed by the U. S. Army Corps of Engineers (1978; Appendix D, Plate 2) indicates that the maximum discharge capacity of the dam spillway is 360 cfs. However, a flood event of greater magnitude than the 100-year event (greater than 4,900 cfs) will result in overtopping of the dam (U. S. Army Corps of Engineers, 1978, p.14). Such overtopping will cause erosion of the earthfill and ultimately failure of the dam structure.

A measure of the discharge values obtained from the regression equations and the magnitude of the standard error of estimate are listed in Table 3. The standard error of the estimate is a measure of how well the peak discharge estimated

TABLE 3
CALCULATION OF PEAK DISCHARGE
USING ROESKE METHOD

	in cfs						
	Q ₂	Q ₅	Q ₁₀	Q ₂₅	Q ₅₀	Q ₁₀₀	Q ₅₀₀ *
Main Watershed at Bridge	1717	4365	6930	11717	15928	22148	40508
Ganado Lake	272	733	1197	2081	2881	4052	7592
Upper Tributary	87	254	431	777	1107	1592	3115
Lower Tributary	121	346	583	1048	1475	2114	4104
Main Watershed at Cross Section #1	1925	4965	7944	13542	18510	25854	55319

*Q₅₀₀ assumes Ganado Lake Dam overtopped and failed.

VARIABLES FOR REGRESSION EQUATIONS

	Mean Elevation (1000 ft.)	Area (M ²)
Main Watershed at Bridge	7.102	252.25
Ganado Lake	6.615	8.19
Upper Tributary	6.490	0.89
Lower Tributary	6.550	1.65
Main Watershed at Section #1	7.102	256.94

REGION 4 - NORTHEAST PLATEAU AREA (21 STATIONS) (Roeske, 1978)

Equation	Standard Error of Estimate - in Percent
Q ₂ = 1.38A ^{0.491} E ^{2.25}	83
Q ₅ = 0.319A ^{0.446} E ^{3.60}	74
Q ₁₀ = 0.143A ^{0.423} E ^{4.31}	75
Q ₂₅ = 0.0590A ^{0.398} E ^{5.10}	80
Q ₅₀ = 0.0327A ^{0.383} E ^{5.60}	85
Q ₁₀₀ = 0.0188A ^{0.369} E ^{6.09}	91
Q ₅₀₀ = 0.0062A ^{0.342} E ^{7.04}	107

from the regression equation approximates the observed peak discharges used in the regression analysis. About 68 percent of the observed values used in a regression are within one standard error of the estimated value of the peak discharge. Standard errors for each regression equation were calculated by Roeske (1978), and are presented in Table 3 as percentages for convenience. Much of the error in the calculated values can be attributed to the extreme temporal and spatial variability of the annual peak discharges in Arizona. The variability of annual peak discharges in Arizona is greater than in most other states.

5.2 Channel Hydraulic Data

Channel hydraulics in the main channel of the Pueblo Colorado Wash and in the Upper Tributary during flows of known magnitudes and frequency (recurrence interval) were calculated using the U. S. Army Corps of Engineers HEC-2 program. The use of this computer program was made necessary because of the complexities introduced into the hydraulic analyses by the steepness of the channel reaches (including knickpoints) which had the potential to induce supercritical flow, the backwater effects caused by the confluence of the main wash and the Upper Tributary, and the geometry of the two bridges within the study area.

In addition to the calculated discharge values discussed above, the data required for the hydraulic analysis comprised three sets:

- (1) stream channel geometry,
- (2) resistance to flow, and
- (3) bridge geometry.

5.2.1 Channel Geometry

The active and high flow channels and terrace sequences for both the Pueblo Colorado Wash and the Upper Tributary were surveyed during the Earth Technology field program in May 1983. This survey was later supplemented with information from 1"=50' scale topographic maps by Airborne Systems Inc. from a flight in July 1983. The information from the maps enabled the extension of surveyed lines to higher elevations (to enable

the more accurate calculation of high magnitude flood elevations), and to check and calibrate the surveyed sections.

The cross sections were located at intervals of approximately 500 feet. Downstream of the Trading Post the actual spacing of the sections was greater because flows at this point do not directly affect the study area and the flat, broad nature of the wash facilitated the simulation. At critical reaches (such as at the Sand Dune site), at steep reaches and at bridges, a closer spacing was chosen.

The surveyed and extrapolated cross sections are located on Plate 3. A total of 19 cross sections were employed in the simulation. The longitudinal gradient of the 19 cross sections was employed in the simulation. The longitudinal gradients of the channel thalwegs were also surveyed in the field, and are presented in Plate 3.

5.2.2 Resistance to Flow

Resistance to flow across the sections was characterized by the use of Manning's roughness coefficient "n". This empirical coefficient was allowed to vary as necessary across the section (rather than simplifying the section to channel overbank areas) in order to differentiate between the characteristics of the flood plain and different terrace levels.

In the Pueblo Colorado Wash and tributary washes, bed and bank samples were collected to characterize the channel material (Section 9, Table 14). Bed material was found to range from sand, in the lower reaches of the main wash and in the tributary channels, to silty-sand and coherent sandstone bedrock in the Pueblo Colorado Wash adjacent to the Trading Post. As it was anticipated that velocities in the wash would be high enough to produce upper regime flow, a range of Manning's "n" from 0.03 to 0.027 was chosen for the main channel. A value of 0.03 was chosen for the channel of the Upper Tributary.

The inner terrace areas of the Pueblo Colorado Wash are generally covered with shrubs and trees. This vegetation further retards the streamflow,

so "n" values of 0.04 and 0.05 were assigned depending on the density of the vegetative cover.

5.2.3 Bridge Section Geometry

The field survey program also included a detailed description of the two bridges, the Highway 264 and access road bridges, within the study area. The bridge subroutine of the HEC-2 program requires the inclusion of sections upstream, downstream, and under each bridge. The elevation of low chord and road of each bridge was also established, together with a description of the bridge approach (for example, pier diameter and spacing) in order to calculate loss coefficients required for the hydraulic calculations.

5.3 Channel Hydraulics Summary

The channel hydraulic characteristics of the Pueblo Colorado Wash and Upper Tributary under existing conditions, and for flood events of known recurrence intervals, are summarized in Tables 4 to 8. The results of this analysis clearly indicate for all floods, the channel velocities are sufficiently high to require the protection of the wash bed, banks, and primary archaeological resources (Sand Dune site and Wide Reed Ruin). Channel velocities are highest in the main channel between cross sections 6 and 9, which coincides with the steep, narrow reach from the knickpoint and gabion structure, past both primary archaeological sites and the Trading Post. At cross sections 7 to 9, the analysis indicates that supercritical flow will occur during flood events.

The top width of flows and the mapped flood plains (Plate 4) indicate that, to the south of the Pueblo Colorado Wash, flood flows are generally contained within the channel and lower terraces due to the presence of the steep banks. The immediate Trading Post area remains flood-dry even during the 500-year recurrence interval event. To the north of the wash, flows spread widely over the broad terrace surfaces. Away from the channel, however, flow velocities decline significantly because of the resistance to flow posed by the shrub and tree communities. On the lower reaches of the Pueblo Colorado Wash (cross



TABLE 4

SUMMARY OF CHANNEL HYDRAULICS
FOR 10-YEAR RECURRENCE INTERVAL FLOW

<u>Section Number</u>	<u>Water Surface Elevation (ft. msl)</u>	<u>Maximum Depth of Flow (ft)</u>	<u>Top Width of Flow (ft)</u>	<u>Discharge (cfs)</u>	<u>Left Overbank Velocity (ft/s)</u>	<u>Channel Velocity (ft/s)</u>	<u>Right Overbank Velocity (ft/s)</u>
1	6293.7	5.47	835.0	7944	3.2	6.6	4.0
2	6296.0	5.65	886.8	7361	2.7	5.6	3.4
3	6304.7	7.8	354.9	7361	-0-	7.5	3.2
4	6307.6	8.1	154.4	7361	5.8	12.1	4.1
5	6311.5	9.5	197.3	7361	3.1	11.4	0.0
6	6313.5	8.9	125.5	7361	1.1	12.5	1.5
7	6318.6	10.8	229.8	7361	9.0	12.7	6.1
8	6321.1	11.6	214.1	6930	9.9	14.5	5.3
9	6322.9	8.8	149.4	6930	8.5	13.8	5.6
10	6326.1	11.45	334.9	6930	1.3	4.5	1.5
11	6326.0	11.02	182.7	6930	-0-	5.0	-0-
12	6326.0	10.9	183.3	6930	-0-	5.1	-0-
13	6326.1	10.8	316.3	6930	1.3	5.0	1.6
-7 (14)	6318.6	6.99	35.3	431	0.6	3.9	1.9
15	6323.4	2.7	31.1	431	-0-	7.7	-0-
16	6323.6	3.0	32.9	431	-0-	6.7	-0-
17	6324.8	2.8	34.5	431	4.9	9.1	4.5
18	6326.8	2.7	95.6	431	0.5	6.7	3.1
19	6331.7	2.7	52.6	431	0.0	7.2	1.3

TABLE 5

SUMMARY OF CHANNEL HYDRAULICS
FOR 25-YEAR RECURRENCE INTERVAL FLOW

Section Number	Water Surface Elevation (ft. msl)	Maximum Depth of Flow (ft)	Top Width of Flow (ft)	Discharge (cfs)	Left Overbank Velocity (ft/s)	Channel Velocity (ft/s)	Right Overbank Velocity (ft/s)
1	6294.7	6.5	1035.4	13542	3.7	7.4	4.9
2	6297.0	6.7	1059.0	12494	3.2	6.4	4.2
3	6306.3	9.5	510.6	12494	1.5	8.6	4.5
4	6310.1	10.6	356.2	12494	5.3	12.6	4.3
5	6313.3	11.2	206.2	12494	6.2	13.7	0.0
6	6316.3	11.7	560.3	12494	3.9	11.5	3.3
7	6320.5	12.7	286.1	12494	9.9	14.2	5.0
8	6322.7	13.4	257.7	11717	11.0	17.1	6.8
9	6324.9	10.8	157.8	11717	11.4	16.3	7.2
10	6329.4	14.8	430.4	11717	1.6	5.1	1.8
11	6329.7	14.3	198.0	11717	-0-	5.9	0.5
12	6329.9	14.8	201.0	11717	0.3	5.6	0.6
13	6330.1	14.8	432.7	11717	1.6	5.1	1.7
-7 (14)	6320.5	8.9	44.4	777	1.0	4.7	2.4
15	6324.3	3.7	37.6	777	0.0	8.8	0.0
16	6324.7	4.0	39.2	777	0.0	7.6	0.0
17	6325.8	3.8	41.2	777	6.0	10.9	5.4
18	6327.7	3.7	103.8	777	2.2	6.6	2.9
19	6332.5	3.5	58.3	777	1.2	8.5	3.1

TABLE 6

SUMMARY OF CHANNEL HYDRAULICS
FOR 50-YEAR RECURRENCE INTERVAL FLOW

<u>Section Number</u>	<u>Water Surface Elevation (ft. msl)</u>	<u>Maximum Depth of Flow (ft)</u>	<u>Top Width of Flow (ft)</u>	<u>Discharge (cfs)</u>	<u>Left Overbank Velocity (ft/s)</u>	<u>Channel Velocity (ft/s)</u>	<u>Right Overbank Velocity (ft/s)</u>
1	6295.4	7.2	1072.1	18510	4.1	8.0	5.5
2	6297.7	7.4	1072.7	17035	3.6	6.9	4.7
3	6307.5	10.7	543.1	17025	2.4	9.2	5.2
4	6311.4	11.8	420.9	17035	5.3	13.4	5.1
5	6314.6	12.6	254.2	17035	7.8	14.7	1.5
6	6317.4	12.8	625.2	17035	4.8	12.1	3.9
7	6321.5	13.7	295.7	17035	11.0	15.6	8.2
8	6322.9	14.5	286.5	15928	11.7	18.7	7.8
9	6326.6	12.5	247.4	15928	12.6	16.9	7.3
10	6331.7	17.1	497.6	15928	1.8	5.5	1.9
11	6331.5	16.6	268.1	15928	0.8	6.5	0.8
12	6332.5	17.4	333.3	15928	0.7	6.1	0.8
13	6332.8	17.5	510.0	15928	1.7	5.3	1.8
-7 (14)	6321.5	9.9	55.1	1107	1.3	5.5	2.8
15	6324.9	4.3	39.7	1107	0.0	9.7	0.0
16	6325.4	4.8	40.0	1107	0.0	8.4	0.0
17	6326.5	4.5	45.2	1107	6.8	12.0	6.1
18	6328.4	4.4	109.2	1107	2.8	6.9	3.0
19	6333.1	4.1	63.8	1107	2.4	9.3	3.9

TABLE 7

SUMMARY OF CHANNEL HYDRAULICS
FOR 100-YEAR RECURRENCE INTERVAL FLOW

Section Number	Water Surface Elevation (ft. msl)	Maximum Depth of Flow (ft)	Top Width of Flow (ft)	Discharge (cfs)	Left Overbank Velocity (ft/s)	Channel Velocity (ft/s)	Right Overbank Velocity (ft/s)
1	6296.3	8.1	1074.3	25854	4.7	8.7	6.1
2	6298.6	8.3	1075.0	23740	4.1	7.5	5.3
3	6308.9	12.1	568.6	23740	3.2	9.9	5.9
4	6312.6	13.1	447.4	23740	6.1	14.8	6.3
5	6316.3	14.3	346.0	23740	9.4	15.8	3.1
6	6319.4	14.8	763.9	23740	5.3	10.9	4.1
7	6322.7	14.9	310.0	23740	12.5	17.6	9.9
8	6325.3	15.9	321.6	22148	12.4	20.6	8.9
9	6328.6	14.5	329.0	22148	13.6	17.7	7.3
10*	6331.1	16.6	758.1	22148	7.5	13.1	5.2
11*	6332.7	17.7	940.8	22148	3.5	6.1	2.6
12**							
13**							
-7 (14)	6322.7	11.1	67.1	1592	1.7	6.4	3.2
15	6325.8	5.1	40.0	1592	0.0	10.9	0.0
16	6326.4	5.7	40.0	1592	0.0	9.4	0.0
17	6327.3	5.3	49.4	1592	7.8	13.4	6.8
18	6329.4	5.4	119.1	1592	3.1	6.6	2.8
19	6333.8	4.8	67.3	1592	4.0	10.4	4.8

*Cross section interpolated due to weir flow at Highway 264 bridge and abutment.

**Cross sections 12 & 13 not used because State Highway 264 bridge was removed due to flow.



TABLE 8

SUMMARY OF CHANNEL HYDRAULICS
FOR 500-YEAR RECURRENCE INTERVAL FLOW

Section Number	Water Surface Elevation (ft. msl)	Maximum Depth of Flow (ft)	Top Width of Flow (ft)	Discharge (cfs)	Left Overbank Velocity (ft/s)	Channel Velocity (ft/s)	Right Overbank Velocity (ft/s)
1	6299.0	10.8	1100.9	55319	6.4	10.7	8.1
2	6301.5	11.2	1140.1	51215	5.7	9.3	7.1
3	6313.2	16.4	715.9	51215	5.1	11.8	7.5
4	6316.1	16.5	468.9	51215	9.5	19.2	9.7
5	6321.1	19.1	713.9	51215	11.2	17.8	6.0
6	6324.4	19.8	1003.8	51215	6.2	10.4	4.9
7	6326.6	18.9	431.9	51215	15.2	21.4	12.8
8	6329.9	20.6	438.9	40508	11.3	20.2	9.4
9	6332.3	18.2	483.6	40508	15.7	19.7	8.2
10*	6335.4	20.9	1838.3	40508	5.5	11.7	3.4
11*	6336.0	21.0	1407.9	40508	4.4	7.6	2.7
12**							
13**							
-7 (14)	6326.7	15.1	91.2	3115	2.1	7.0	3.7
15	6327.9	7.2	40.0	3115	0.0	13.6	0.0
16	6328.8	8.2	40.0	3115	0.0	11.6	0.0
17	6329.3	7.3	57.4	3115	9.8	16.4	8.4
18	6332.1	8.1	133.9	3115	3.5	6.7	3.0
19	6335.4	6.5	73.5	3115	6.4	13.0	6.8

*Cross section interpolated due to weir flow at Highway 264 bridge and abutment.

**Cross sections 12 & 13 not used because State Highway 264 bridge was removed due to flow.



sections 1-3), the depths of flow are reduced and top widths are increased as the broad flood plain is able to accommodate high flows. The overbank velocities remain high, however, because of the low resistance to flow offered by the unvegetated wash.

The Highway 264 bridge is overtopped during the 50-year recurrence interval event, and weir flow occurs during the 100-year and 500-year events. Consequently, it was assumed that during the 100- and 500-year floods the bridge would not be able to withstand the discharge and would collapse. The hydraulic characteristics of these flows were then recalculated without the bridge. The entrance bridge to the Trading Post is not overtopped, but the flow velocities suggest that undercutting could result in its collapse during high magnitude events.

5.4 Design Analysis

5.4.1 Rockfill Lining Analysis

Rockfill, within a stabilizing wire mesh, provides an economical lining that can be designed to prevent scour of the underlying channel bed. The cost of loose rockfill is considerably less than concrete per unit volume. Although a thicker layer may be required for rockfill, particularly when a graded filter is required, it still has a number of additional advantages over other linings:

- ° Backfill is more economical per unit volume than most other linings;
- ° It is easier to repair if the lining is damaged;
- ° A rockfill liner, such as a Reno-type mattress, is flexible and will not undergo severe damage if settlement occurs;
- ° The lining is permeable, so the danger of soil back pressure resulting in spalling of the lining is eliminated;
- ° A rockfill lining is aesthetically pleasing, blending into a stream environment;

- ° The nature of the lining promotes the growth of vegetation and provides an acceptable environment for the stream ecosystem;
- ° The increased roughness of the rockfill, compared to a concrete liner and many natural streambeds, dissipates excess stream energy;
- ° The weight and roughness of the liner help maintain the stability of the streambed and banks, and of the liner itself; and
- ° Well selected rocks will be durable and weather resistant.

In the design of a stream channel, the increased roughness (and hence resistance to flow) of the rockfill liner compared to concrete requires a large cross sectional area for a given discharge. However, this additional roughness can also act to dissipate excess stream energy and decrease stream velocities.

5.4.2 Lining Design

Within a lining, the size and grading of the rockfill must be selected to satisfy a number of design criteria. Among the most important of these are:

- (1) the required channel roughness as expressed by Manning's "n",
- (2) the resistance of the lining to erosion, and hence its ability to protect the streambed and banks, and
- (3) the prevention of erosion of the underlying bed material by use of suitably graded filters.

5.4.3 Friction Losses in Rock-Lined Channels

The resistance to flow in the existing Pueblo Colorado Wash and the proposed rock-lined channel can be characterized by the Manning's "n" roughness coefficient. A drawback to the use of this coefficient, derived from the Manning equation, is that it must be derived from empirical data. Its advantage over alternatives, such as the Chezy "e", is that it is

assumed to be a unique value for any channel and is not dependent on flow depth.

The roughness coefficient for the main channel of the Pueblo Colorado Wash, at the Hubbell Trading Post, was estimated at 0.03, based on field observation and comparison with USGS standards (Barnes, 1967). The limited published literature on the hydraulic characteristics of rock liners (e.g. Stephenson, 1979) indicates that "n" values for such liners range from 0.016 to 0.03. Based on this literature, it has been established that an "n" value of 0.027 can be achieved through the supervised packing of Reno mattresses with borrow material. This will enable a close approximation of the natural stream roughness, within a more regular trapezoidal channel.

5.4.4 Stability of Rockfill in Flowing Water

The lining of the channel must be stable against the motion of water flowing over it. The erosive velocity of particles on the perimeter of a channel depends on the bed slope, bank slope, and stone characteristics. In this project it is intended to maintain the integrity of the liner by packing the rockfill into Reno mattresses, or a similar mesh framework, which will hold the stones down against uplift and thus increase friction.

5.4.5 Flow Velocities in the Rock Interstices

Optional rock size, and flow velocities within the liner, and hence the potential for scour of the underlying bed, can both be calculated using the methodology developed by Stephenson (1979, 1980).

For a wide channel, Stephenson (1980, p. 652) proposes that the design stone size for a liner can be calculated from the following:

$$d = \left[\frac{(q)(n^{1/6})(i^{7/6})}{0.25 q^{1/2} ([1-n] [s-1] \tan \theta)^{5/3}} \right]^{2/3} \quad (1)$$

where d = median mean stone size



q = discharge per foot width ($\text{ft}^3/\text{sec}/\text{ft}$)
 n = porosity of rockfill
 g = acceleration due to gravity ($32 \text{ ft}/\text{sec}$)
 s = rockfill relative density
 ϕ = angle of friction
 i = channel slope (ft/ft)

For the proposed modified channel of the Pueblo Colorado Wash, the following values have been assigned to these variables for a 25-year recurrence interval flow event.

$q = 114 \text{ ft}^3/\text{sec}/\text{ft}$ = discharge per foot width (from hydraulic calculations)
 $i = 0.014 \text{ ft}/\text{ft}$ = channel slope (from design specifications)
 $n = 0.4$ = porosity of rockfill (Stephenson, 1979)
 $g = 32 \text{ ft}/\text{sec}$ = acceleration due to gravity
 $s = 2.6$ = rockfill relative density (ibid)
 $\phi = 35^\circ$ = angle of friction (Carson & Kirkby, 1972, p. 92)

Substituting these values into (1), results in a stone size equal to 0.73 ft., Stephenson (1979) indicates that a layer thickness of at least 1.5 times the stone size is required to obtain the required interstitial flow velocities. Consequently, the layer would be at least 1.08 feet thick.

Assuming a flow depth of 9.7 feet for a 25-year recurrence interval flow (based upon the hydraulic calculations), the interstitial flow velocity within the liner can be calculated using the following (Stephenson, 1982, Equation 6):

$$\begin{aligned}
 v_v &= (gdi/3)^{1/2} & (2) \\
 &= 0.33 \text{ ft}/\text{sec}
 \end{aligned}$$

Where:

v_v = interstitial flow velocity (ft/s)
 g = acceleration due to gravity (ft/s)



d = stone size (ft)
i = bed gradient (ft/ft)

This is below the scour velocity for the silts and fine sands which comprise the bed material on this reach of the Pueblo Colorado Wash.

5.4.6 Rockfill Gradation

A lack of proper gradation is one of the most common causes of rockfill failure. Such gradation simply implies that the rockfill should be composed of a distributed size range of rock. With a distributed size range, the interstices formed by the larger stones are filled with the smaller sizes in an interlocking fashion to prevent the formation of open pockets. Jets of water can contact the underlying alluvial material through such open pockets, resulting in the erosion of material supporting the rockfill liner.

Rockfill gradation guidelines are commonly given by defining the D_{max} (maximum rockfill diameter) and the D_{10} or D_{20} (10 or 20 percentile) size as some percentage of the D_{50} (median) size. These three points are then plotted on semi-log paper and a smooth S-shaped curve drawn through them to define the entire gradation range. For protection on steep channel slopes, the maximum rock size (D_{max}), should be no larger than 1.25 times the median size. The ratio between the median diameter and the 10 to 20 percent size should be in the range of 2 to 3 (Office of Surface Mining, 1982). Based on a median rock size of 0.73 feet (Section 5.4.5), the following gradation should be maintained to prevent failure:

Percent <u>Finer</u>	<u>Size</u>	
	<u>Ft.</u>	<u>In.</u>
D_{max}	0.91	10.9
D_{50}	0.73	8.8
D_{10}	0.24	2.9

This size distribution is presented graphically in Figure 14.



5.4.7 Filter Layers

It is usually necessary to place a filter layer beneath rockfill material to prevent leaching of the underlying soil and possible resultant stability problems. Without a filter layer, the loss of underlying soil can occur in several ways. During high flows, the lift and drag forces created by the movement of water through the channel can create an uplift pressure. This pressure can generate enough suction to draw soil particles vertically through the voids in the rockfill. Also during high flows, turbulent eddies and jets can penetrate the lining, causing the erosion of non-cohesive bed material even at the low interstitial velocities calculated in Section 5.4.6. Finally, during all flows, but more visibly during low flows, water can move at the interface between the rockfill liner and the underlying soil. If large enough voids are present, erosion can be significant, particularly if the underlying material is erodible fill. In all cases, the loss of soil can result in the formation of cavities and potential slumping of the liner. The use of a properly designed filter layer will minimize this occurrence and greatly increase liner stability. In the Pueblo Colorado channel an additional advantage to the use of a granular filter is that fill material may be used to simultaneously regrade the channel bed and minimize erosion.

A layer of well graded gravel (possibly obtained from the same source as the rockfill material) should be placed over the channel bed prior to rockfill placement. The size of durable particles in the filter blanket should range from 3/16 inches to an upper limit depending on the gradation of the rockfill. The Office of Surface Mining (1982) recommends that the filter thickness equal the D_{max} of the filter, with a minimum of six inches.

Several filter gradation specifications have been developed, including a comprehensive set developed by the U. S. Army Corps of Engineers (Anderson et al, 1970). The Corps of Engineers criteria relating the gradation of the filter cover to the particle size distribution of the underlying bed material is as follows:



$$\frac{D_{15} \text{ (Filter)}}{D_{85} \text{ (Base)}} < 5$$

$$5 < \frac{D_{15} \text{ (Filter)}}{D_{15} \text{ (Base)}} < 40$$

$$\frac{D_{50} \text{ (Filter)}}{D_{50} \text{ (Base)}} < 40$$

Where the subscripts denote percentage of particles fines by weight.

The filter layer should not contain too many fines. A general guideline is that no more than 5% by weight of the particles in a filter sample should pass through a 200-mesh sieve.

In order to calculate an appropriate filter gradation for the channel of the Pueblo Colorado, the characteristics of the channel bed material are assumed to be:

$$D_{85} = 0.03 \text{ ins.}$$

$$D_{50} = 0.01 \text{ ins.}$$

$$D_{15} = 0.004 \text{ ins.}$$

These values are based on the particle size analyses of bed sample in the channel reach to be overlain by the rockfill liner, presented in Figure 9.

The rockfill properties (determined from Figure 14) are assumed to be:

$$D_{85} = 10.5 \text{ ins.}$$

$$D_{50} = 8.8 \text{ ins.}$$

$$D_{15} = 3.6 \text{ ins.}$$

Based upon the Corps of Engineers criteria, the filter material must show the following limits with respect to both the base and rockfill material:

$$0.02 \text{ ins.} < D_{15} \text{ (Filter)} < 0.16 \text{ ins.}$$

$$0.22 \text{ ins.} < D_{50} \text{ (Filter)} < 0.4 \text{ ins.}$$

$$0.72 \text{ ins.} < D_{85} \text{ (Filter)}$$

$$\text{Filter Layer Thickness} = D_{\max} \quad 6 \text{ ins.}$$



5.4.8 Check Dam Design

The design of low (<4 feet in height), erosion control check dams at the Hubbell Trading Post site take into consideration the spacing, height, and configuration of the structures. The check dams designed are each provided with a spillway and apron to minimize erosion around the dam and at the dam's toe.

In general, the most efficient and economical spacing is obtained if a check dam is placed at the upstream toe of the final sediment of the next dam downstream (Heede, 1976). Spacing definitions are established using empirical relationships. The following equation developed by Heede and Merfich (1973) is used to determine preliminary spacing estimates:

$$S = \frac{He}{KG \cos \psi} \quad (4)$$

where:

S = spacing between dams

He = effective dam height, as measured from gully bottom to spillway crest

G = gully gradient as a rate ($G = \tan \psi$)

ψ = angle corresponding to the gully gradient

K = an empirical constant

This equation assumes the gradient of the sediment deposits is $(1-K)G$. For preliminary design, K values developed by Heede (1966) may be employed:

(5) $K = 0.3$ for $G \leq 0.20$

(6) $K = 0.5$ for $G > 0.20$

Slope gradient (G) determinations were made by analysis of the most severely gullied areas within or immediately adjacent to the Trading Post site. The recent (1983) 1:600 scale topographic maps were used to establish three (3) average slope gradient groupings for design purposes (Table 9).



TABLE 9

EROSION CHECK DAM DIMENSIONS

<u>Slope</u> <u>Gradient (G)</u>	<u>Height</u> <u>(He) (inches)</u>	<u>Spacing</u> <u>(feet)</u>	<u>Apron Length</u> <u>(inches)</u>
$G \geq 0.400$	24	8.9	42
$0.300 < G \leq 0.399$	16	7.2	28
$0.299 \leq G$	16	9.3	28

Height of the check dams, for preliminary design purposes, is assumed to be 16 inches and 24 inches. The spillway is designed with a trapezoidal cross section to permit optimum sediment retention. Based on studies by Heede (1976), minimum apron design lengths below the spillway are designed as follows:

- ° Length equal to 1.5 times the height of the structure where gradient does not exceed 15 percent.
- ° Length equal to 1.75 times the height where gradient is steeper than 15 percent.

The apron should be embedded about 0.45 feet below the original bottom elevation of the gully.

5.4.9 Revegetation of Stabilized Slopes

An integral part of the erosion control program proposed in this report is the revegetation of slopes. Such revegetation is critical to slope stabilization for a number of reasons:

- ° vegetation will reduce the impact of falling raindrops as a result of rainfall interception;

- ° vegetation will increase the resistance to air (wind) and water flow (and hence reduce erosion) through greater roughness;
- ° deposition of sediment will be brought about by a reduction in flow velocity;
- ° increased infiltration capacity will result from root growth opening up the soil;
- ° additional structural stability will follow an increase in organic matter and the development of a root net; and
- ° lower runoff will occur on vegetated versus bare soil, resulting from greater interception, infiltration and evaporation.

In order to achieve all of these objectives, a plant cover must be selected which can successfully revegetate a slope under the prevailing environmental conditions. Communication between the Earth Technology Corporation and the University of Arizona, Agricultural Extension Service (August, 1983) have indicated that only a limited number of plants and grasses can be successfully grown, without extensive irrigation, because of the dry climate of the Trading Post site. The Agricultural Extension Service has recommended the use of Western Wheat Grass for slope cover and protection, if the planting is watered two or three times in the first year to develop an established growth. Enka matting has been used to provide a stable surface for seed holding and growth.

The detailed programs suggested by the Earth Technology Corporation to successfully revegetate the slopes which are undergoing erosion are presented in Section 7.



6.0 EROSION CONTROL OPTIONS

6.1 Structural Control Classes

The two general classes of stream channel control structures may be roughly divided into two groups: those designed primarily to prevent erosion of an existing bank and those designed primarily to guide the flow or promote deposition of sediment in designated areas, or some combination of these two classes. The two classifications may overlap or they may be combined, and either may utilize one or more of several types of solid or pervious construction.

The type of protection for a specific stream is determined primarily by the physical dimensions and flow and sediment transport characteristics of the stream. For convenience in describing various control methods, streams are generally classified as bedload and non-bedload streams. A bedload stream is one which transports coarse material by sliding and rolling along the bottom of the channel. Intermittent streams and other streams that vary from practically no flow to flood flow stages are often "bedload" streams. The non-bedload streams may carry quantities of fine-grained suspended material that will deposit only after significant changes in velocity. In addition to the sediment transport characteristics of the stream, other factors which must be considered in selecting methods for channel control include: 1) probable effect of floating materials on control devices, 2) stability of channel materials, 3) channel width, (4) degree of curvature of the stream, 5) depth of water, 6) height of banks, and 7) degree of protection required.

The ability of streamflow to scour varies inversely with the amount of debris load the stream is already carrying. Clear water flow in a channel with erodible bed material will scour and transport sediment up to the maximum size of particles and volume of load that the hydraulic properties of the stream are competent to transport. A stream that is carrying its maximum debris load can therefore flow at higher velocities without accumulating scoured material; but a stream carrying less than its full capacity load may erode more channel material at a lower velocity. However, the critical conditions for debris-laden turbulent flow at which neither scouring or deposition takes place as a sustained, dependable condition is practically never attained in erodible channels.

Generally, there is either scouring or deposition taking place at any point in a channel. The formation of transverse "valleys" and ridges or transverse bars in the stream channel is characteristic of unstable flow along with longitudinal "surging" and "traveling waves." Variations in discharge during passage of a storm hydrograph also cause changes in the transporting and scouring characteristics of a stream.

Various devices and protective measures have been developed to stabilize eroding stream channels. Those most commonly used include grade stabilizing structures to arrest degradation of a channel thalweg and some form of revetment to stabilize eroding banks. The four general types of revetment are blanket, pervious, solid fence, and groins. Each of these structural measures are discussed in the following sections:

6.1.1 Grade Stabilizing Structures

Grade stabilizing structures are installed to stop the advance or prevent the formation of gullies in natural or constructed waterways, diversions, and other points of concentrated water flow. They are also commonly used to safely convey water from tributary watercourses or ditches into larger streams or canals. They, therefore, provide the means for conducting water through differentials in elevation without downcutting in the tributaries.

The stabilizing structures may be drop inlets, chutes, or earth dams and each must be designed for specific soils and site conditions and flow characteristics. Structures may be constructed of reinforced concrete, masonry, steel, rock, compacted earthfill, or treated wood. To ensure stability they must be adequately supported and sufficient cutoff trenches or walls provided. Toe drains and weep-holes must be provided to minimize building of hydrostatic pressures. Inlets must be adequately protected from floating trash and debris, and flow velocities through the utilization of trash racks. The design and physical dimensions must be adequate to safely pass stream discharge in accordance with the basic purpose and design criteria of the structure.

6.1.2 Blanket Revetment

Structures used primarily for bank protection are designated as revetment, and they are generally used on a bank that has been sloped and shaped to a desired alignment. Blanket revetment is constructed of rock, concrete, asphalt, wood or other material placed to form a protective cover with or without an accessory mattress extending to the thalweg of the stream, and sometimes across the stream bottom.

Because the purpose of a blanket revetment is to prevent erosion of the bank, it should include the following characteristics:

1. Possess adequate strength to resist movement by the stream discharge or breakage due to the impact of debris.
2. Be sufficiently impermeable to prevent removal of the underlying soil material through the interstices.
3. Be sufficiently flexible to conform to bank irregularities.
4. Be sufficiently mobile to settle into breaks that might develop through soil settlement.

6.1.3 Pervious Revetment

The primary function of a pervious revetment is to establish a zone of resistance that aids in guiding the flow while creating a zone of reduced velocities behind the revetment for deposition of sediment. These are particularly adapted to the formation of smoothly aligned banks; however, they are often utilized where materials for blanket revetment are not readily available or where the cost of a blanket revetment cannot be justified. They are constructed of single or multiple rows of piling, jacks, or fencing backed with brush or other material that can be driven or cabled to form a continuous unit.

In general, pervious revetment is relatively useless against direct attack. Its efficiency is maximum when placed parallel to the direction



of flow, decreasing as the angle of attack increases. Its efficiency can be increased by adding additional elements, either by closer spacing or by multiple rows. It is especially critical that pervious revetment be initiated sufficiently far upstream to obtain a proper angle of entry.

6.1.4 Solid Fence

A solid fence revetment is useful on steep slope streams where the revetment must have strength to resist the forces of flow rather than to guide the flow. These are usually one or more rows of fencing backed by rock, stones, concrete, or other solid material. They are especially useful for short reaches where the angle of attack is too great for the use of pervious revetment.

6.1.5 Groins

Groins are short, usually solid, structures placed into the stream at approximately right angles to the bank. An undesirable characteristic of a groin is that an eddy will generally form immediately downstream from its outer end, and the eddy may generate a scour pattern extending to the bank. The danger of bank scour can be reduced by angling the groin upstream approximately 10° to 15° . Groins should have a length not less than three times the normal water depth at their outer end.

6.2 Proposed Structural Controls

The Upper Pueblo Colorado Wash and its tributaries are intermittent streams with the capability of transporting significant quantities of bedload and suspended sediment. The streams are generally dry and they respond to runoff producing storm activity with a rapid rise in discharge followed by a rapid decline in flow after cessation of rainfall. As described above, considerable erosion has occurred in the study area in the Upper Pueblo Colorado and both the Upper Tributary and Lower Tributary. Structural measures to control the erosion at each of these sites will be described in this section, along with pertinent specifications for incorporation with standard NPS construction specification documents. More detailed construction procedures can be provided during pre-construction conferences.



6.2.1 Upper Pueblo Colorado Wash

The primary problem area in this channel occurs at a relatively sharp bend in the stream located immediately downstream from a constriction caused by the encroachment of bridge abutments. Velocities are high at the bend, and considerable erosion has occurred at both the streambank along the outside of the curve and in the channel invert. The Upper Tributary joins the Upper Pueblo Colorado Wash at the sharpest point in the bend and this creates a discontinuity in the streambank at a critical point that encourages eddies and turbulent flow conditions. Streambank erosion in the reach between the Upper Tributary and the highway appears to be accelerating. Continuing erosion in this area threatens the access road and bridge leading to the Trading Post and important archaeological resources (the Wide Reed and Sand Dune sites) adjacent to the channel.

To adequately protect this area from high velocity impinging flow, a solid wall-blanket revetment will be required. The log-rock revetment shown in Plate 4 is recommended for this area. The solid wall will prevent stream flow from attacking the streambank for flows up to the 25-year event; for the more infrequent flood events that exceed the 25-year storm, it is proposed that a reinforced nylon erosion control matting be placed on the banks. The general configuration of the matting is shown in Plate 4; construction details are shown in Plate 4. Because velocities in this area are extremely high, the channel thalweg has experienced substantial degradation. To protect the channel bottom from additional degradation, it is proposed that a wire and rock mattress be placed along the channel bottom and tied to the log rock revetment on the left bank. Details are shown in Plate 4. Alignments of all proposed measures for the Upper Pueblo Colorado Wash site are shown in Plate 4. Specific details of each of these structural measures are described below.

Log-Rock Revetment (Plate 4, Sheet 1; Detail A-3)

- ° Logs should be 8 to 12 inches in diameter and protruding logs should be spaced approximately 6 to 8 feet apart.



- ° Logs should be completely stripped of bark and pressure treated with creosote with the depth of penetration at least 3/4 inch. When sawing or drilling is necessary after plant treatment, the cut surfaces should be thoroughly brushed with two coats of the same preservative used in the pressure treatment.
- ° Every third header must be a tie log securely fastened to a deadman buried at least 6 to 8 feet from the revetment.
- ° Logs should be notched at joints and 1/2 inch drift pins should be used to penetrate and tie 3 logs.
- ° Rock fill should be sized to avoid penetration of the spacing between logs. A recommended minimal size is 0.75 feet at the minimum diameter.
- ° The rock should be durable and dense crushed rock or river run material (potential borrow areas may be located near Fort Defiance, Gallup, and Holbrook).

Reinforced Erosion Control Mat (Plate 4, Sheet 1; Detail B-1)

- ° All surfaces to be protected should be graded, shaped, and finished so that the surfaces are stable, firm, and free of rocks or obstructions.
- ° Wood stakes used for anchoring should be sound, rough sawn hardwood measuring 1 inch by 3 inches with at least 12 inches of penetration, leaving 3 inches above the ground surface.
- ° Lap joints should be at least 3 inches with the upstream width on top. The joints should be staked at intervals of 3 to 5 feet.
- ° The upslope end of the mat should be buried at least 24 inches vertically in an anchor slot dug into the soil. The mat should be secured in the anchor slot by stakes at intervals of 3 feet or less prior to backfill. The backfilled soil should be firmly compacted in

the anchor slot. The ends of each mat roll should be overlapped 36 inches with the upslope mat on top.

- ° The downslope end of the mat should be securely fastened to the upper pole lagging.
- ° The nylon mat should consist of a bulky structure of entangled nylon monofilaments with fitted fabric underlay. Total weight of material should be 715 grams per square meter.

Rock and Wire Mattress (Plate 4, Sheet 1; Detail E-3)

- ° Over-excavate the channel within the limits shown on the preliminary plans to a depth of 2-1/2 feet below finish grade.
- ° In order to contain the rock used to prevent channel erosion, utilize rectangular, compartment gabion baskets or containers fabricated from triple twisted hexagonal mesh of heavily galvanized steel wire; basket dimensions should have a minimum width and depth of 3 feet and 1-1/2 feet, respectively; length of basket may vary according to site conditions.
- ° Stones used to fill baskets should be uniform-sized, durable, and dense crushed rock or river run material with a nominal diameter of roughly 8 inches.
- ° Gabion baskets and/or wire mesh shall be uniformly laced with double loops to avoid gaps between baskets and/or the wire mesh.
- ° Prior to installing gabion, a 12-inch thick layer of sandy gravel bedding material shall be placed as a filter blanket. The bedding material shall be well-graded with at least 15% (by weight) retained on a standard 1 inch sieve.
- ° Bedding material shall be densified using a smooth drummed roller. Flooding may be used with the approval of the engineer and if the fines do not exceed 2% passing the #200 sieve and are non-plastic.

6.2.2 Upper Tributary

The invert elevation of the Upper Tributary at its confluence with the Upper Pueblo Colorado Wash has responded to the degradation in the main stem by a similar degradation. The downcutting has progressed upstream to the extent that it now threatens stability of the access bridge to the Trading Post. This downcutting must be arrested or it will undermine the bridge supports, progress further upstream, and endanger stability of the banks on both sides of the stream. Because of the severity of the problem, the need to stabilize the channel on the downstream side of the bridge, and the short distance from the bridge to the confluence, the most appropriate solution appears to be a reinforced concrete drop structure. A typical drop structure of the type proposed for this site is shown in Plate 4. To ensure stability of the structure it is essential that the wing walls and the toe walls be carefully keyed to stable soil in the adjacent banks and channel bottom. A detailed soil investigation must be performed during the construction phase to complete the final design of the drop structures. This is necessary to establish the allowable bearing pressures, depths of toe walls and wing walls, soil pressures on the head-wall and sidewalls, and the optimum site for the structure. Following the necessary subsurface investigation, laboratory testing, and evaluation of soil characteristics, a detailed design will be required to determine thickness of concrete, placement of steel, the necessity for buttress support, and other design parameters. Following the structural design, final plans and specifications must then be prepared. The final design must also consider the hydraulic characteristics of the confluence to ensure that the drop structure will function as planned during all potential flow conditions in the Upper Pueblo Colorado Wash. Preliminary dimensions for the structure have been developed as part of this study and they are shown in Plate 4. The detail drawing should be adequate for preparing cost estimates. The cost for performing the final design study are included in the engineer's estimate. During the structural design phase a final tie between the log-rock revetment and the drop-structure wing walls should be established. As described above, the confluence occurs at a critical location in the Upper Pueblo Colorado Wash where high velocity flow

impinges on the banks. It is imperative that a positive and permanent tie between the various structural measures be achieved. Undermining of structural controls in this area could lead to failure of the structures.

Rail-jack string deflectors (refer to Section 6.2.3) and structural erosion control check dams are proposed where extensive bank cutting and gullying is found.

Rail-jack string deflectors are placed on the downstream convex curve of narrow channel to reduce bank cutting and for training and slowing the channels flow in a more desirable direction. It is desirable to plant vegetation behind the deflectors to increase erosion resistance.

Erosion control check dams are proposed to decrease the velocity of water moving down the gully thereby allowing sediment to accumulate rather than be eroded. The check dam accomplishes this by flattening the effective gradient of the gully by depositing soils in the small catch basins behind the dam.

Details concerning construction of the check dams are as follows:

- ° At locations defined by the engineer, and according to the schedule of check dam dimensions, a keyway for the dam is constructed to a minimum of 2 inches into the channel bottom and 6 inches into the bank.
- ° Timbers are placed until the desired spillway height is achieved.
- ° The spillway should have a trapezoidal cross section and minimum wingwall width of 12 inches.
- ° Freeboard must be a minimum of 8 inches.
- ° Energy dissipation material must be placed a minimum distance of 1.75 times the spillway height downstream from the dam's toe.

6.2.3 Lower Tributary

Because the main stem at the confluence with the Lower Tributary has remained relatively stable, the invert of the Lower Tributary has not experienced significant recent degradation. However, downstream from the road crossing, the Lower Tributary has developed a sinuous flow pattern and streambank erosion is occurring on the outside of isolated bends in the channel. As shown in Plate 4, structural measures proposed for this channel include a combination of compacted fill with erosion control matting bank protection, and pervious revetment consisting of anchored rail-jack string deflectors.

Except for the tie at the toe of the slope, the method of installation for the erosion control matting is identical with that described above for the Upper Pueblo-Colorado Wash. At the junction of the bank and channel bottom, the mat should be buried at least 12 inches vertically into firm undisturbed soils in an anchor slot dug into the channel bottom. The mat should be secured in the anchor slot by stakes prior to backfilling the slot. The backfilled soil should be firmly compacted in the anchor slot.

Details concerning construction of the deflectors are described below.

Rail-Jack String Deflectors

- ° Each string deflector should be securely anchored to rail imbedded in concrete or equal and buried in stable area of bank.
- ° Anchor and string cable should be 3/4 inch wire cable, minimum.
- ° Rail should be not less than 40 pounds.
- ° Jack spacing should be no more than 30 feet.
- ° Jack should be constructed with #10 gauge wire, minimum.
- ° At least one jack should be placed on top of bank.
- ° String should be placed at 45° from bank, maximum.



7.0 EROSION CONTROL CONSTRUCTION

7.1 Construction Alternatives

Construction of erosion control measures at the Hubbell Trading Post site are formulated based on input from the National Park Service and the engineering analysis. In addition to the engineering and hydraulic design criteria, which ultimately lead to selecting viable options, other factors aided in the final selection of preferred alternatives. These factors include:

- ° environmental compatability;
- ° archaeological mitigation;
- ° labor intensive construction;
- ° ease of construction; and
- ° cost.

Each alternative contains some of the same items of work with differences reflecting whether or not: 1) various archaeological sites are mitigated, and 2) local labor is utilized. The alternatives assume the recommended off-site (i.e. land under Tribal jurisdiction) control measures will be constructed. Each alternative contains the following items of similar work or control measures:

- ° mobilization,
- ° demolition,
- ° excavation,
- ° log-rock revetment wall,
- ° bedding/filter sand,
- ° rail-jack string deflectors,
- ° drop structure,
- ° trash rack,
- ° headwall outlet,
- ° structural erosion check dam.

Differences in each alternative are provided in Table 10. The differences reflect mitigation, or lack thereof, of the archaeological sites.

TABLE 10

MATRIX OF ALTERNATIVES

(Circle indicates engineer's preference)

Design Criteria or Work Items	Alternatives							
	A	A-1	B	B-1	C	C-1	D	D-1
Archaeological Mitigation	No	No	Yes	Yes	No	No	Yes	Yes
Large Embankment Fills	Yes	Yes	No	No	Yes	Yes	No	No
Gabion-Type Mattress	Yes	Yes	Yes	Yes	No	No	No	No
Wire Mesh Mattress	No	No	No	No	Yes	Yes	Yes	Yes
Soil Reinforcement - Natural Slopes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil Reinforcement - Embankment Slopes	Yes	Yes	NR	NR	Yes	Yes	NR	NR
Seed & Hydromulch - Natural Slopes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Seed & Hydromulch - Embankment Slopes	Yes	Yes	NR	NR	Yes	Yes	NR	NR
Disposal of Excess Excavation								
30% of Excavation	Yes	Yes	NR	NR	Yes	Yes	NR	NR
90% of Excavation	NR	NR	Yes	Yes	NR	NR	Yes	Yes
Local Labor Forces Utilized	No	Yes	No	Yes	No	Yes	No	Yes
Engineers Cost Estimate \$(X 1000)	607	551	568	522	457	428	419	398

Note: NR - Not required for Alternative

7.1.1 Alternatives A and A-1

Alternative A assumed protection of archaeological resources at the Sand Dune Site (Site 4, Scurlock, 1979) and an unnamed site adjacent to the lower tributary (Site 10, Scurlock, 1979) (see Figure 2). Approximately 70% of the soil overexcavated from Pueblo Colorado Wash (for the rock mattress construction) can be used to construct large embankment fills to protect the archaeological site where shown on the drawings. This alternative will also require more soil reinforcement matting and hydromulching to reduce erosion of the new fill slopes. The gabion-type mattress is used in the alternative for erosion control along the Pueblo Colorado Wash channel. The engineer's cost estimate for this alternative reflects the use of conventional labor forces that may be employed by the contractor.

Alternative A-1 is similar to Alternative A with the exception that local labor forces are utilized to the fullest possible extent.

7.1.2 Alternatives B and B-1

Alternative B assumes complete mitigation of the archaeological resources potentially affected by the proposed construction will be performed by the National Park Service. With mitigation, large embankment fills to protect Sites 4 and 10 would not be required, thereby eliminating the need for seeding/hydromulching slopes other than natural slopes. Ninety percent of overexcavated soils from Pueblo Colorado Wash for the erosion control mattress construction will require disposal or stockpiling at a site to be designated. In addition, a substantial reduction in soil reinforcement matting would be permitted in this alternative. As in Alternatives A and A-1, the gabion-type erosion control mattress is utilized. The engineer's cost estimate for this alternative reflects the use of conventional labor forces that may be employed by the contractor.

Alternative B-1 is similar to Alternative B with the exception that local labor forces are utilized to the fullest possible extent.



7.1.3 Alternatives C and C-1

Alternative C is an unmitigated alternative which incorporated Alternative "A" (Section 7.1.1) work items with the exception that a wire mesh mattress is used in lieu of the gabion-type mattress for erosion control along Pueblo Colorado Wash.

Alternative C-1 is similar to Alternative C except that the engineer's cost estimate reflects the use of local labor forces to the fullest possible extent.

7.1.4 Alternative D and D-1

Alternative D is a mitigated alternative which incorporated Alternative B (Section 7.1.2) work items with the exception that a wire mesh mattress is used in lieu of the gabion mattress for erosion control along Pueblo Colorado Wash.

Alternative D-1 is similar to Alternative D except that the cost of using local labor forces is incorporated into the engineer's estimate.

7.2 Description of Work Items

7.2.1 Mobilization

This item shall include those activities performed by the contractor in preparation for the start of work. Such items may include the transport of personnel, equipment, and supplies to the site, establishing temporary site facilities, obtaining utilities, acquiring necessary permits, and paying premiums on bonds and insurance. Payment for this item will be made on a not-to-exceed contract lump price.

7.2.2 Demolition

This item shall include the removal of the existing gabion revetments located downstream from State Highway 264 bridge adjacent to the Wide Reed Archaeological site and the stockpiling of rock fill for later use. Also included is the removal and disposal of the old bridge timber piles

located in the channel area of Pueblo Colorado Wash north of the Trading Post complex. A temporary drop structure constructed downstream from the access road bridge will also require removal.

7.2.3 Excavation

This work shall consist of excavation of the main channel area in the vicinity of (1) the log-rock revetment; (2) the rock and wire mattress, and (3) the channelized wash downstream from the rock wire mattress. This item also includes removal and disposal of vegetation found in the cut areas and water necessary for effective dust control.

7.2.4 Embankment

This item applies to the construction of the embankments and/or fills necessary to (1) protect the archaeological resources, (2) provide limited bank fill behind the log-rock revetment, and (3) construct earthen erosion control berms. Embankments will be constructed in accordance with the mitigation plan selected by the National Park Service at the locations shown on the plan. Embankment construction would include the following tasks: (1) grubbing and scarifying the area to receive fills (no benching will be permitted); (2) placing soil in lifts no greater than 8 inches in thickness; (3) moisturizing the fill soil to aid in the densification (+ 3 percent of optimum moisture, based on ASTM D698); (4) compaction of the fill soil to a minimum relative density of 90 percent of maximum density determined from the standard Proctor-test ASTM D698 (compaction of embankment fill by flooding shall not be permitted).

7.2.5 Log-Rock Revetment

This item includes the construction of the log-rock revetment in the area shown on the plans to the approximate dimension shown on the details and includes preparation of the revetment foundation area and building of the wall. Materials would consist of the (1) debarked timbers 8 to 10 inches in diameter; (2) steel pins to join timbers; (3) rock fill consisting of crushed, durable, dense rock or river run material; (4) geotextile filter

fabric to encase the rock if the nominal rock size is less than the open space between facing logs.

7.2.6 Rock and Wire Mattress

This item includes the construction of the rock and wire mattress at the location shown on the plans and in accordance with the alternative adopted by the National Park Service. The first alternative includes the gabion-type wire baskets with crushed, durable, dense rock or river run material with a nominal diameter, as specified in Section 6.2.1. Each basket will be joined by wiring. Material will include gabion baskets, rock fill, and wire ties.

The second alternative would utilize a 4" x 4" galvanized welded wire mesh or chain link to encase the rock fill to minimum thickness of 1.5 feet in lieu of gabion baskets. Material would include the wire mesh or chain link tie wire, and rock fill.

7.2.7 Bedding/Filter Sand

Bedding for the rock and wire mattress shall be placed at the locations shown on the plans with a minimum thickness of 1 foot. The material shall be a select pervious mixture of well graded coarse grained material with the following gradation limits:

0.02 ins. <D₁₅ <0.16 ins.

0.22 ins. <D₅₀ <0.4 ins.

0.72 ins. <D₈₅

The construction operation would include the handling and placement in such a manner as to prevent particle segregation. Also included is a nominal amount of compaction and moisturizing to result in a uniform layer for bedding the mattress. Flooding may be used to compact the bedding if it contains less than 2 percent of non-plastic fines and if the water can be effectively drained prior to placing the mattress.



7.2.8 Rail-Jack String Deflectors

This item includes the construction of rail-jack deflectors and their placement at the locations shown on the plans and as directed by the engineer. Materials included in this item are: (1) rails, (2) cable, (3) anchor blocks, (4) wire, (5) drilling and cutting of holes and flanges in rails, and (6) hardware.

7.2.9 Soil Reinforcement Nylon Matting

This work shall consist of placing preformed matting on the embankment fill slopes or natural slope as shown on the drawings and as directed by the engineer. Where matting is placed on natural slopes, the heavy brush shall be removed prior to placement. Trees and large shrubs shall not be removed and the matting shall be placed around the tree or shrub. Material for this item of work will include (1) matting (Enkamat No. 7020, American Excelsior Co. or equal), and (2) stakes.

7.2.10 Seeding and Hydromulching

Work in this item will include the seeding and hydromulching of new embankment fill slopes and natural slopes where shown on the plans or as directed by the engineer. Seed shall consist of commercially available Western Wheat Grass and shall be placed at rates sufficient to provide a coverage of 10 pounds per acre. Fertilizer should be ammonium phosphate with 50 percent nitrogen (slow release form) spread at a rate of 4.5 pounds per 1,000 square feet. A hydromulch of good water holding capacity should be used at a rate to accommodate the required seed and fertilizer coverage. A newsprint-based hydromulch should be used such as Cal-Fiber, Astromulch, or Agrifiber. Equipment for mulching should be the gear-type pump and paddle agitation to avoid seed damage. Materials for this item include (1) seed, (2) fertilizer, and (3) mulch and water.

7.2.11 Drop Structure

The work shall consist of the construction of a reinforced concrete drop structure at the confluence of the Pueblo Colorado Wash and the upper tri-



butary at the approximate location shown on the plans. Work activities will include: (1) excavation of the foundation area, (2) forming, (3) placing reinforcing steel, (4) pouring foundation and wall, (5) cleaning and finishing, (6) backfilling necessary. Material would include forms, reinforcing bar (#4), coloring agent for concrete, and select backfill material.

7.2.12 Trash Rack

This item shall consist of constructing a trash rack structure for a 24 inch diameter corrugated metal pipe (CMP) culvert located off-site. The culvert provides drainage for the upstream area of the upper tributary through a roadway embankment fill constructed across the tributary. The work activities would include: (1) preparation of the culvert area, (2) excavating the foundation, (3) forming and reinforcing the walls, (4) pouring concrete, (5) building the gate, (6) backfilling as required with select material, and (7) painting. Material will include: concrete, reinforcing steel (#4 bars), forms, select backfill, steel bars for gate, and hardware.

7.2.13 Headwall Outlet

This item shall consist of construction of a headwall outlet structure for a 24 inch diameter CMP culvert (refer to Trash Rack discussion). Work components will include: (1) excavation, (2) formwork, (3) reinforcing, and (4) concrete placement. Materials will include: concrete, reinforcing steel (#4 bars), forms, and select backfill.

7.2.14 Structural Erosion Check Dams

Erosion control check dams will be constructed at various locations within the Historic Site where shallow gullies have or are forming. Construction activities will consist of staking the location of the dam where shown on the drawing and as directed by the engineer, according to Schedule of Check Dam Dimensions. Other activities will include: (1) excavating the keyway, (2) placement of timber, (3) staking or pinning timber for addi-



tional support, (4) backfilling, as required, with local soils, and (5) installation of energy dissipation materials. Construction materials will include railroad ties (or suitable alternative), heavy stakes or pins and dissipation materials (rock, branches, brush or woody slash that is locally available).

7.2.15 Disposal of Excess Excavation

This activity shall consist of the removal of excess excavation material from the construction site and placement of the material at a location acceptable to the National Park Service. Dust control, using occasional watering of the disposal site, will be required.

7.3 Preliminary Engineer's Cost Estimate of Construction Alternatives

The preliminary cost estimate(s) to construct the proposed structural control measures at the Hubbell Trading Post National Historic Site is based on the preferred alternative selected from the various erosion control opinions and described in detail in Section 6.0. Alternative items of work are provided which include the mitigation of the following archaeological sites:

- 1) Wide Reed Ruin,
- 2 Sand Dune Site, and an
- 3 unnamed site adjacent to the Lower Tributary.

A unit price schedule and alternative cost estimates are provided in Tables 11.



TABLE 11

(1 of 8)

ENGINEERS ESTIMATE - UNIT PRICE SCHEDULE
ALTERNATIVE A

HUBBELL TRADING POST NATIONAL HISTORIC SITE
EROSION CONTROL MEASURES

<u>Item No.</u>	<u>Item</u>	<u>Quantity & Amount of Measure</u>	<u>Unit Price</u>	<u>Extension</u>
1	Mobilization	Lump Sum	Not-to-exceed	\$ 6,000
2	Demolition	Lump Sum	Not-to-exceed	3,000
3	Excavation (common)	12,000 cu.yds.	\$ 2.50	30,000
4	Embankment Fill (common)	8,500 cu. yds.	4.00	34,000
5	Log-Rock Revetment	1,100 lin. ft.	110.00	121,000
6	Rock & Wire Mattress Gabion-Type	8,200 sq. yds.	33.50	274,700
7	Bedding/Filter Sand	3,600 cu. yds.	4.00	14,400
8	Rail-Jack String Deflectors	400 lin. ft.	15.00	6,000
9	Soil Reinforcement Nylon Mesh	8,000 sq. yds.	7.00	56,000
10	Seed & Hydromulching	7,500 sq. yds.	0.75	5,625
11	Drop Structure	1 each	Lump Sum	30,000
12	Trash Rack	1 each	Lump Sum	2,000
13	Headwall Outlet	1 each	Lump Sum	2,500
14	Structural Erosion Check Dam	75 each	145.00	10,875
15	Disposal of Excess Excavation	3,500 cu. yds.	3.00	10,500

Total Engineer's Estimate
Alternative A ----- \$606,600

TABLE 11

(2 of 8)

ENGINEERS ESTIMATE - UNIT PRICE SCHEDULE
ALTERNATIVE A-1

HUBBELL TRADING POST NATIONAL HISTORIC SITE
EROSION CONTROL MEASURES

<u>Item No.</u>	<u>Item</u>	<u>Quantity & Amount of Measure</u>	<u>Unit Price</u>	<u>Extension</u>
1	Mobilization	Lump Sum	Not-to-exceed	\$ 6,000
2	Demolition	Lump Sum	Not-to-exceed	3,000
3	Excavation (common)	12,000 cu.yds.	\$ 2.50	30,000
4	Embankment Fill (common)	8,500 cu. yds.	3.50	29,750
5	Log-Rock Revetment	1,100 lin. ft.	100.00	110,000
6	Rock & Wire Mattress Gabion-Type	8,200 sq. yds.	30.20	247,640
7	Bedding/Filter Sand	3,600 cu. yds.	4.00	14,400
8	Rail-Jack String Deflectors	400 lin. ft.	12.75	5,100
9	Soil Reinforcement Nylon Mesh	8,000 sq. yds.	5.85	46,800
10	Seed & Hydromulching	7,500 sq. yds.	0.75	5,625
11	Drop Structure	1 each	Lump Sum	30,000
12	Trash Rack	1 each	Lump Sum	1,500
13	Headwall Outlet	1 each	Lump Sum	2,000
14	Structural Erosion Check Dam	75 each	120.00	9,000
15	Disposal of Excess Excavation	3,500 cu. yds.	3.00	10,500

Total Engineer's Estimate
Alternative A-1 ----- \$551,315



TABLE 11

(3 of 8)

ENGINEERS ESTIMATE - UNIT PRICE SCHEDULE
ALTERNATIVE B

HUBBELL TRADING POST NATIONAL HISTORIC SITE
EROSION CONTROL MEASURES

<u>Item No.</u>	<u>Item</u>	<u>Quantity & Amount of Measure</u>	<u>Unit Price</u>	<u>Extension</u>
1	Mobilization	Lump Sum	Not-to-exceed	\$ 6,000
2	Demolition	Lump Sum	Not-to-exceed	3,000
3	Excavation (common)	12,000 cu.yds.	\$ 2.50	30,000
4	Embankment Fill (common)	1,000 cu. yds.	4.00	4,000
5	Log-Rock Revetment	1,100 lin. ft.	110.00	121,000
6	Rock & Wire Mattress Gabion-Type	8,200 sq. yds.	33.50	274,700
7	Bedding/Filter Sand	3,600 cu. yds.	4.00	14,400
8	Rail-Jack String Deflectors	400 lin. ft.	15.00	6,000
9	Soil Reinforcement Nylon Mesh	4,000 sq. yds.	7.00	28,000
10	Seed & Hydromulching	4,000 sq. yds.	0.75	3,000
11	Drop Structure	1 each	Lump Sum	30,000
12	Trash Rack	1 each	Lump Sum	2,000
13	Headwall Outlet	1 each	Lump Sum	2,500
14	Structural Erosion Check Dam	75 each	145.00	10,875
15	Disposal of Excess Excavation	11,000 cu. yds.	3.00	33,000

Total Engineer's Estimate
Alternative B ----- \$568,475



TABLE 11

(4 of 8)

ENGINEERS ESTIMATE - UNIT PRICE SCHEDULE
ALTERNATIVE B-1

HUBBELL TRADING POST NATIONAL HISTORIC SITE
EROSION CONTROL MEASURES

<u>Item No.</u>	<u>Item</u>	<u>Quantity & Amount of Measure</u>	<u>Unit Price</u>	<u>Extension</u>
1	Mobilization	Lump Sum	Not-to-exceed	\$ 6,000
2	Demolition	Lump Sum	Not-to-exceed	3,000
3	Excavation (common)	12,000 cu.yds.	\$ 2.50	30,000
4	Embankment Fill (common)	1,000 cu. yds.	3.50	3,500
5	Log-Rock Revetment	1,100 lin. ft.	100.00	110,000
6	Rock & Wire Mattress Gabion-Type	8,200 sq. yds.	30.20	247,640
7	Bedding/Filter Sand	3,600 cu. yds.	4.00	14,400
8	Rail-Jack String Deflectors	400 lin. ft.	12.75	5,100
9	Soil Reinforcement Nylon Mesh	4,000 sq. yds.	5.85	23,400
10	Seed & Hydromulching	4,000 sq. yds.	0.75	3,000
11	Drop Structure	1 each	Lump Sum	30,000
12	Trash Rack	1 each	Lump Sum	1,500
13	Headwall Outlet	1 each	Lump Sum	2,000
14	Structural Erosion Check Dam	75 each	120.00	9,000
15	Disposal of Excess Excavation	11,000 cu. yds.	3.00	33,000

Total Engineer's Estimate
Alternative B-1----- \$521,540

TABLE 11

(5 of 8)

ENGINEERS ESTIMATE - UNIT PRICE SCHEDULE
ALTERNATIVE C

HUBBELL TRADING POST NATIONAL HISTORIC SITE
EROSION CONTROL MEASURES

<u>Item No.</u>	<u>Item</u>	<u>Quantity & Amount of Measure</u>	<u>Unit Price</u>	<u>Extension</u>
1	Mobilization	Lump Sum	Not-to-exceed	\$ 6,000
2	Demolition	Lump Sum	Not-to-exceed	3,000
3	Excavation (common)	12,000 cu.yds.	\$ 2.50	30,000
4	Embankment Fill (common)	8,500 cu. yds.	4.00	34,000
5	Log-Rock Revetment	1,100 lin. ft.	110.00	121,000
6	Rock & Wire Mattress Wire Mesh/Chainlink	9,500 sq. yds.	13.15	124,925
7	Bedding/Filter Sand	3,600 cu. yds.	4.00	14,400
8	Rail-Jack String Deflectors	400 lin. ft.	15.00	6,000
9	Soil Reinforcement Nylon Mesh	8,000 sq. yds.	7.00	56,000
10	Seed & Hydromulching	7,500 sq. yds.	0.75	5,625
11	Drop Structure	1 each	Lump Sum	30,000
12	Trash Rack	1 each	Lump Sum	2,000
13	Headwall Outlet	1 each	Lump Sum	2,500
14	Structural Erosion Check Dam	75 each	145.00	10,875
15	Disposal of Excess Excavation	3,500 cu. yds.	3.00	10,500

Total Engineer's Estimate
Alternative C ----- \$456,825

TABLE 11

(6 of 8)

ENGINEERS ESTIMATE - UNIT PRICE SCHEDULE
ALTERNATIVE C-1

HUBBELL TRADING POST NATIONAL HISTORIC SITE
EROSION CONTROL MEASURES

<u>Item No.</u>	<u>Item</u>	<u>Quantity & Amount of Measure</u>	<u>Unit Price</u>	<u>Extension</u>
1	Mobilization	Lump Sum	Not-to-exceed	\$ 6,000
2	Demolition	Lump Sum	Not-to-exceed	3,000
3	Excavation (common)	12,000 cu.yds.	\$ 2.50	30,000
4	Embankment Fill (common)	8,500 cu. yds.	3.50	29,750
5	Log-Rock Revetment	1,100 lin. ft.	100.00	110,000
6	Rock & Wire Mattress Wire Mesh/Chainlink	9,500 sq. yds.	12.95	123,025
7	Bedding/Filter Sand	3,600 cu. yds.	4.00	14,400
8	Rail-Jack String Deflectors	400 lin. ft.	12.75	5,100
9	Soil Reinforcement Nylon Mesh	8,000 sq. yds.	5.85	46,800
10	Seed & Hydromulching	7,500 sq. yds.	0.75	5,625
11	Drop Structure	1 each	Lump Sum	30,000
12	Trash Rack	1 each	Lump Sum	1,500
13	Headwall Outlet	1 each	Lump Sum	2,000
14	Structural Erosion Check Dam	75 each	120.00	9,000
15	Disposal of Excess Excavation	3,500 cu. yds.	3.00	10,500

Total Engineer's Estimate
Alternative C-1 ----- \$426,700



TABLE 11

(7 of 8)

ENGINEERS ESTIMATE - UNIT PRICE SCHEDULE
ALTERNATIVE D

HUBBELL TRADING POST NATIONAL HISTORIC SITE
EROSION CONTROL MEASURES

<u>Item No.</u>	<u>Item</u>	<u>Quantity & Amount of Measure</u>	<u>Unit Price</u>	<u>Extension</u>
1	Mobilization	Lump Sum	Not-to-exceed	\$ 6,000
2	Demolition	Lump Sum	Not-to-exceed	3,000
3	Excavation (common)	12,000 cu.yds.	\$ 2.50	30,000
4	Embankment Fill (common)	1,000 cu. yds.	4.00	4,000
5	Log-Rock Revetment	1,100 lin. ft.	110.00	121,000
6	Rock & Wire Mattress Wire Mesh/Chainlink	9,500 sq. yds.	13.15	124,925
7	Bedding/Filter Sand	3,600 cu. yds.	4.00	14,400
8	Rail-Jack String Deflectors	400 lin. ft.	15.00	6,000
9	Soil Reinforcement Nylon Mesh	4,000 sq. yds.	7.00	28,000
10	Seed & Hydromulching	4,000 sq. yds.	0.75	3,000
11	Drop Structure	1 each	Lump Sum	30,000
12	Trash Rack	1 each	Lump Sum	2,000
13	Headwall Outlet	1 each	Lump Sum	2,500
14	Structural Erosion Check Dam	75 each	145.00	10,875
15	Disposal of Excess Excavation	11,000 cu. yds.	3.00	33,000

Total Engineer's Estimate
Alternative D ----- \$418,700

TABLE 11

(8 of 8)

ENGINEERS ESTIMATE - UNIT PRICE SCHEDULE
ALTERNATIVE D-1

HUBBELL TRADING POST NATIONAL HISTORIC SITE
EROSION CONTROL MEASURES

<u>Item No.</u>	<u>Item</u>	<u>Quantity & Amount of Measure</u>	<u>Unit Price</u>	<u>Extension</u>
1	Mobilization	Lump Sum	Not-to-exceed	\$ 6,000
2	Demolition	Lump Sum	Not-to-exceed	3,000
3	Excavation (common)	12,000 cu.yds.	\$ 2.50	30,000
4	Embankment Fill (common)	1,000 cu. yds.	3.50	3,500
5	Log-Rock Revetment	1,100 lin. ft.	100.00	110,000
6	Rock & Wire Mattress Wire Mesh/Chainlink	9,500 sq. yds.	12.95	123,025
7	Bedding/Filter Sand	3,600 cu. yds.	4.00	14,400
8	Rail-Jack String Deflectors	400 lin. ft.	12.75	5,100
9	Soil Reinforcement Nylon Mesh	4,000 sq. yds.	5.85	23,400
10	Seed & Hydromulching	4,000 sq. yds.	0.75	3,000
11	Drop Structure	1 each	Lump Sum	30,000
12	Trash Rack	1 each	Lump Sum	1,500
13	Headwall Outlet	1 each	Lump Sum	2,000
14	Structural Erosion Check Dam	75 each	120.00	9,000
15	Disposal of Excess Excavation	11,000 cu. yds.	3.00	33,000

Total Engineer's Estimate
Alternative D-1 ----- \$396,925

8.0 IMPACTS OF EROSION CONTROL MEASURES

In order to assess the effectiveness of the proposed erosion control measures, hydraulic and aggradation analyses were conducted on the modified channel of the Pueblo Colorado Wash. The hydraulic analyses again required data on the channel geometry and roughness characteristics. In addition, the channel aggradation/degradation analysis required data on channel bed and bank sediment characteristics, sediment discharge relationships, and streamflow characteristics.

The geometry of the designed channels was obtained from the sections and plans presented in Section 7, Plate 4. The roughness characteristics of the modified channels were calculated from published literature. Sediment data for the Pueblo Colorado Wash were collected during the field program and are summarized in Table 3. Sediment discharge relationship and flow hydrographs were not available for the Pueblo Colorado Wash and had to be estimated, based on published data for other streams in the region.

A summary of the hydraulic characteristics of the modified channel during a 25-year flood event is presented in Table 12. This analysis indicates that channel velocities will be lower for the modified channel than exist in the present channel. This decline is a consequence of both the lower channel gradients at the location of the knickpoint and adjacent to the Trading Post, and the increased resistance to flow offered by the log-rock revetment and rockfill channel liner. This decline in velocity is especially noticeable in the bank areas where the control structures and natural vegetation cover to the north of the wash most dramatically increase the resistance of flow.

The channel is designed to contain a 25-year recurrence interval flow. However, if this is exceeded and flow occurs in the overbank areas, the low velocities which have been calculated indicate that scour would be limited.

Downstream of the rockfill lining, the stability of the channel bed has been evaluated using the HEC-6 scour and deposition. Extensive calibration of this model was not possible because of the lack of discharge and sediment transport data. However, a preliminary analysis does indicate that, with the flow velocities calculated for the design channel, the wash appears to be significantly



TABLE 12

PRELIMINARY SUMMARY OF CHANNEL HYDRAULICS
FOR 25-YEAR RECURRENCE INTERVAL FLOW
IN MODIFIED CHANNEL OF
PUEBLO COLORADO WASH

<u>Section Number</u>	<u>Water Surface Elevation (ft. msl)</u>	<u>Maximum Depth of Flow (ft)</u>	<u>Discharge (cfs)</u>	<u>Left Overbank Velocity (ft/s)</u>	<u>Channel Velocity (ft/s)</u>	<u>Right Overbank Velocity (ft/s)</u>
5	6314.2	11.2	12494	4.2	6.8	0.0
6	6316.3	11.7	12494	3.9	8.5	3.2
7	6317.6	10.0	12494	0.0	10.6	0.5
8	6319.1	9.7	11717	0.0	15.8	0.0
9	6323.2	9.1	11717	0.0	15.4	5.1

more stable than under existing hydraulic conditions. This analysis can be regarded as conservative, as neither the HEC-6 nor HEC-2 programs can simulate the declines in discharge and velocity which are associated with the increased transmission losses in the lower reaches of the Pueblo Colorado.



9.0 LABORATORY TESTING

Bulk soil samples were collected at 18 representative locations. Sixteen of the samples were collected within or adjacent to the Pueblo Colorado Wash or the Upper Tributary, and two additional bulk samples were collected along the centerline of the main access road (Table 13).

Laboratory tests were performed on the samples to provide parameters for input into calculations used in the design of erosion control measures in the channels, and to evaluate the potential effects of the control measures on the aggradational/degradational processes. The following laboratory tests were performed:

- ° Particle size analysis (method: ASTM D422),
- ° Atterberg limits (methods: ASTM D423 and ASTM D424; performed to determine plasticity index and liquid limit), and
- ° Hydrometer test (ASTM D422; performed to determine the percent of silt and clay fines).

The records of the laboratory tests are listed on Table 13. Gradation curves for the particle size analysis are presented in Figures 7 to 11.



TABLE 13

LABORATORY SOIL TEST RESULTS

Sample ¹ No.	Cross Section No.	Other Locations	Gradation				Atterberg Limits		USCS Soil Type ⁴
			Gravel (%)	Sand (%)	Silt & Clay (%)	D ₅₀ ² (mm)	Liquid Limit	Plasticity Index	
1	13 ⁵	Lowest Terrace S.E.	1	53	46	0.09	25	10	SC
2	13 ⁵	Top of S.E. Bank	0	71	29	0.1			SM
3	13 ⁵	Stream Bed	3	94	3	0.37			SP
4	9	North Bank Below Lowest Terrace	0	81	19	0.16			SM
5	9	Stream Bed, Sediment Over Shallow Rock	0	99	1	0.35			SP
6	14	Stream Bed, Upper Tributary	0	58	42	0.09	23	7	SM-SC
7	14	Lowest Terrace, Upper Tributary	0	31	69	0.005			CL ³
8	15	Fill Under Wooden Bridge	47	36	17	7			GP-GM
9		Stream Bed, Upper Tributary	0	89	11	0.25			SP-SM
10		Point Bar, Upper Tributary	0	87	13	0.19			SM
11	9	Rock Ledge, Stream Bed - Fine Silty Sandstone							
12	8	Chinle Formation, Stream Bed - Mudstone	0	10	90	0.0009	71	45	CH ³
13	7	Bank, 3' Above Stream Bed	0	50	50	0.08	32	15	SC-CL
14	5	Stream Bed	0	49	51	0.07	28	13	CL
15	5	Second Terrace, Toward South	0	87	13	0.18			SM
16	4	Bank, 6' From Stream Bed	0	81	9	0.22			SP-SM
17		Access Road, 105' East of Visitors Center	1	83	16	0.15	--	NP	SM
18		Access Road, 150' West of Bridge	2	82	16	0.19	--	NP	SM

¹Bulk samples were collected at depths of 0 to 6".²D₅₀ = mean particle diameter.³Hydrometer tests performed.⁴Soil classification aided by visual estimation where Atterberg limits or hydrometer tests were not performed.⁵Cross section 13 is located about 100 feet upstream from Highway 264 bridge.

10.0 GLOSSARY

<u>Agatized</u>	Replaced by silica which forms a waxy, color banded quartz deposit in the case of petrified wood.
<u>Aggradation</u>	The process of building up the grade or slope of the earth by sediment depositon.
<u>Alluvial</u>	Pertaining to fresh water deposited sediments, especially stream deposits, but including alluvial fans, lake deposits, and deposits of estuaries.
<u>Alluvial Fan</u>	A cone shaped deposit of alluvium made by a stream where it runs out onto a level plain or meets a slower stream.
<u>Anthropogenic</u>	Influenced by or formed by man.
<u>Anticline</u>	A fold that is convex upward or had such an attitude at some stage of development.
<u>Arroyo</u>	The channel of an ephemeral or intermittent stream, usually with vertical banks of unconsolidated material 2 feet or more high.
<u>Atterberg Limits</u>	Mechanical tests performed to determine the physical properties of silt and clay-sized sediments.
<u>Badlands</u>	Highly eroded and actively eroding landforms which are highly dissected and commonly devoid of vegetation.
<u>Bentonite</u>	A clay formed from the decomposition of volcanic ash.
<u>Colluvium</u>	Loose and incoherent deposits, usually at the foot of a slope or cliff, which are brought there chiefly by gravity.
<u>Conglomerate</u>	Rounded water-worn deposits of pebbles or larger rocks which are cemented together.
<u>Cross Stratification</u>	The arrangement of layers at one or more angles to the dip direction of the formation.
<u>Climbing Ripple Laminations</u>	Undulating surface layers created in loose sediments by water currents. Layers are less than one centimeter thick and ripple crests are offset in a vertical succession.
<u>Degradation</u>	Lowering of the land surface by erosive processes, commonly sediment removal by stream erosion.
<u>Eolian</u>	Deposits transported or eroded by wind action.

<u>Era</u>	A large division of geologic time which is comprised of geologic periods.
<u>Flood Plain</u>	The portion of a stream valley which is covered with water when the stream overflows its banks at flood stage.
<u>Formation</u>	The primary rock-stratigraphic unit described in geology and used for mapping or description.
<u>Fluvial</u>	Pertaining to rivers or streams and their deposits.
<u>Gabion</u>	Baskets of coarse wire mesh filled with stone and rocks, which are placed to prevent erosion.
<u>Geomorphology</u>	Study of the surface form of the earth, land forms, and the changes that take place in the evolution of land forms.
<u>Groin</u>	Structure designed to prevent erosion of the channel bank or shore, usually narrow in width and extends outward from the bank or shore.
<u>Header</u>	Log beams perpendicular to the channel in a log-rock revetment.
<u>Hydrometer Test</u>	Grain size analysis test used to determine the diameter of silt and clay-sized particles based upon the settling of particles in water.
<u>Knickpoint</u>	Point of abrupt change in the longitudinal profile of stream valleys.
<u>Lagoonal</u>	Pertaining to deposition in a body of shallow water which possesses a restricted connection with the sea.
<u>Loam</u>	Soil composed of a mixture of sand, silt, clay, and organic matter.
<u>Manning's "n" Roughness Coefficient</u>	Factor representing the average roughness (irregularities) of stream channel materials, which is used in the Manning's Equation to determine the average velocity of steamflow.
<u>Member</u>	A division of a formation, generally of distinct lithologic character.
<u>Monocline</u>	Step-like fold flexure in which beds which are horizontal at one point dip in one direction.
<u>Mudstone</u>	Sedimentary rock consisting primarily of silt and clay in which there is doubt to the exact proportion of silt to clay.



<u>Normal Fault</u>	Fault in which one side is down dropped along a high angle plane relative to the other side.
<u>Period</u>	A major, world-wide, standard geologic time unit corresponding to a system (rocks formed during a specific period).
<u>Physiographic</u>	Pertaining to the study of the genesis and evolution of land forms.
<u>Point Bar Deposit</u>	Sediment deposit on the inside curve of a growing stream meander loop.
<u>Reach</u>	An extended portion of water, such as a portion of a river or stream.
<u>Regression Residuals</u>	Trend reflecting the average fluctuation of rainfall above or below the regression line for this study.
<u>Revetment</u>	A structural armoring constructed along a slope or bank to prevent erosion or mass movement.
<u>Scour</u>	Erosion by moving water.
<u>Sinuosity</u>	Winding pattern.
<u>Stage</u>	The time stratigraphic unit next in order below a series, roughly corresponds to rocks forming during a certain epoch.
<u>Syncline</u>	A fold in rocks in which the strata dip inward from both sides toward the axis.
<u>Terrace</u>	A stream terrace is a relatively flat surface bounded by a steeper descending slope on the streamward side. Typically, terraces are step-like in character.
<u>Terrace Tread</u>	Flat, top part of a terrace.
<u>Thalweg</u>	The line joining the deepest parts of a stream channel.
<u>Trapezoidal</u>	Shaped like a trapezoid.
<u>Tuff</u>	A rock formed of compacted volcanic fragments, generally smaller than 4 mm. in diameter.
<u>Unconformity</u>	A surface of erosion or nondeposition, usually the former, that separates younger strata from older rocks.



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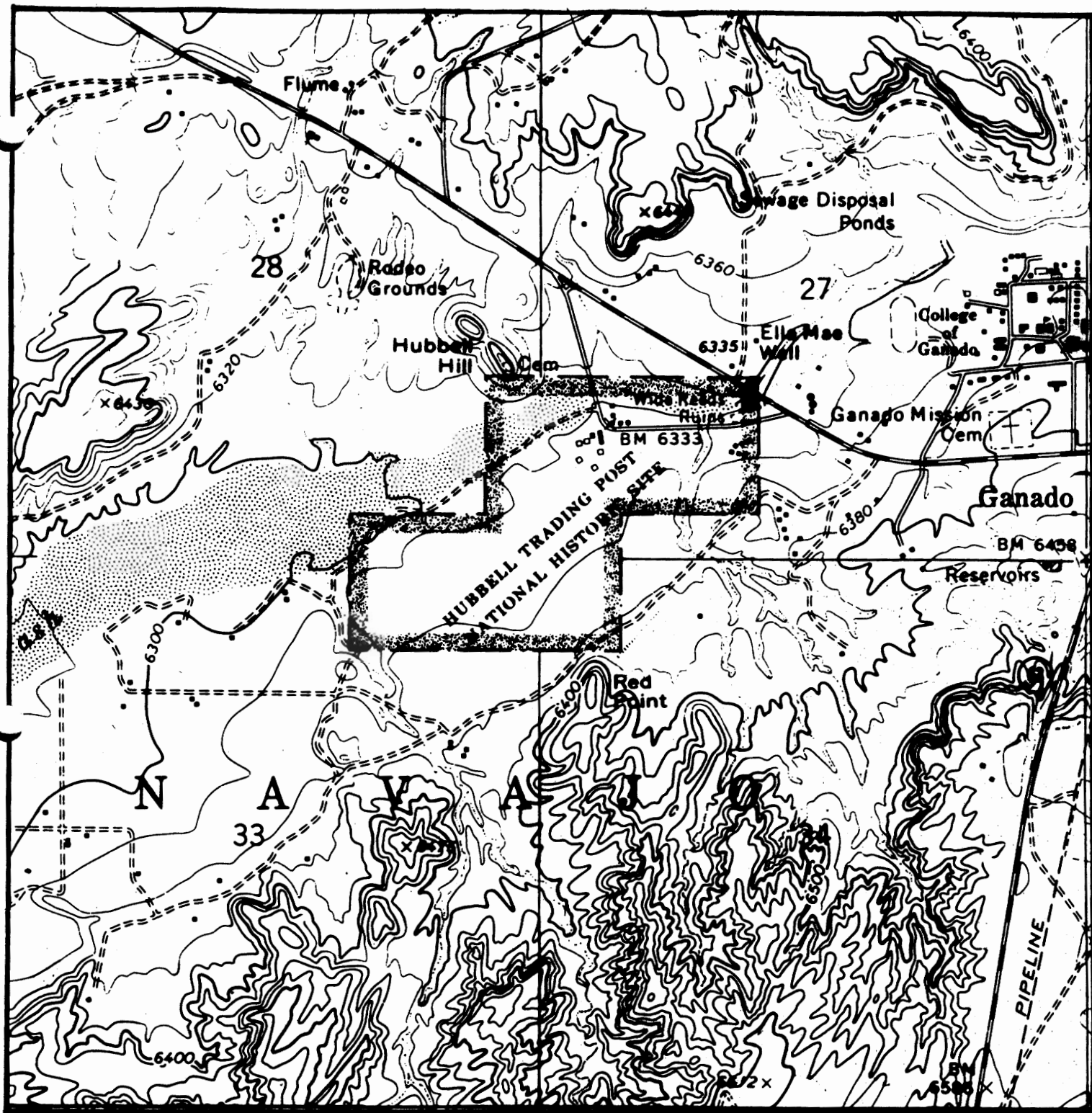
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0 ¼ ½ mile



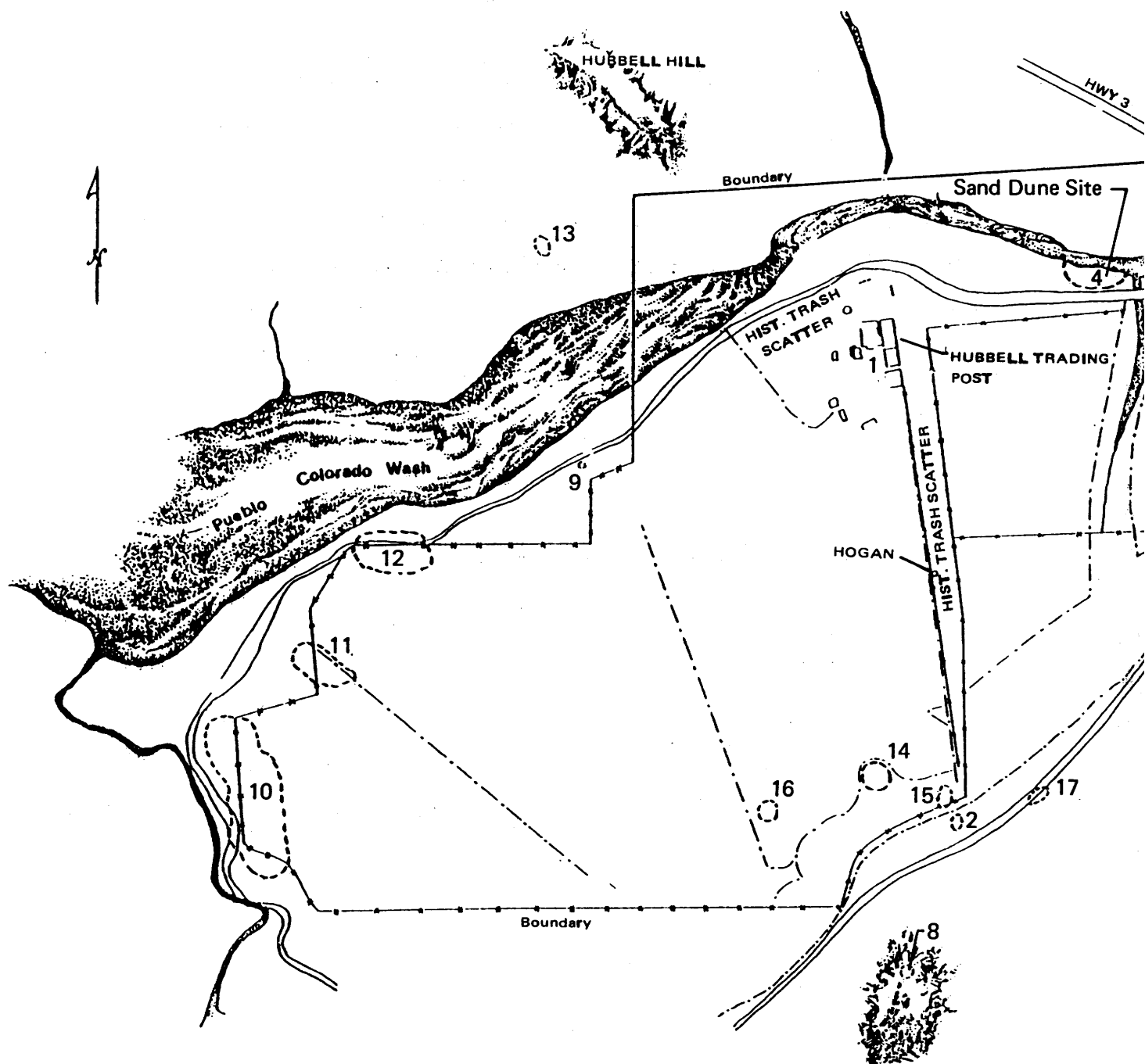
X Approximate Site Location



The Earth Technology Corporation

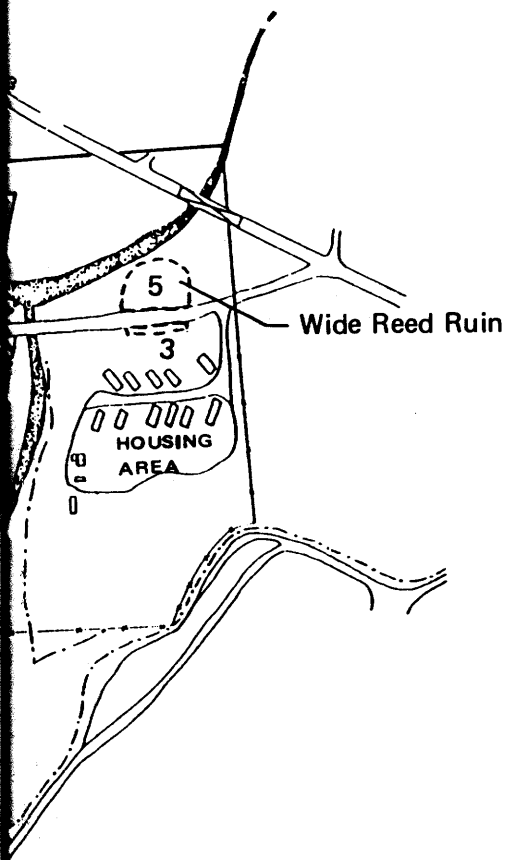
**HUBBELL TRADING POST
NATIONAL HISTORIC SITE
EROSION STUDY**

**LOCATION MAP
Figure 1**



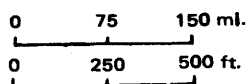
* From Scurlock, D., 1979 An Archaeological Assessment
Of Hubbell Trading Post Natl. Hist. Site.

ARCHAEOLOGICAL SITES AT THE HUBBELL TRADING POST NATIONAL HISTORIC SITE



Site No.	Cultural Affiliation	Site Area (m)
1	Historic Anglo-American, Navajo	42,273 m. ²
2	Prehistoric Pueblo	66 m. ²
3	Pueblo III ?	224 m. ²
4	Prehistoric Pueblo - Historic Navajo	1,671 m. ²
5	Pueblo III	1,347 m. ²
8	Pueblo II - Pueblo III -- Possible Navajo Component	29 m. ²
9	Pueblo I	57 m. ²
10	Basketmaker III - Pueblo I	11,148 m. ²
11	Pueblo III	2,318 m. ²
12	Pueblo I -- 18th or 19th - Century Navajo Component	3,830 m. ²
13	Basketmaker II or III	392 m. ²
14	Pueblo I -- III	1,970 m. ²
15	Navajo Hogan?	450 m. ²
16	Prehistoric Pueblo	308 m. ²
17	Prehistoric Pueblo	450 m. ²

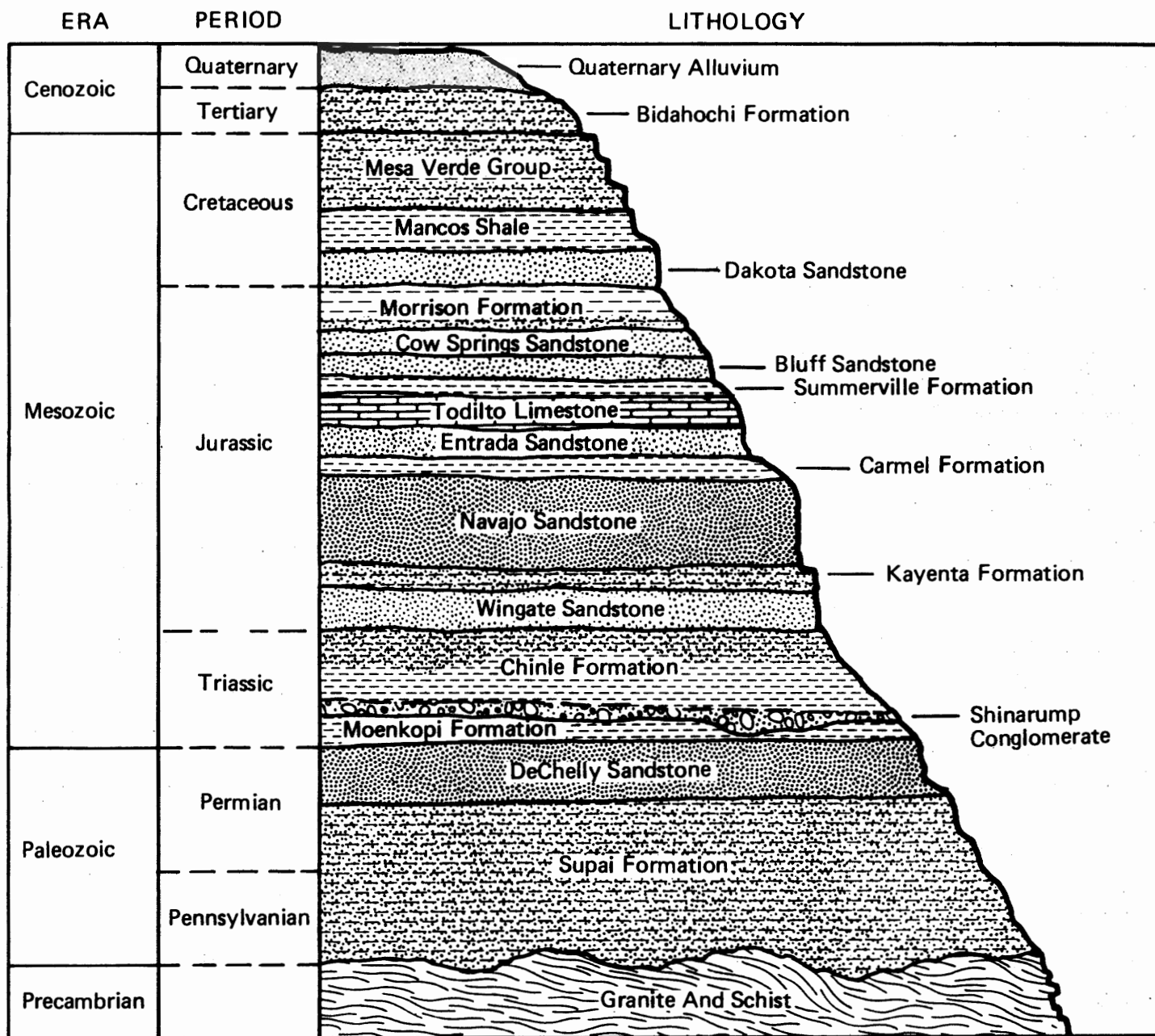
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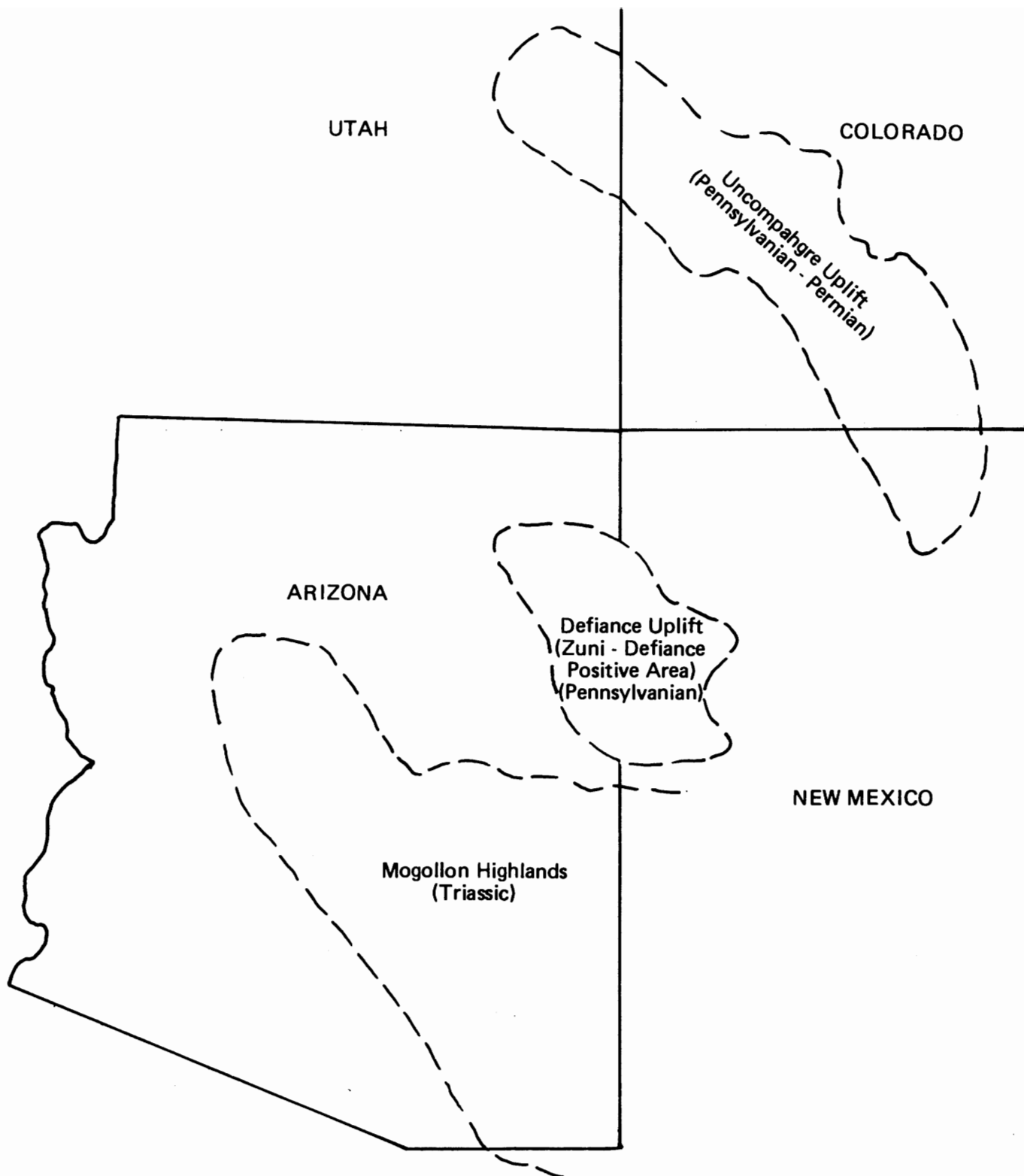
- SITE
- BARBED WIRE FENCE
- IRRIGATION DITCH

 The Earth Technology Corporation	HUBBELL TRADING POST NATIONAL HISTORIC SITE EROSION STUDY
ARCHAEOLOGICAL SITES AT HUBBELL Figure 2	

GENERALIZED STRATIGRAPHY FOR DEFIANCE PLATEAU,
ARIZONA - NEW MEXICO



 The Earth Technology Corporation	HUBBELL TRADING POST NATIONAL HISTORIC SITE EROSION STUDY
GENERALIZED STRATIGRAPHY DEFIANCE PLATEAU, ARIZONA - NEW MEXICO Figure 3	



Note:

Time periods indicate approximate location of uplifted area during noted periods. Uplifted areas prevailed over longer time periods but locations varied.

Modified from Nations, D. and Stump, E., 1981; Blakey, R., 1980; and Rascoe, B. and Baars, D., 1972.

 The Earth Technology Corporation	HUBBELL TRADING POST NATIONAL HISTORIC SITE EROSION STUDY
PALEOGEOGRAPHIC UPLIFTED AREAS APPROXIMATE LOCATION Figure 4	

UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

COARSE-GRAINED SOIL

MORE THAN 50% LARGER THAN 200 SIEVE SIZE

		DESCRIPTION	MAJOR DIVISIONS
	GW	WELL-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LESS THAN 5% - 200 FINES	GRAVELS More than half of coarse fraction is larger than No. 4 sieve size.
	GP	POORLY GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LESS THAN 5% - 200 FINES	
	GM	SILTY GRAVELS GRAVEL-SAND-SILT MIXTURES, MORE THAN 12% - 200 FINES	
	GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES, MORE THAN 12% - 200 FINES	SANDS More than half of coarse fraction is smaller than No. 4 sieve size.
	SW	WELL-GRADED SANDS OR GRAVELLY SANDS, LESS THAN 5% - 200 FINES	
	SP	POORLY-GRAINED SANDS OR GRAVELLY SANDS, LESS THAN 5% - 200 FINES	
	SM	SILTY SANDS, SAND-SILT MIXTURES MORE THAN 12% - 200 FINES	
	SC	CLAYEY SANDS, SAND-CLAY MIXTURES MORE THAN 12% - 200 FINES	

NOTE - Soils with 5 to 12 percent minus 200 fines should be classified with dual symbols.

FINE-GRAINED SOIL

MORE THAN 50% SMALLER THAN 200 SIEVE SIZE

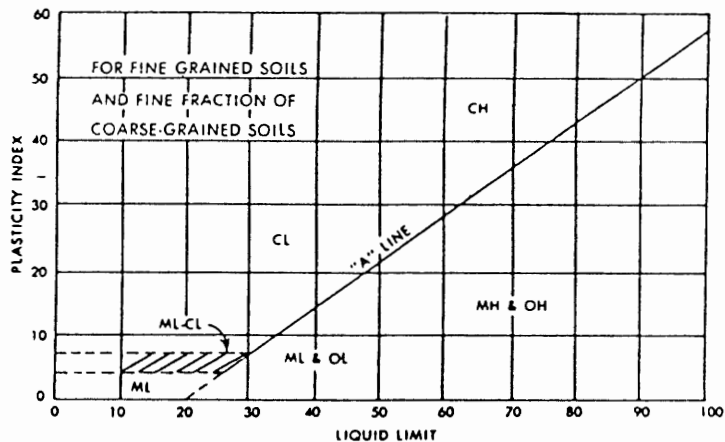
		DESCRIPTION	MAJOR DIVISIONS
	ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY	SILTS AND CLAYS Liquid limit less than 50
	CL	INORGANIC DCLAYS OR LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS	
	OL	ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY	
	MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS	SILTS AND CLAYS Liquid limit greater than 50
	CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS	
	OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS	
	PT	PEAT AND OTHER HIGHLY ORGANIC SOILS	

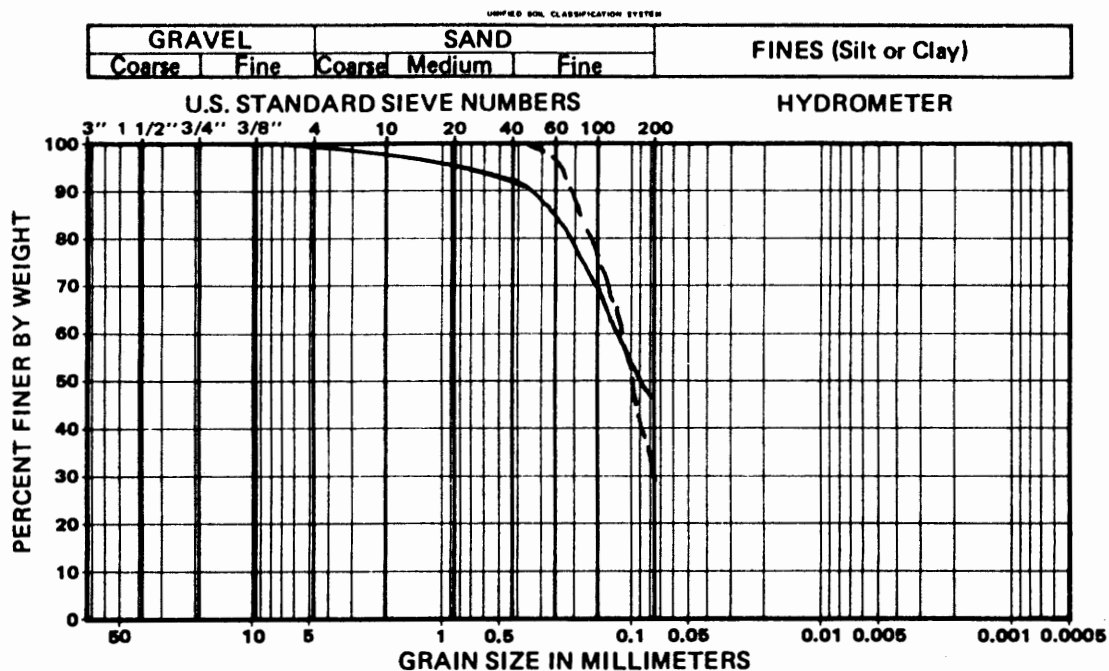
SOIL FRACTIONS

Component	Size Range
Boulders	Above 12 in.
Cobbles	3 in. to 12 in.
Gravel	3 in. to No. 4 sieve
Coarse Gravel	3 in to 3/4 in.
Fine gravel	3/4 in. to No. 4 sieve
Sand	No. 4 to No. 200
Coarse	No. 4 to No. 10
Medium	No. 10 to No. 40
Fine	No. 40 to No. 200
Fines (silt or clay)	Below No. 200 sieve

FROM: ASTM D-2487

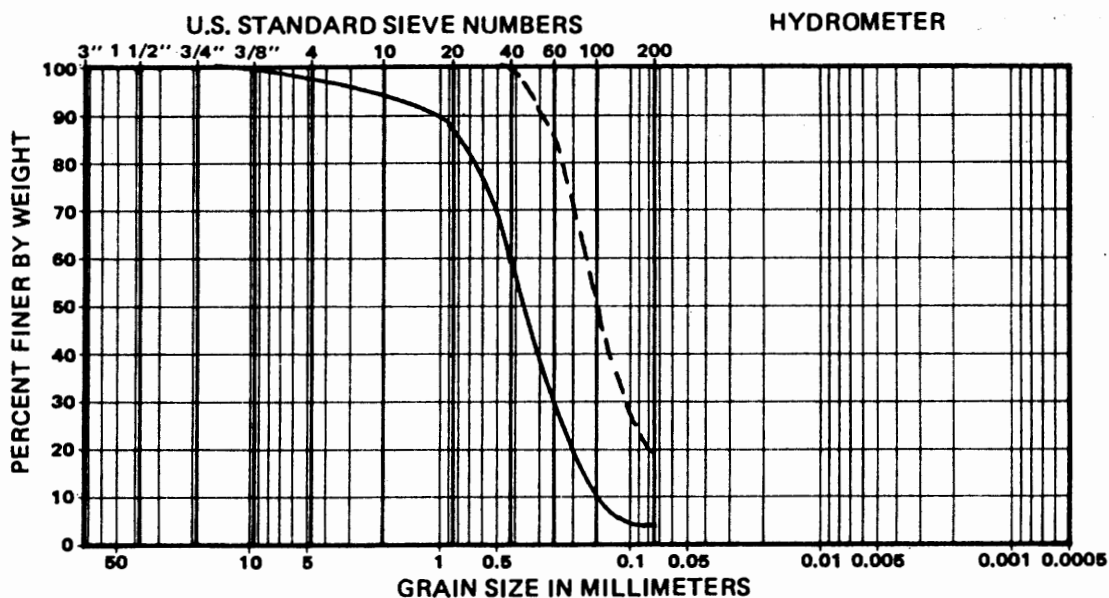
PLASTICITY CHART





SYMBOL	X-SECT. NUMBER	SAMPLE NUMBER	DEPTH (FEET)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
—	13	1	0 - 0.5	25	15	10	SC
- -	13	2	0 - 0.5				SM

Lowest Terrace S.E.
Top Bank S.E.



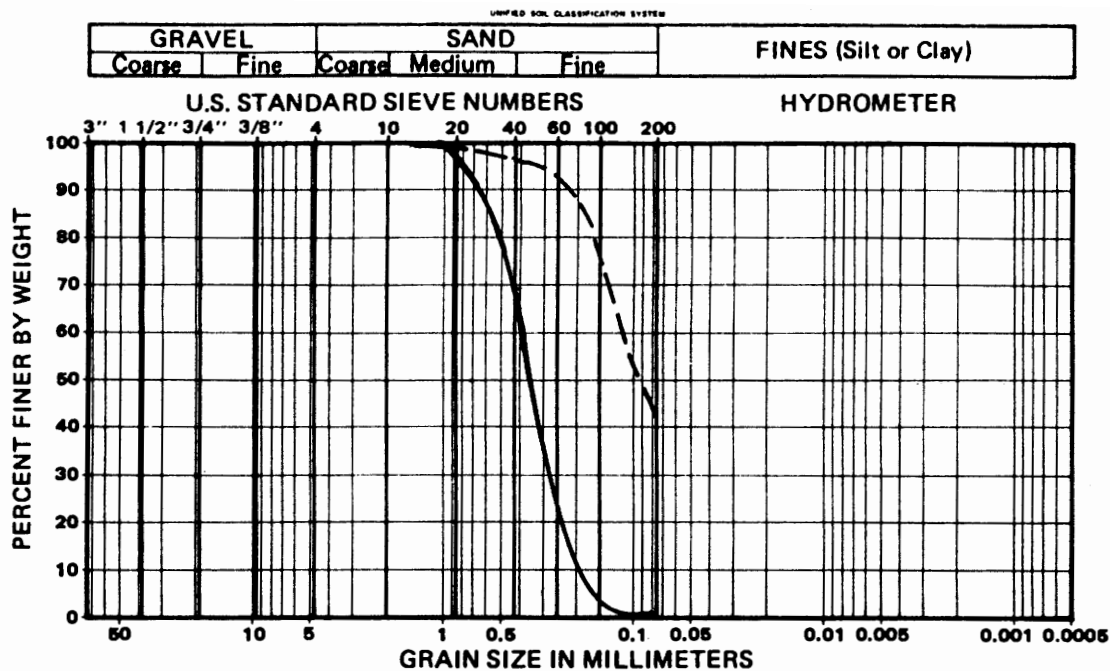
SYMBOL	X-SECT. NUMBER	SAMPLE NUMBER	DEPTH (FEET)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
—	13	3	0 - 0.5				SP
- -	9	4	0 - 0.5				SM

Stream Bed
Banks Below First
Terrace.

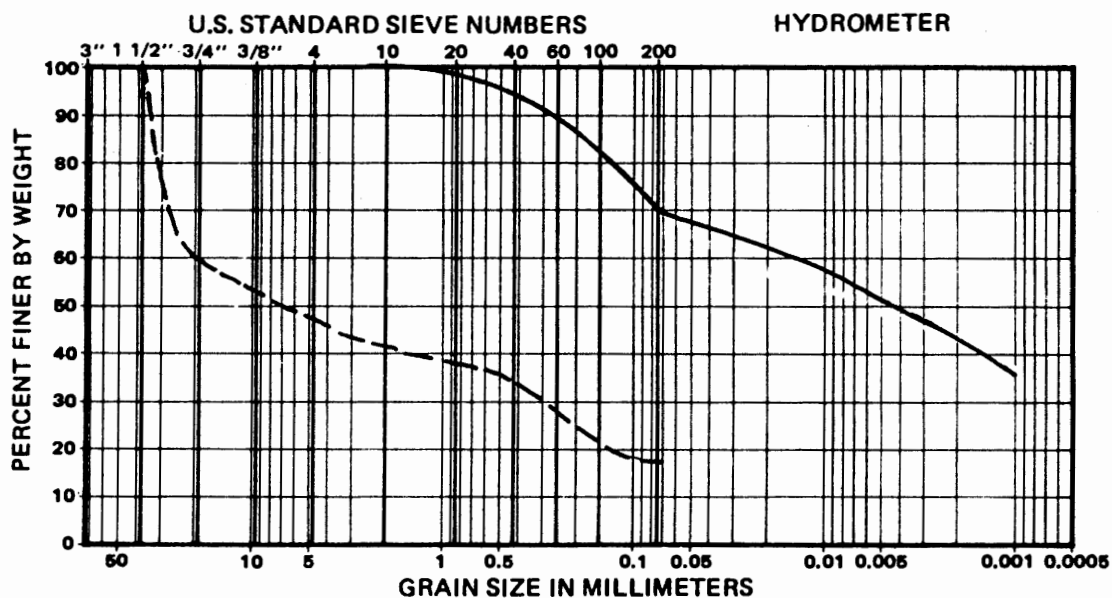


HUBBELL TRADING POST
NATIONAL HISTORIC SITE
EROSION STUDY

GRADATION AND ATTERBERG LIMITS
TEST RESULTS
Figure 7



SYMBOL	X-SECT. NUMBER	SAMPLE NUMBER	DEPTH (FEET)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE	
—	9	5	0 - 0.5				SP	Bed
- -	14	6	0 - 0.5	23	16	7	SM-SC	Bed

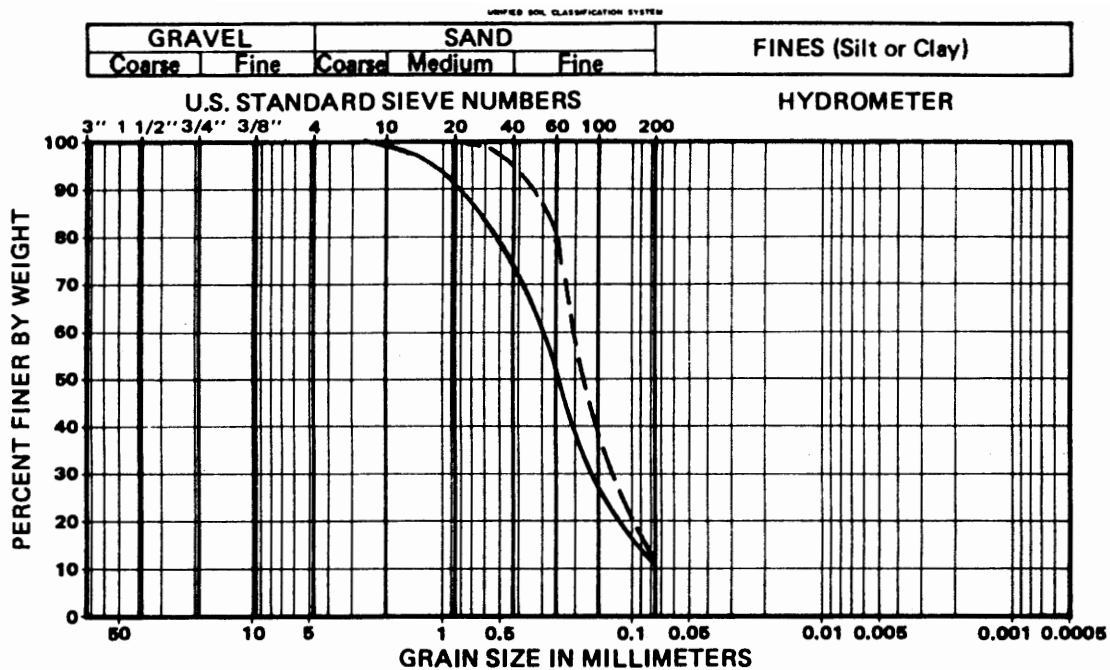


SYMBOL	X-SECT. NUMBER	SAMPLE NUMBER	DEPTH (FEET)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE	
—	14	7	0 - 0.5				CL	Bank on lowest terrace
- -	15	8	0 - 0.5				GP-SM	Fill under wood bridge



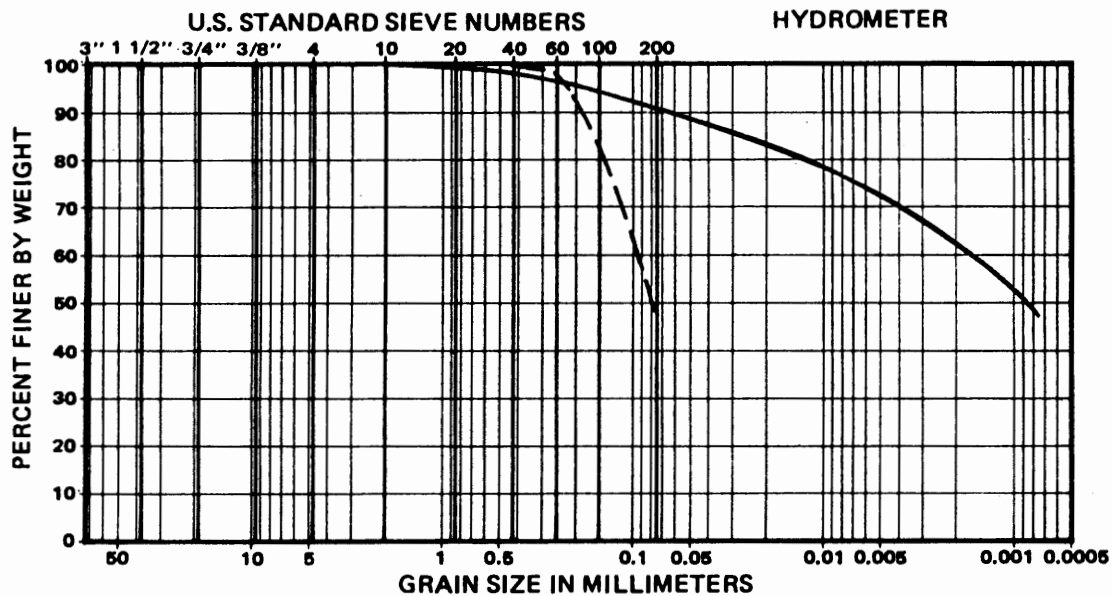
HUBBELL TRADING POST
NATIONAL HISTORIC SITE
EROSION STUDY

GRADATION AND ATTERBERG LIMITS
TEST RESULTS
Figure 8



SYMBOL	X-SECT. NUMBER	SAMPLE NUMBER	DEPTH (FEET)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
—	13	9	0 - 0.5				SP-SM
- -	13	10	0 - 0.5				SM

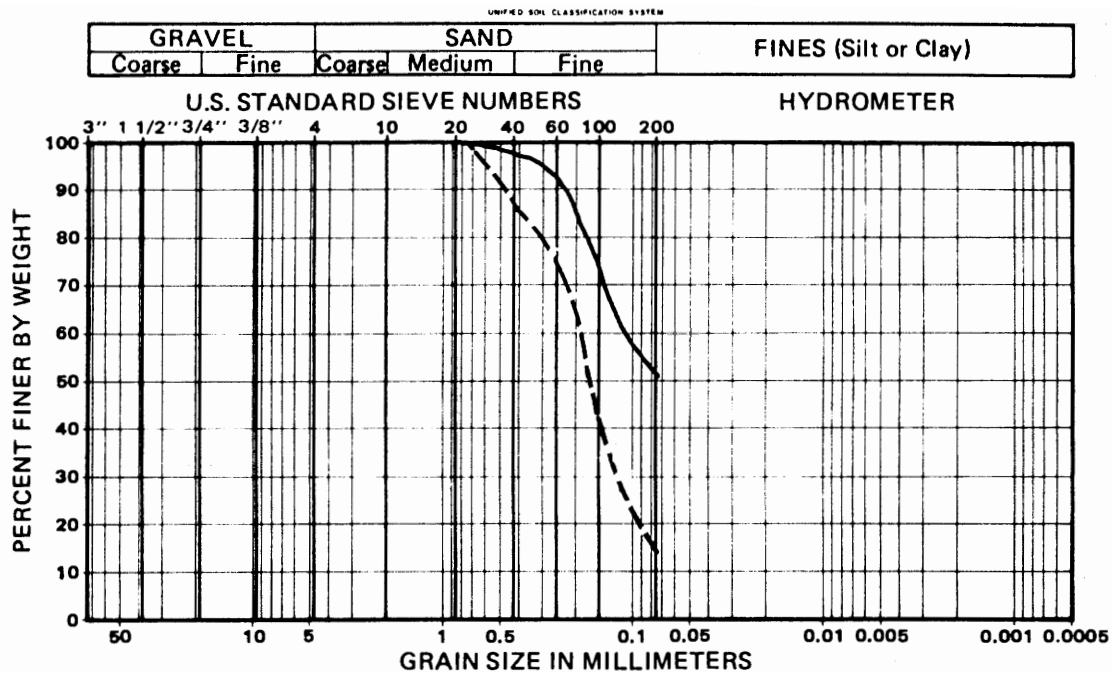
Stream Bed
Point Bar



SYMBOL	X-SECT. NUMBER	SAMPLE NUMBER	DEPTH (FEET)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
—	8	12	0 - 0.5	71	26	45	CH
- -	7	13	0 - 0.5				SC-CL

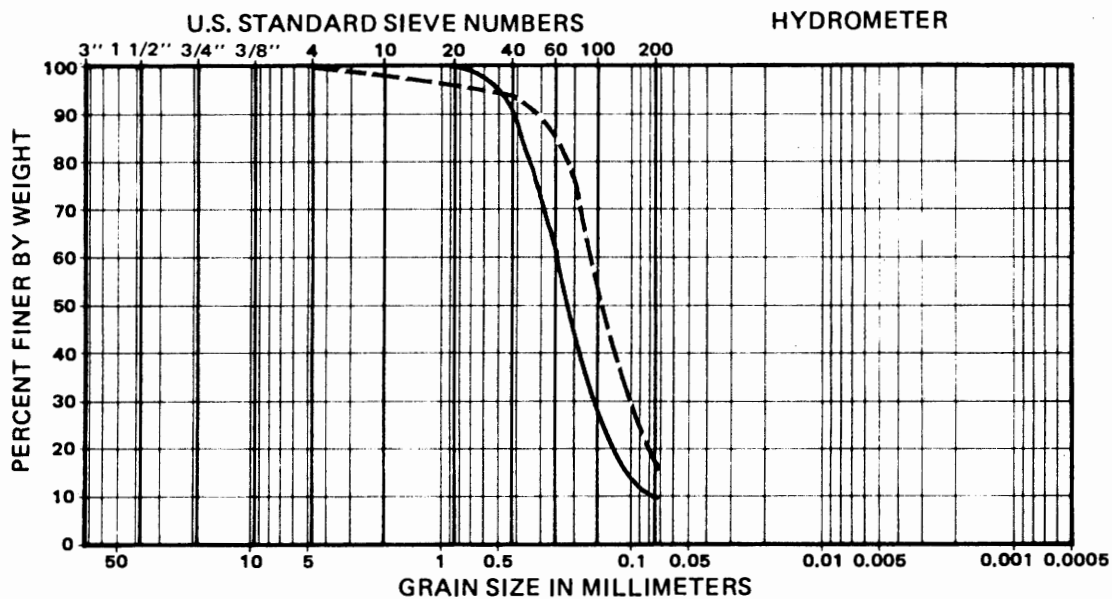
Mudstone - High In
Chinle.
Bank 3' Above Stream
Bed.

 The Earth Technology Corporation	HUBBELL TRADING POST NATIONAL HISTORIC SITE EROSION STUDY
GRADATION AND ATTERBERG LIMITS TEST RESULTS Figure 9	



SYMBOL	X-SECT. NUMBER	SAMPLE NUMBER	DEPTH (FEET)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
—	5	14	0 - 0.5	28	15	13	CL
- -	5	15	0 - 0.5				SM

Bed.
2nd terrace 60'
from stream to-
wards t.p.

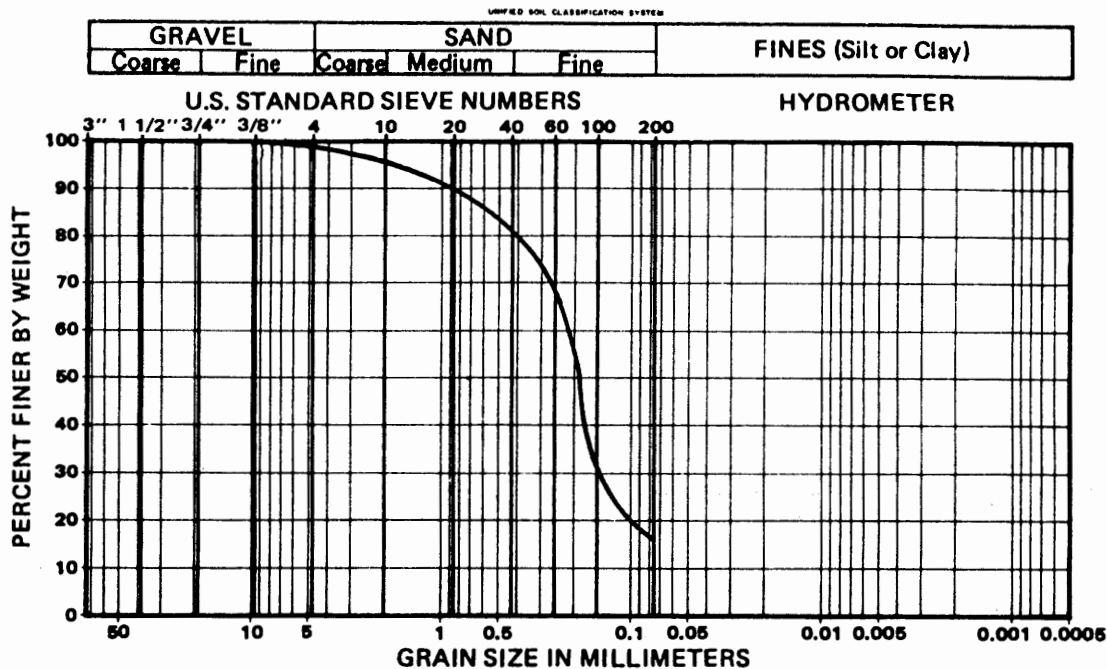


SYMBOL	X-SECT. NUMBER	SAMPLE NUMBER	DEPTH (FEET)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
—	4	16	0 - 0.5'				SP-SM
- -		17	0 - 0.5'			N.P.*	SM

Bank 6' from stream
Road fill 105' E. of
visitor center.

* Non-plastic

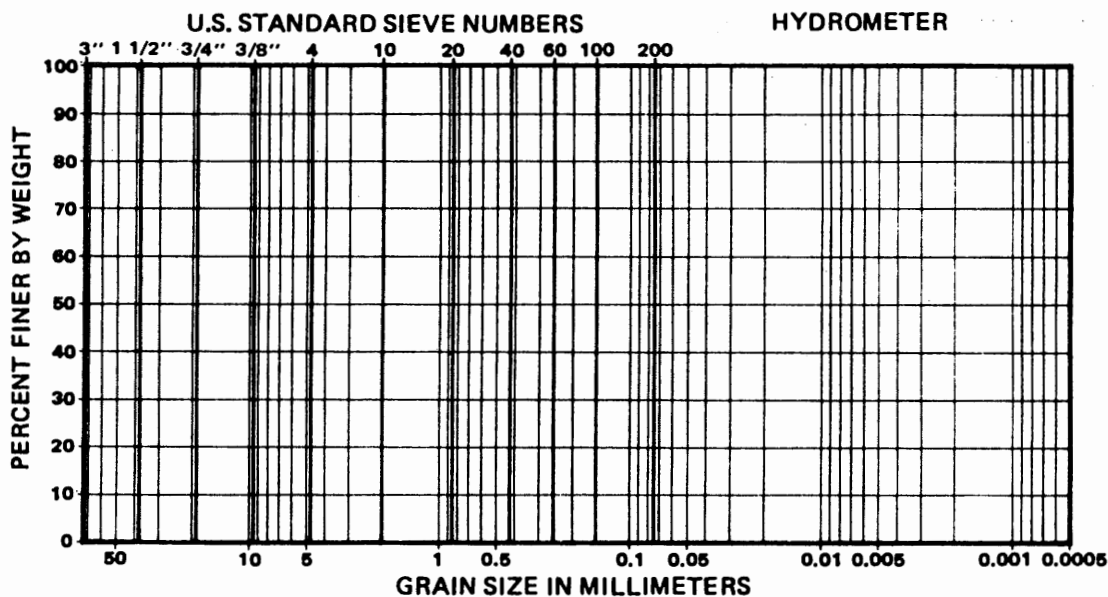
 The Earth Technology Corporation	HUBBELL TRADING POST NATIONAL HISTORIC SITE EROSION STUDY
GRADATION AND ATTERBERG LIMITS TEST RESULTS Figure 10	



SYMBOL	X-SECT. NUMBER	SAMPLE NUMBER	DEPTH (FEET)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE
—	—	18	0 - 0.5			N.P.*	SM

Road fill 150' west of wood bridge.

* Non-plastic



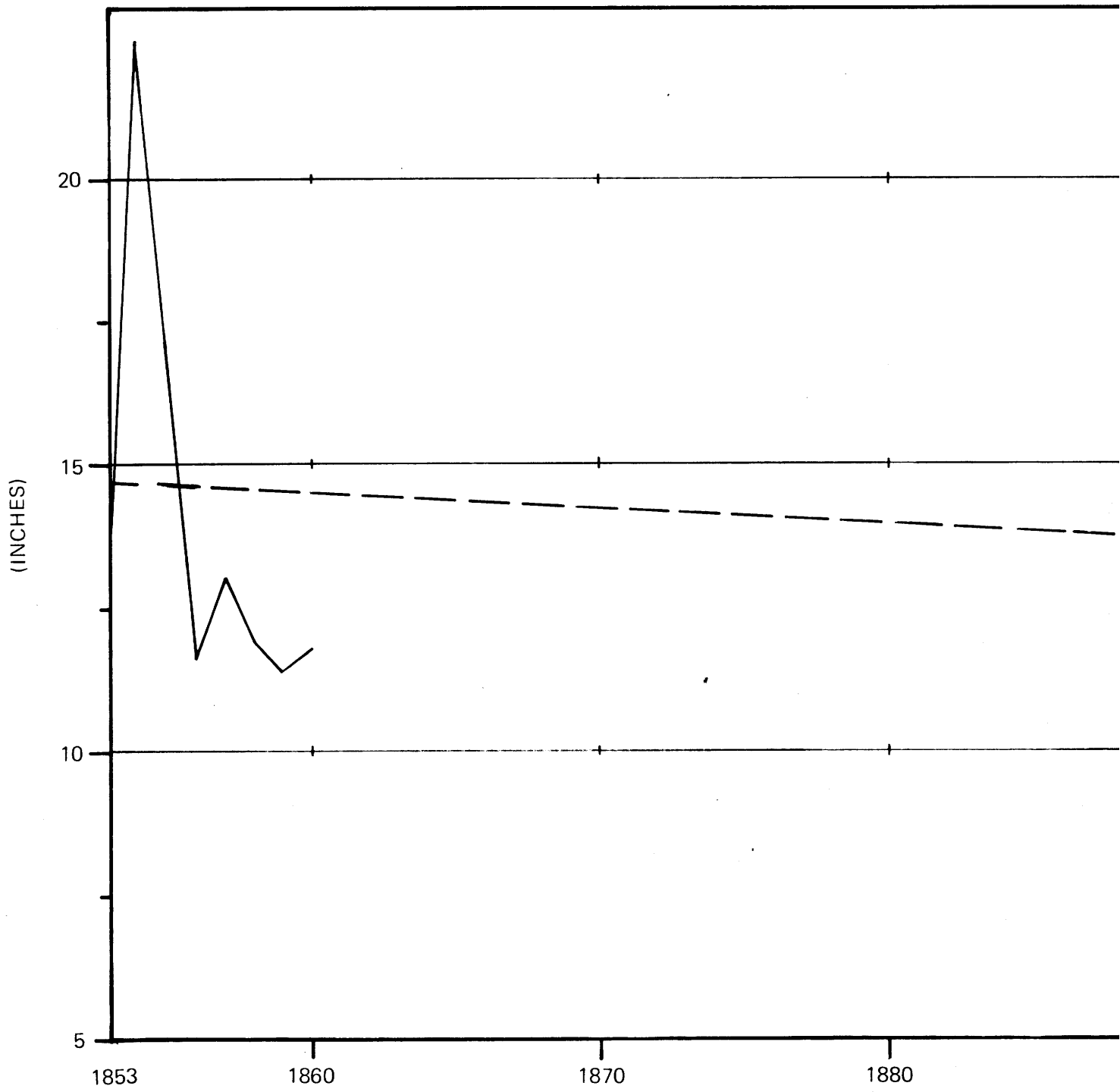
SYMBOL	X-SECT. NUMBER	SAMPLE NUMBER	DEPTH (FEET)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL TYPE



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HUBBELL TRADING POST
NATIONAL HISTORIC SITE
EROSION STUDY

GRADATION AND ATTERBERG LIMITS
TEST RESULTS
Figure 11



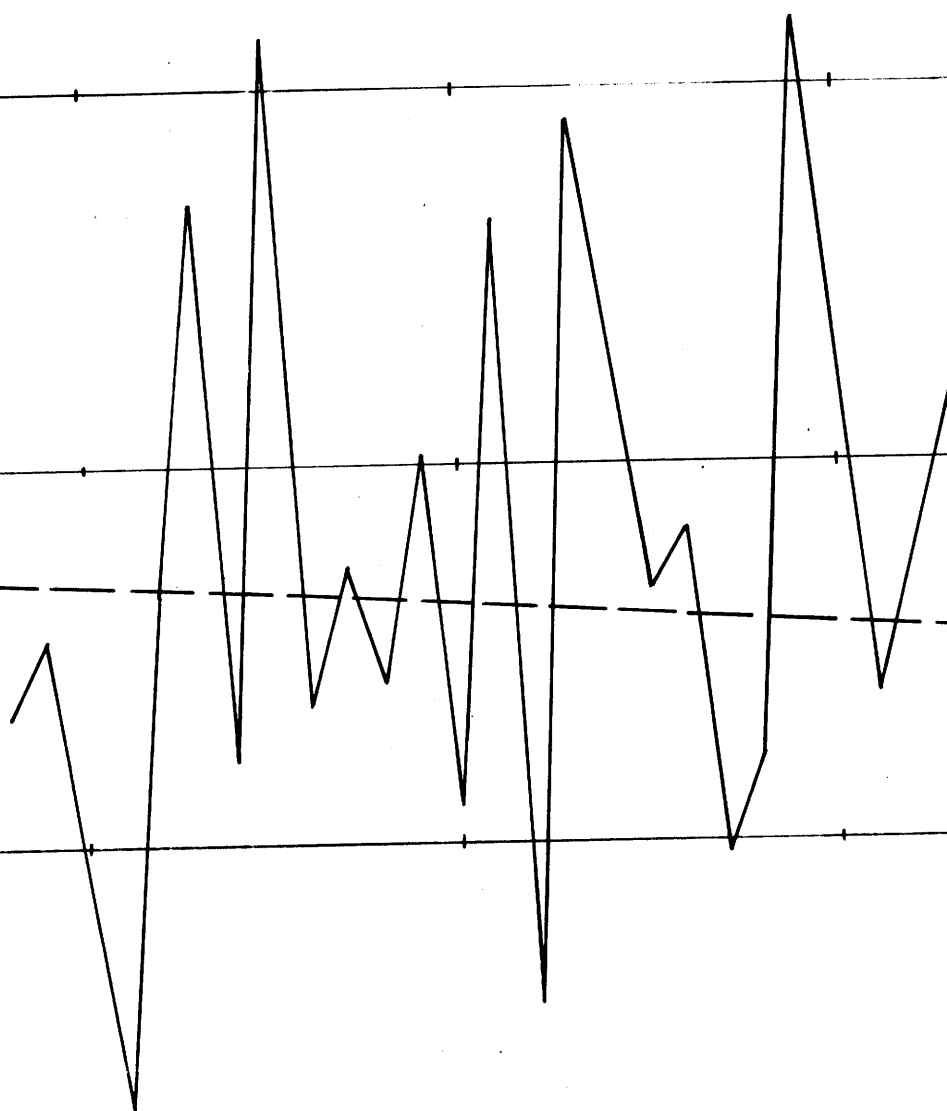
1890

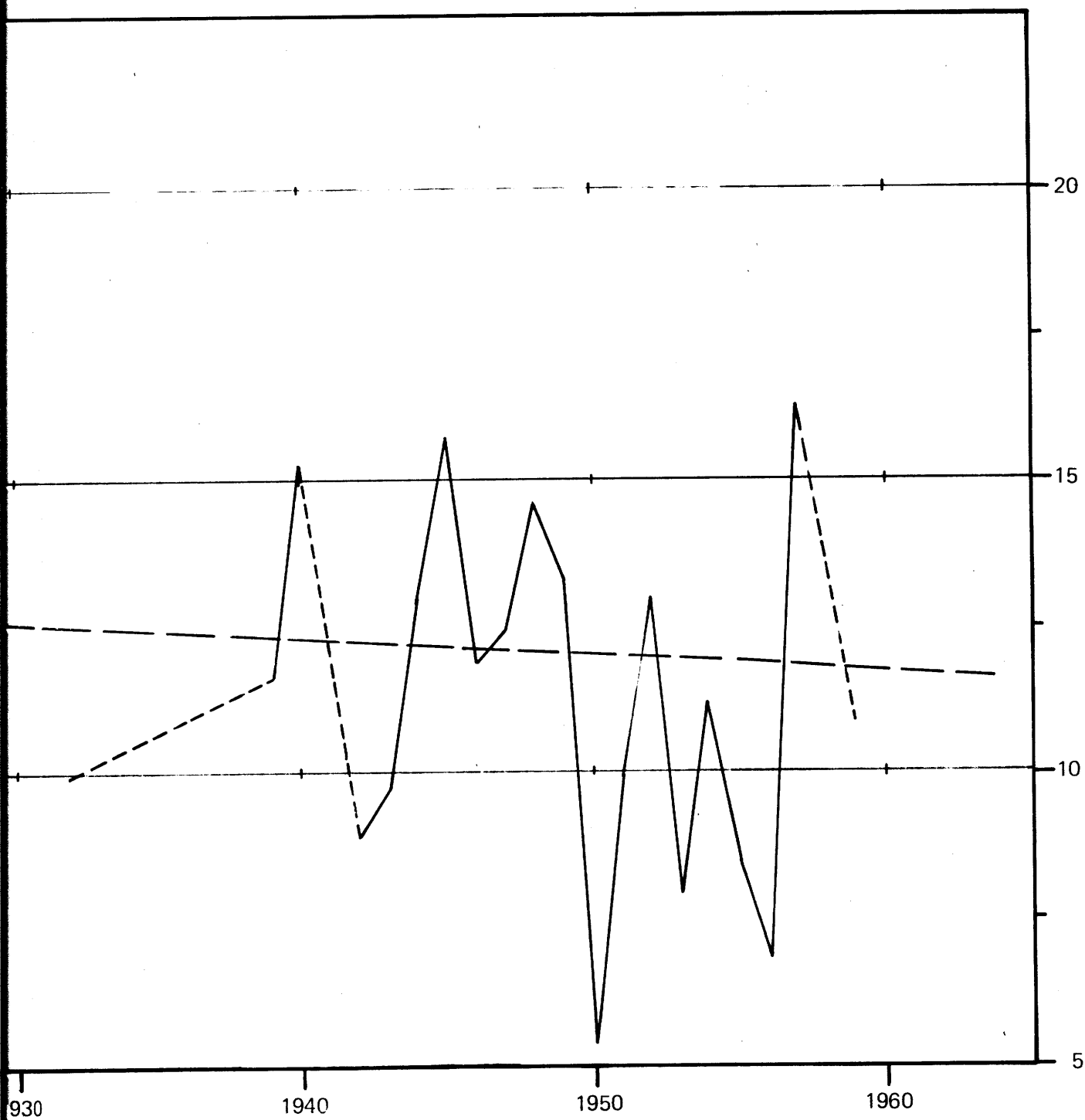
1900

1910

1920

(YEARS)



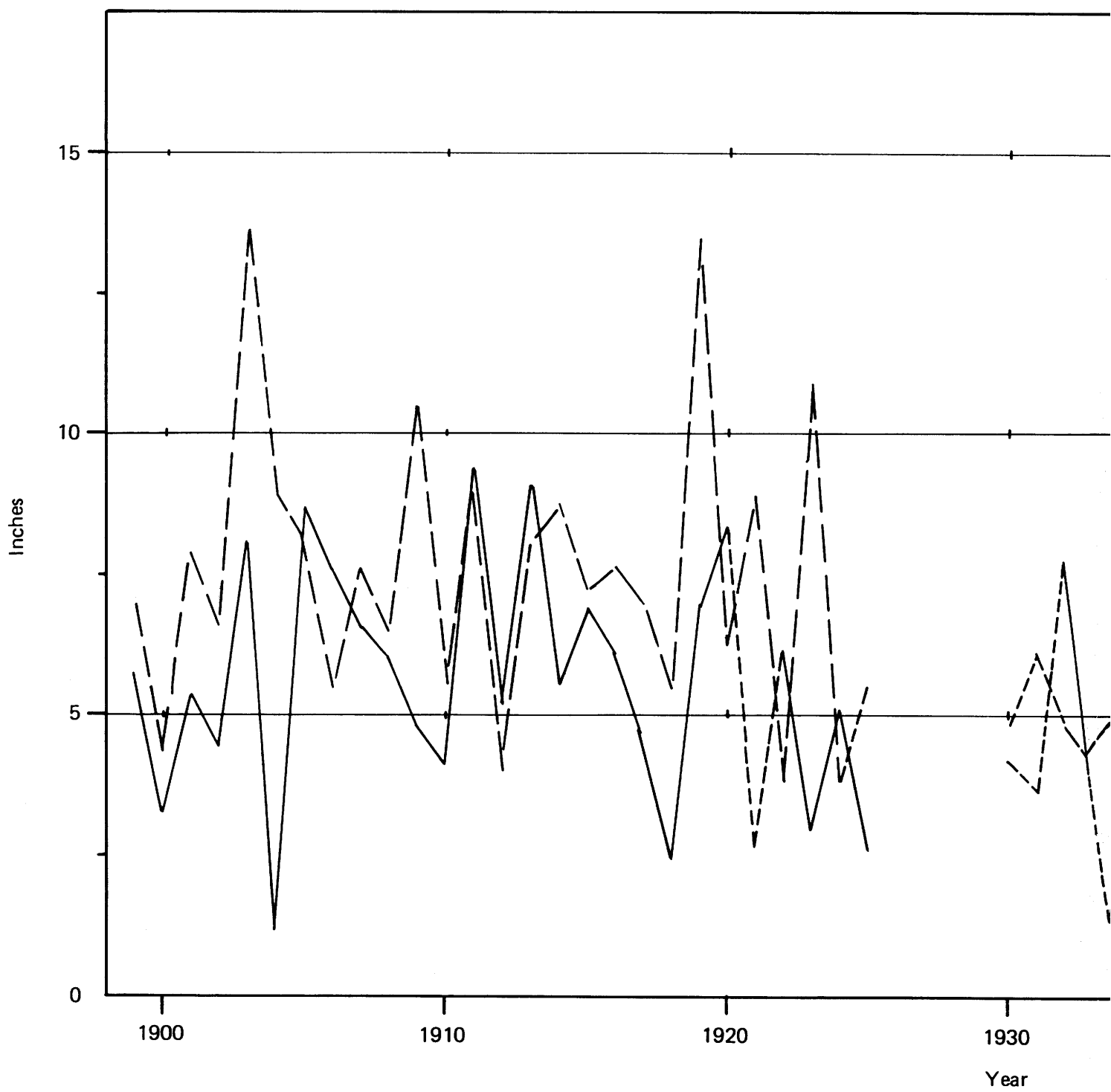


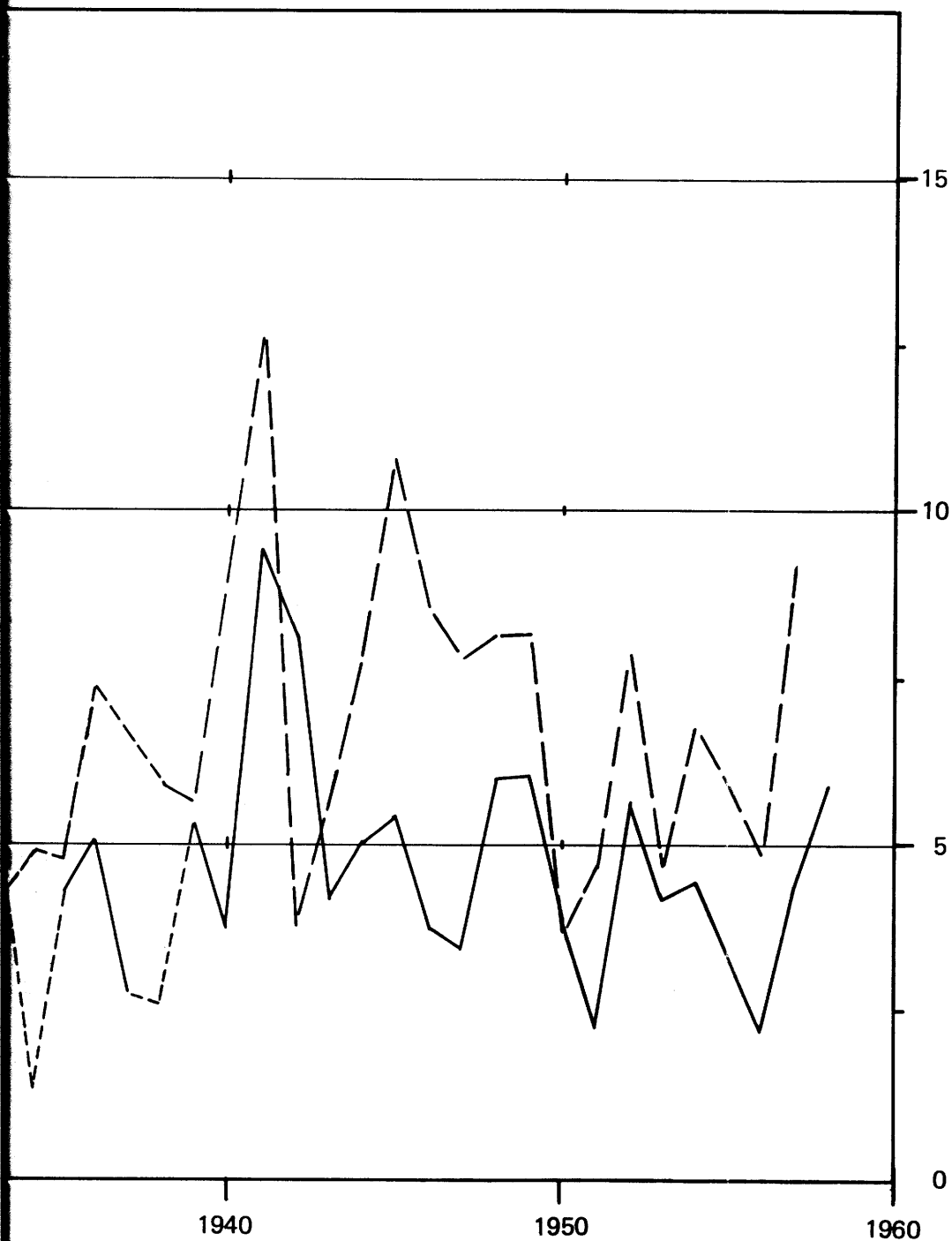
— ANNUAL PRECIPITATION
 - - - REGRESSION RESIDUALS
 - . - - BASED ON INCOMPLETE DATA
 THAT YEAR.



HUBBELL TRADING POST
 NATIONAL HISTORIC SITE
 EROSION STUDY

ANNUAL PRECIPITATION TOTALS
 AND REGRESSION RESIDUALS
 ST. MICHAELS / WINDOW ROCK
 Figure 12



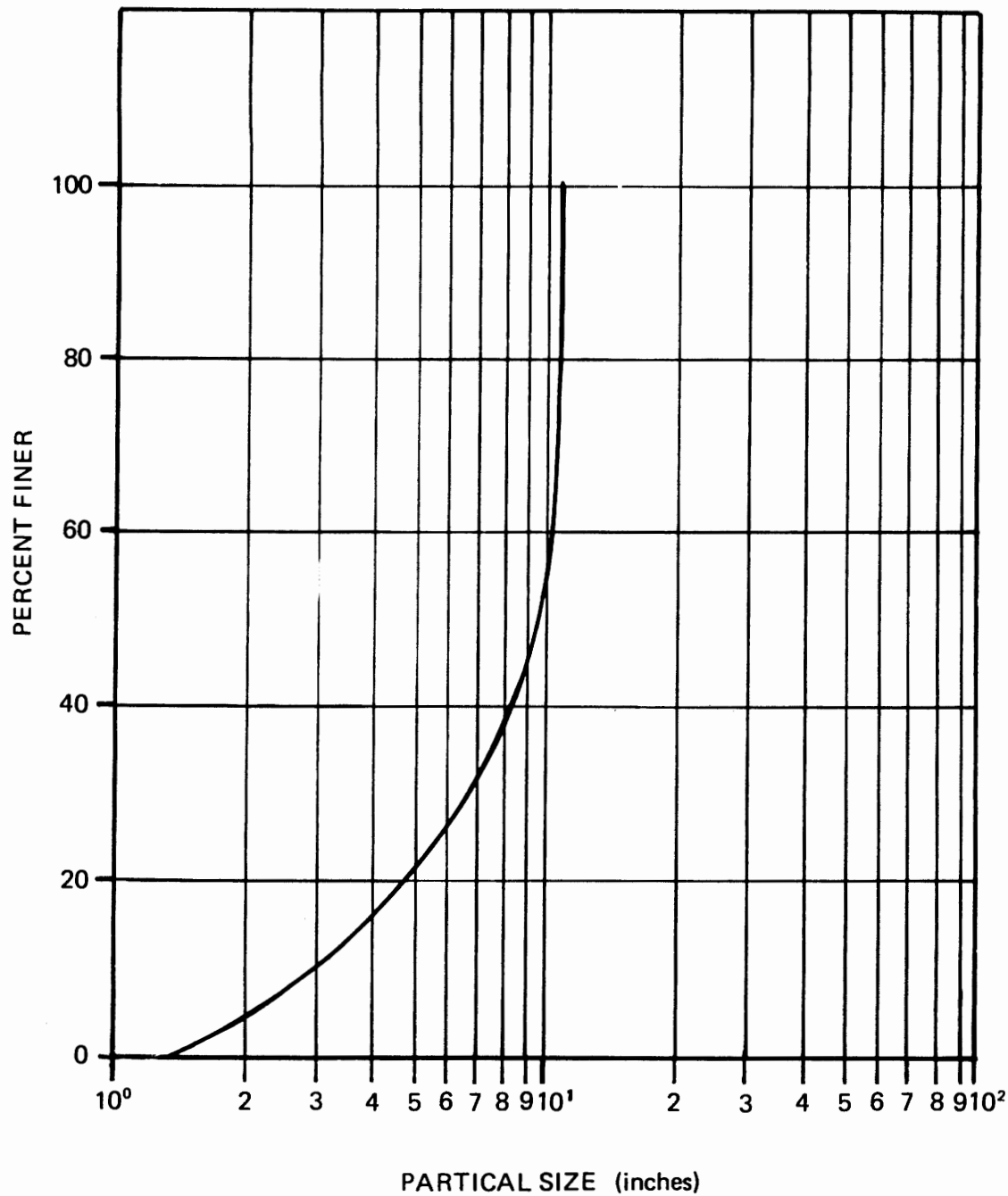


— WINTER PRECIPITATION
 - - - SUMMER PRECIPITATION
 - - - BASED ON INCOMPLETE DATA
 THAT YEAR.

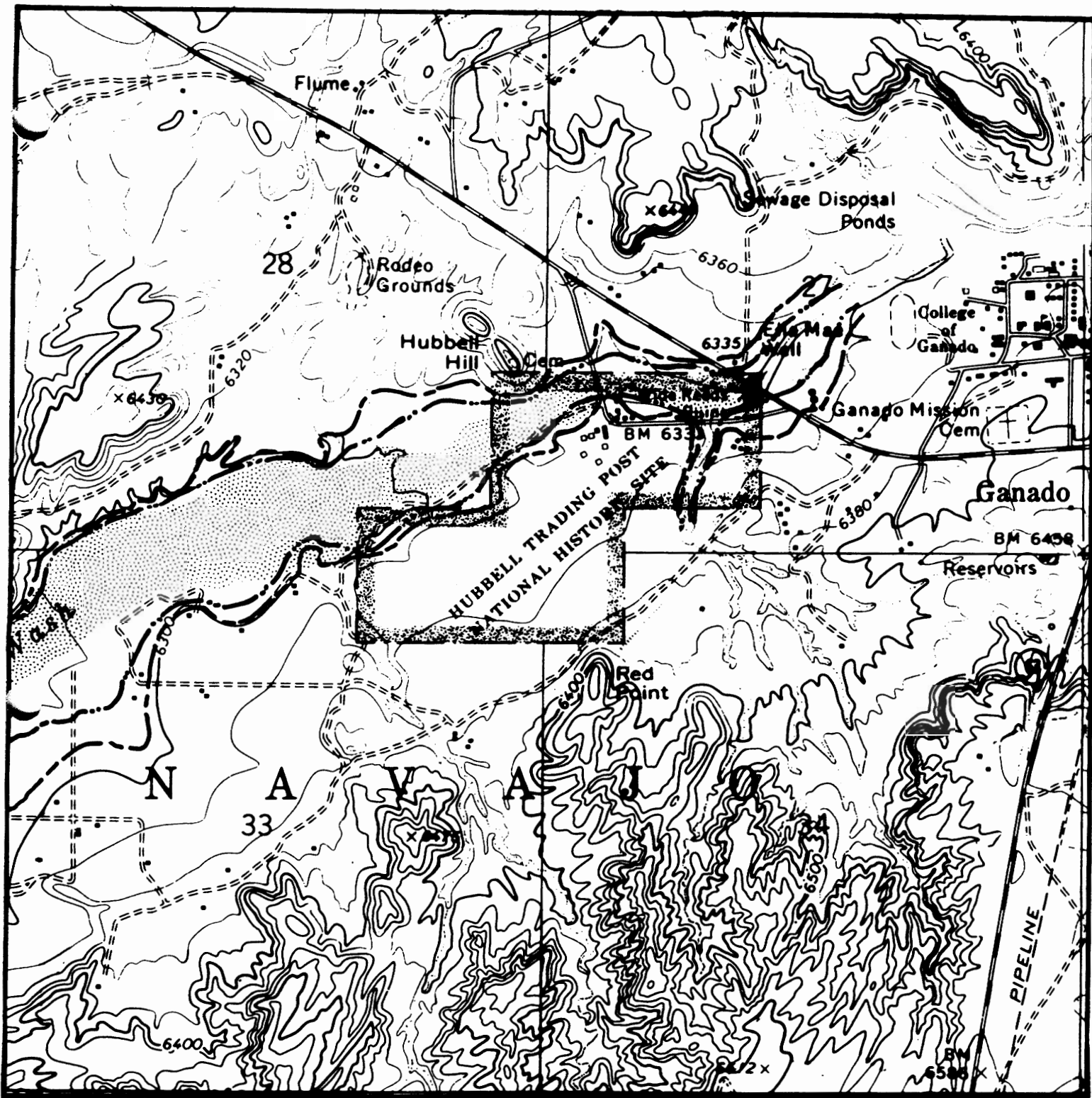


HUBBELL TRADING POST
 NATIONAL HISTORIC SITE
 EROSION STUDY

SEASONAL PRECIPITATION
 ST. MICHAELS / WINDOW ROCK
 Figure 13



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ROCKFILL LINER GRADATION CURVE Figure 14	



0 ¼ ½ mile

- · — · — 100-Year Floodplain Approximate Location
- - - - - 500-Year Floodplain Approximate Location

For Details At Site See Plate 4.

 The Earth Technology Corporation	HUBBELL TRADING POST NATIONAL HISTORIC SITE EROSION STUDY
100 AND 500 YEAR EVENT GENERALIZED FLOODPLAINS Figure 15	

EXPLANATION



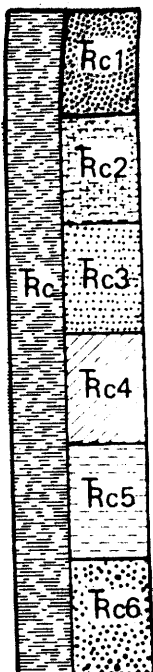
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HUBBELL TRADING POST
NATIONAL HISTORIC SITE
EROSION STUDY

GEOLOGIC MAP OF HUBBELL TRADING POST AREA
APACHE COUNTY, ARIZONA
Plate 1

Surficial Deposits

Pleistocene To Recent	Qal	Qal, Active stream alluvium; silty sand, sandy silt, sand, clayey silt, clay, and gravel.	Quaternary
	Qe	Qe, Eolian deposits and deflation areas; silty sand, sand, and sandy gravel.	
	Qco	Qco, Colluvium on or near bedrock of the Chinle Formation; clayey sand and sandy clay, with surface gravel, scattered petrified wood, and concretions.	
	Qt1	Qt1, Lower alluvial terrace deposits; silty sand and silt, sparsely vegetated, point bar deposits.	
	Qt2	Qt2, Slightly elevated alluvial terrace deposits; silty sand and silt, sparsely vegetated.	
	Qt3	Qt3, Elevated alluvial terrace deposits; fine and medium silty sand, mostly grass cover with some low shrubs, and trees.	
	Qt4	Qt4, Elevated alluvial terrace deposits; fine and medium silty sand, gently sloping, well developed tree and grass cover.	
	Qt5	Qt5, Elevated alluvial terrace deposits; fine and medium silty sand and clayey sand, gently to moderately sloping, well developed vegetation cover.	
	Qt6	Qt6, Older elevated dissected or sloping terrace deposits of clayey sand, silty sand, and sandy clay with some surface gravels, mostly erosional terraces on Chinle Formation at base of Hubbel Hill.	
	Qoal	Qoal, Undifferential terrace, eolian, and other alluvial deposits; silty sand, and clayey sand, gently sloping, previously cultivated farm land when on trading post site.	



Rc1, Sandstone; fine sand, silica cemented, white to light pink, crossbedded with 3 to 5 feet thick intermediate angle sets, resistant.

Rc2, Sandy Mudstone; clay and silt fines with some fine sand, brown, desiccated, contains thin light green bentonitic interbeds, non-resistant.

Rc3, Sandstone; fine sand, silica cemented, dark brown, finely laminated, climbing ripple laminations, cross-bedded, resistant.

Rc4, Claystone; and Clayey Siltstone, Contains some fine sand, brown, contains light green bentonitic interbeds, calcareous, moderately resistant.

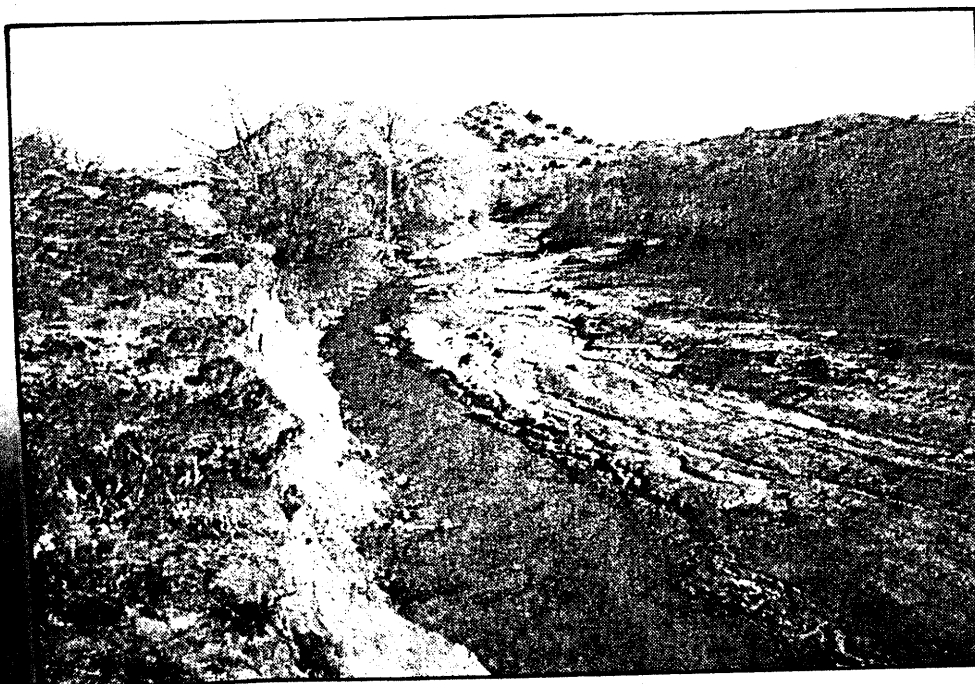
Rc5, Claystone; highly plastic, dark brown, desiccated, crumbly, contains several light green one foot thick bentonite horizons, purplish brown mudstone horizons, mostly non-calcareous, non-resistant.

Rc6, Sandstone; fine sand with some sandy siltstone horizons, silica cemented, gray and purple, non to slightly calcareous, moderately indurated.

Triassic

Af

Af, Artificial fill.



Pueblo Colorado Wash Looking Downstream; Dune Site (Left Center Foreground) Exhibits Steep Erosional Bank Cutting; Stream Terrace (Qt1, Qt2, & Qt3) To Right Of View; Hubbell Hill Center Background.

— ? — Contact: Dashed Where Approximately Located;
Queried Where Questionable

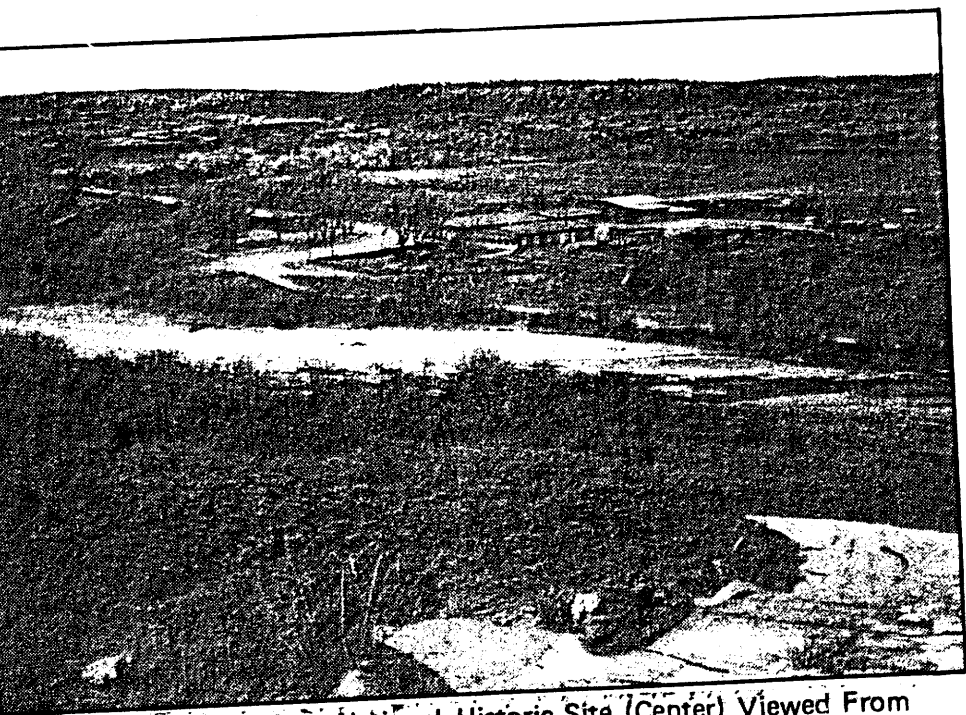
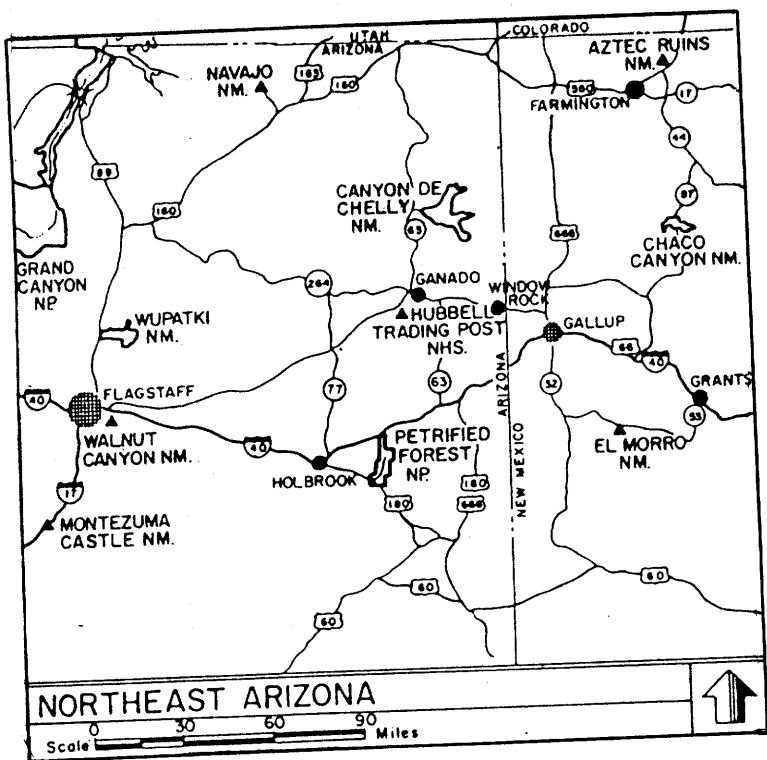
Y Strike And Dip Of Beds

⊘ Embankment

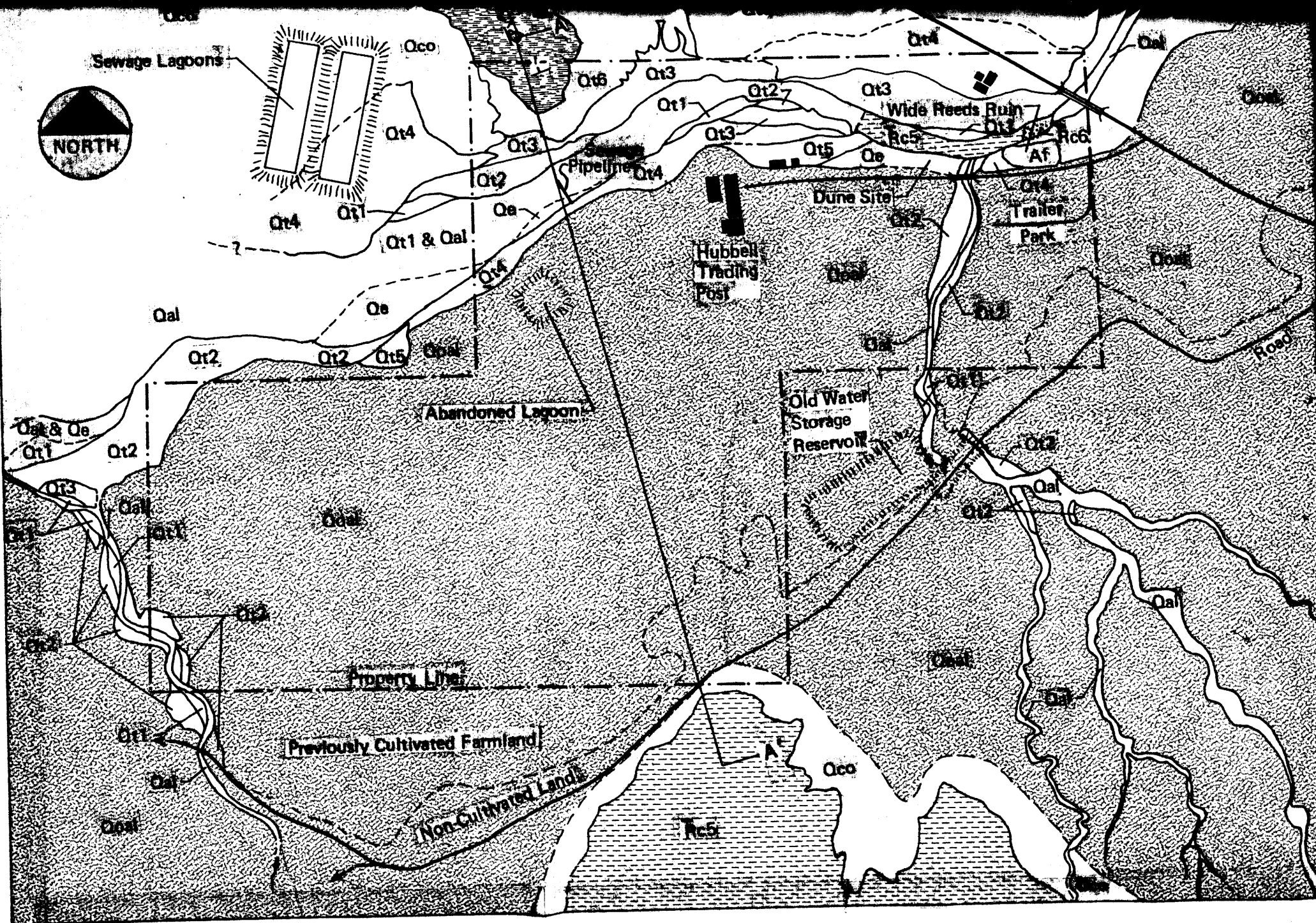
— . — Historic Site Boundary (R).

Note:

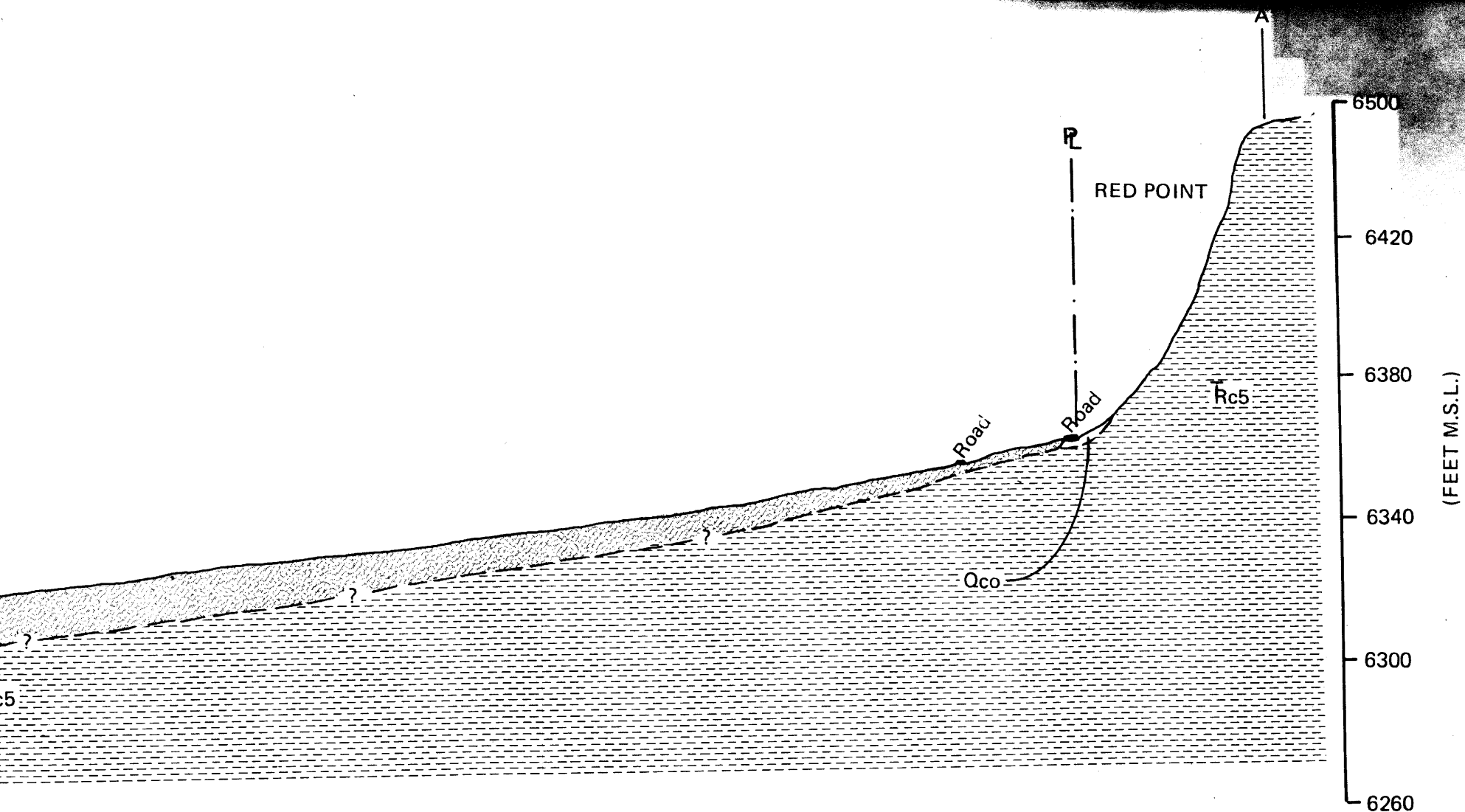
(a) Stream Width 28 Feet On 5/19/83
At Intersection A - A'.



Hubbell Trading Post National Historic Site (Center) Viewed From Hubbell Hill. Pueblo Colorado Wash (Middle Foreground) Flows Left To Right.

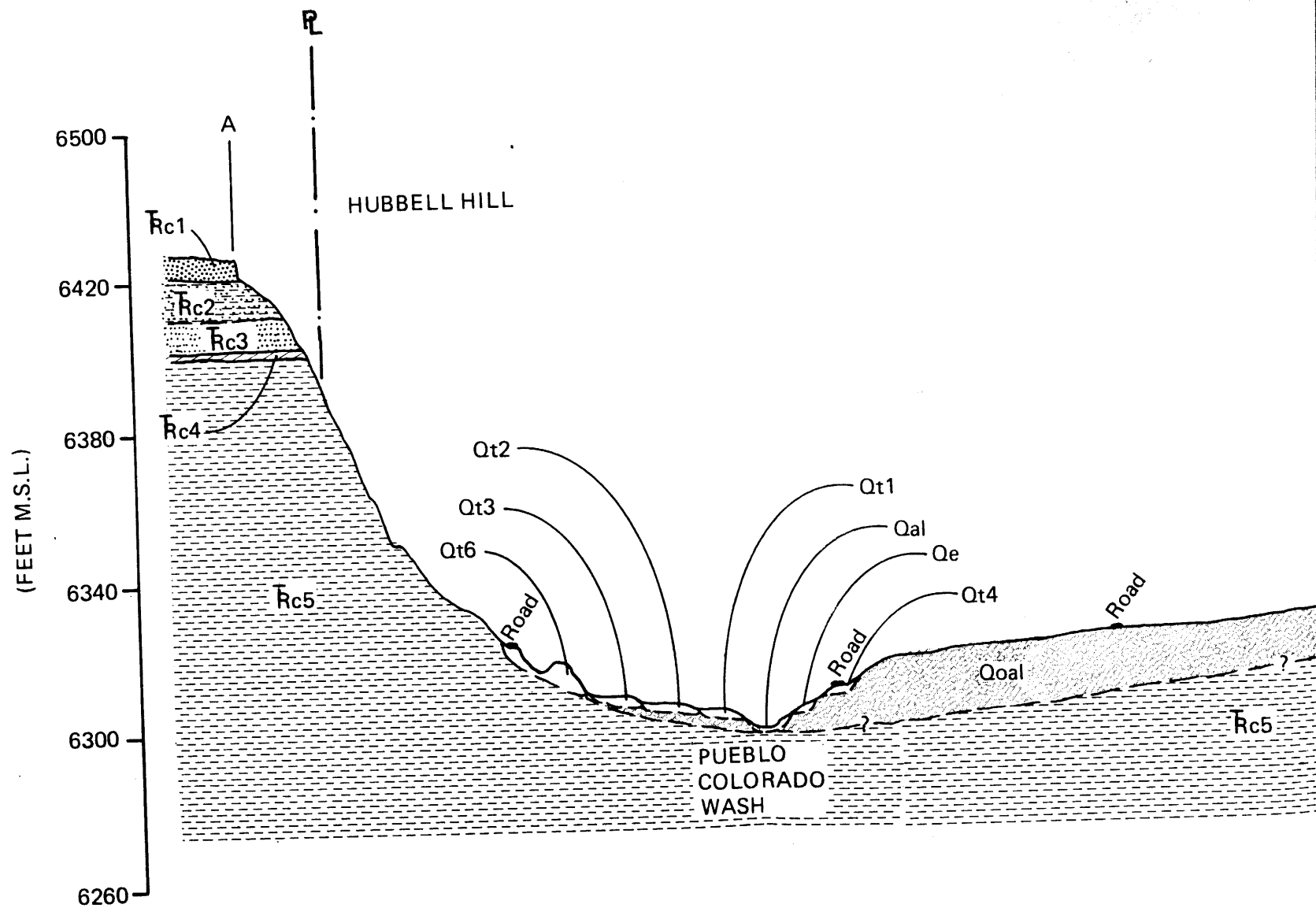


0 500 1000'
(feet)



0 100 200 400 ft.
(feet)

Vertical Exaggeration 5X.

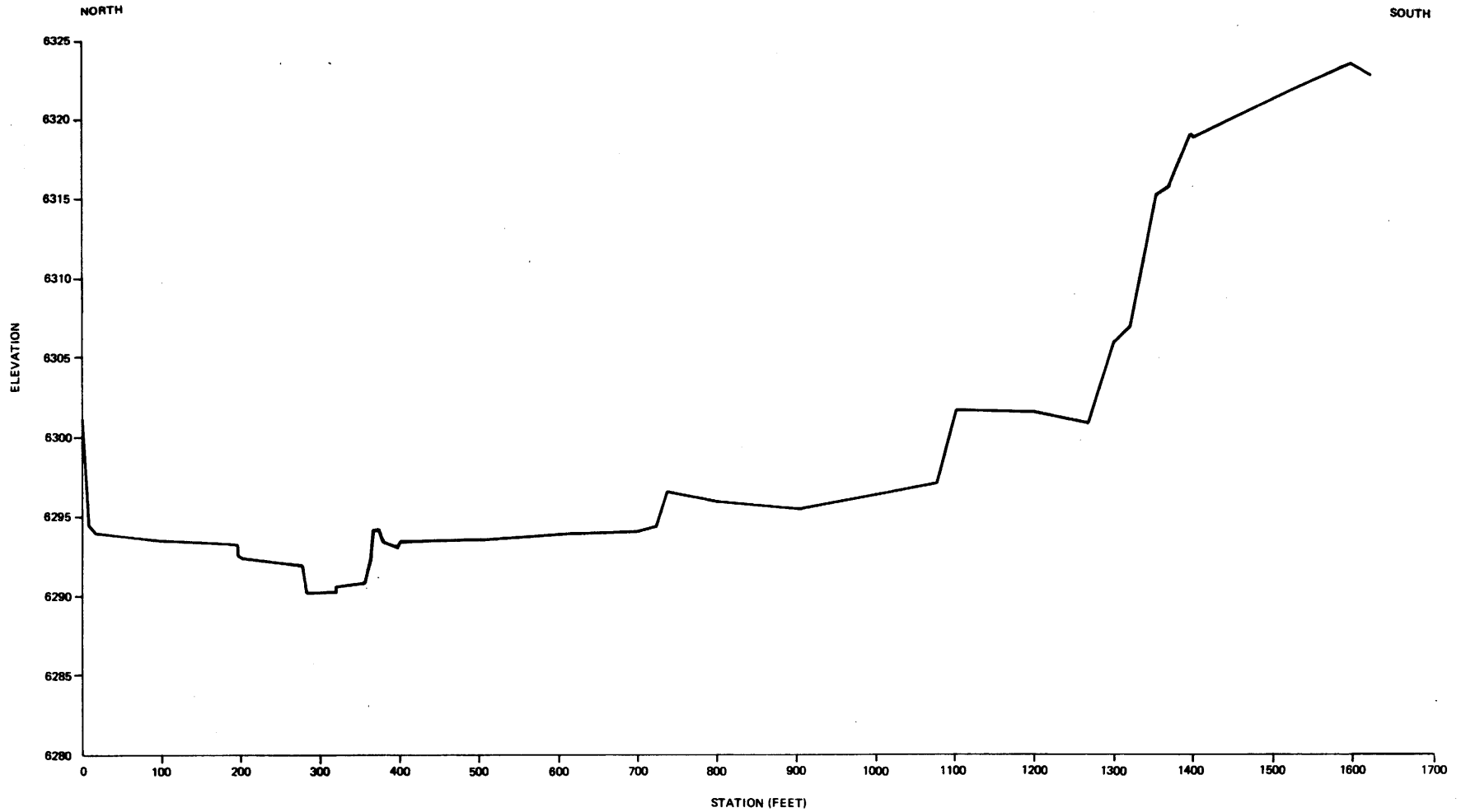


 The Earth Technology Corporation	HUBBELL TRADING POST NATIONAL HISTORIC SITE EROSION STUDY
HYDRAULIC CROSS-SECTIONS Plate 3 Sheet 1 of 2	

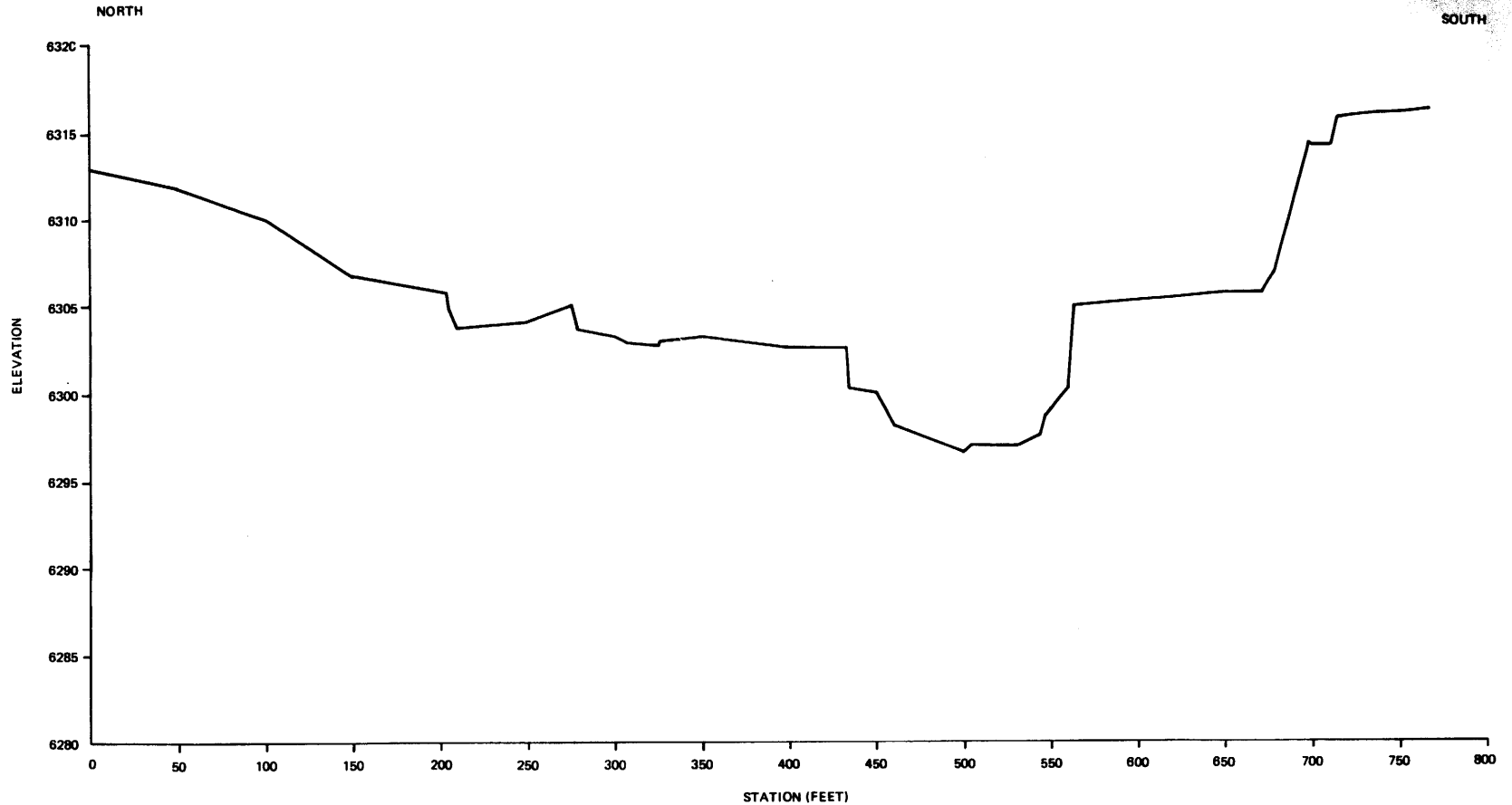
NOTE:

- * Cross-section located on Plate 4, Sheet 1 of 4.
- ** Cross-section located on Plate 4, Sheet 3 of 4.
- † Cross-section located on Plate 4, Sheets 1 of 4 and 3 of 4.

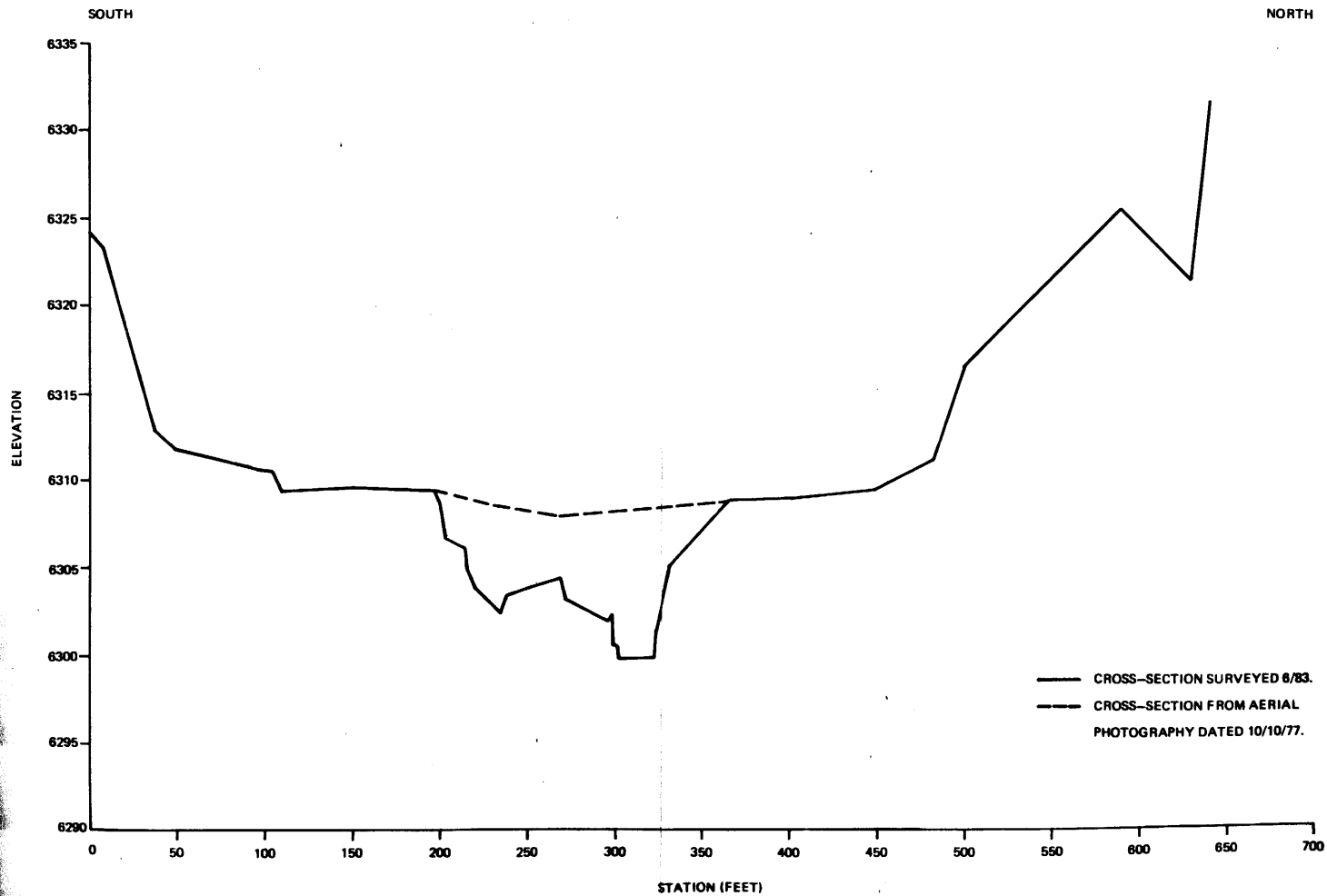
• CROSS-SECTION 2



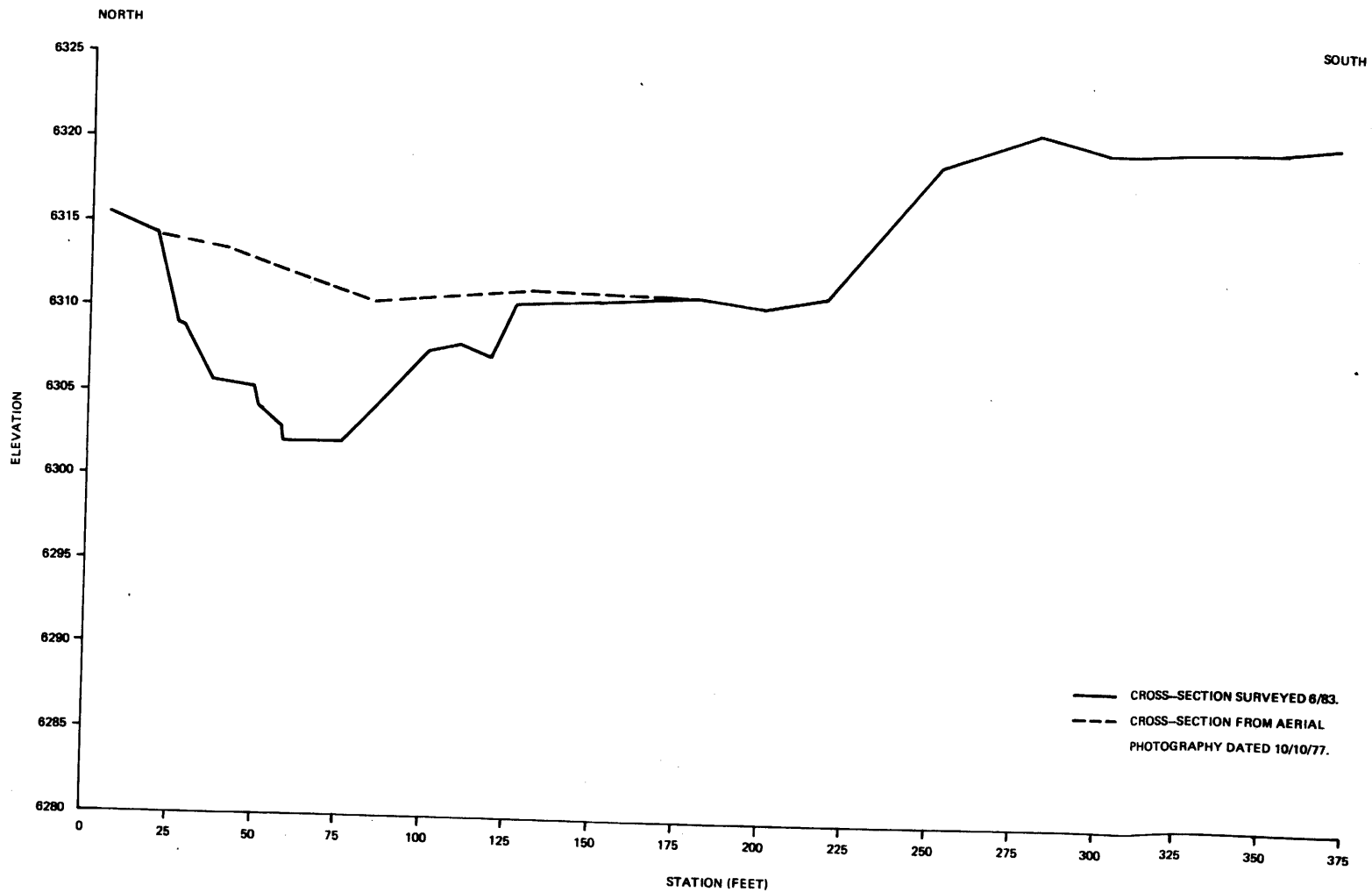
* CROSS-SECTION 3

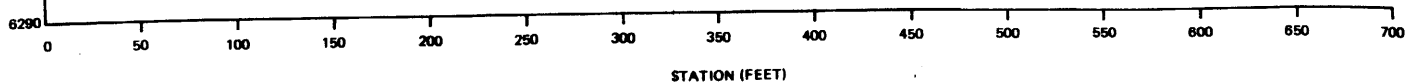


† CROSS-SECTION 4



** CROSS-SECTION 5

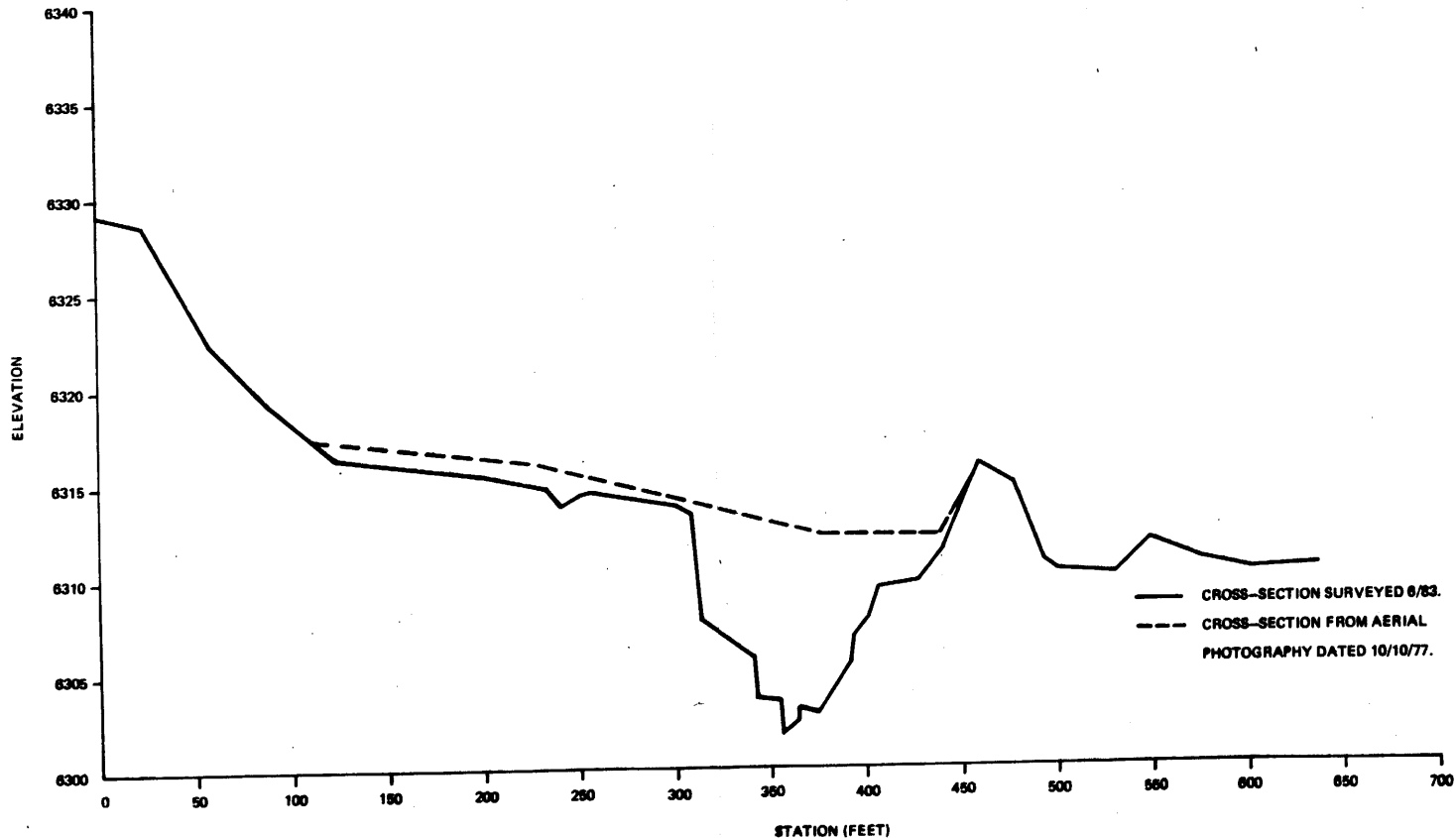




*** CROSS-SECTION 8

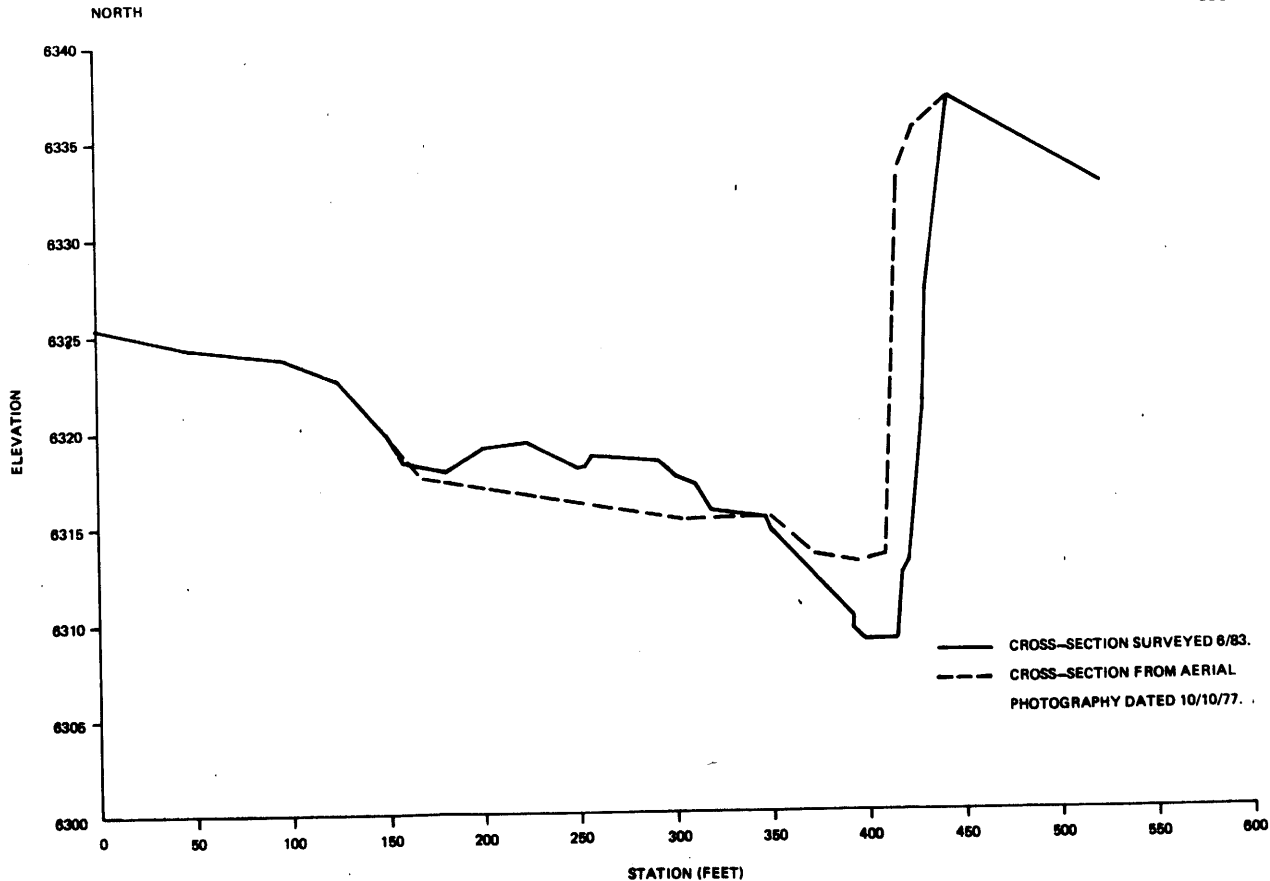
SOUTH

NORTH



** CROSS-SECTION 7

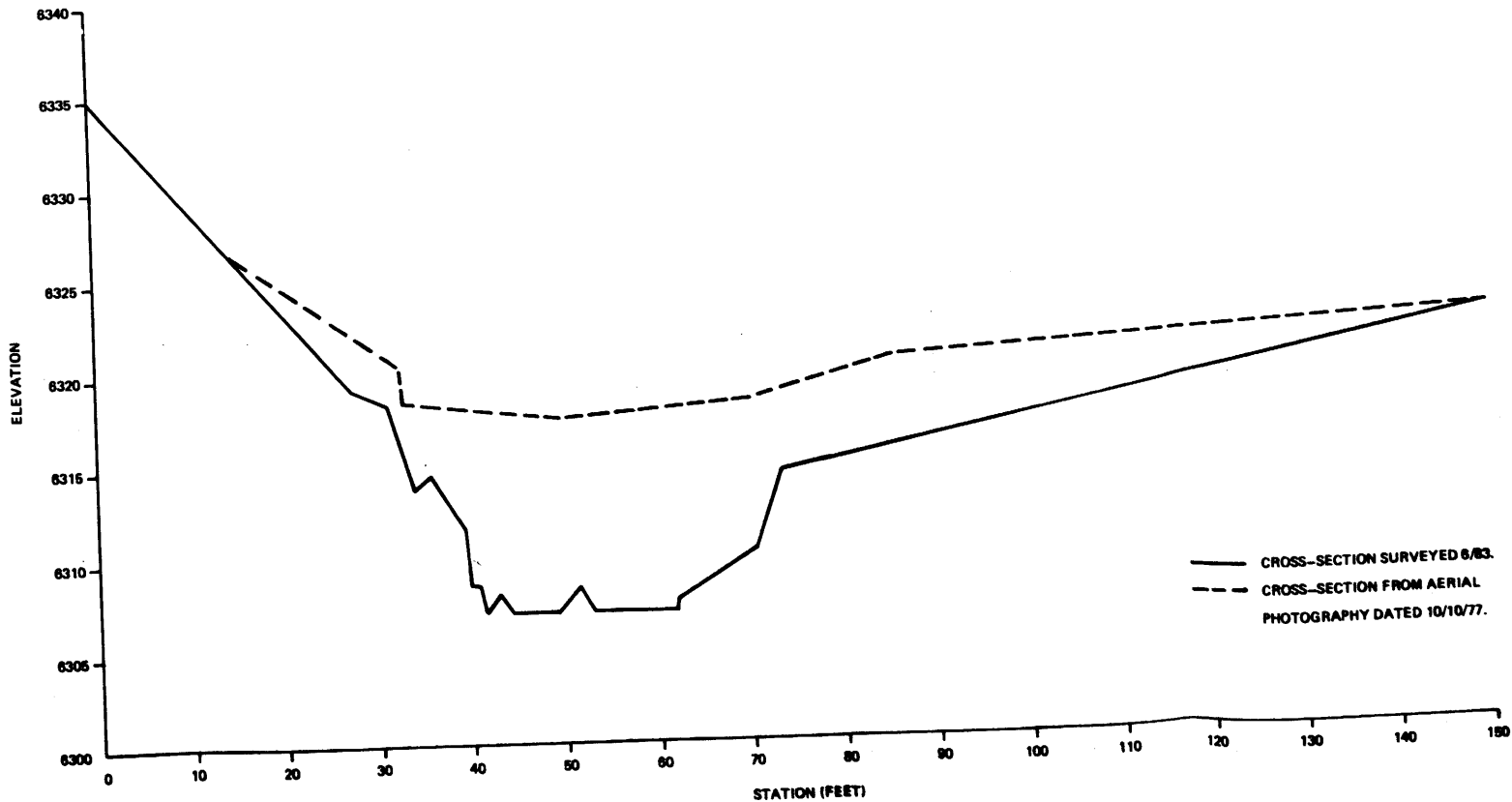
SOUTH



*** CROSS-SECTION 8

NORTH

SOUTH





The Earth Technology Corporation

**HUBBELL TRADING POST
NATIONAL HISTORIC SITE
EROSION STUDY**

HYDRAULIC CROSS-SECTIONS

Plate 3

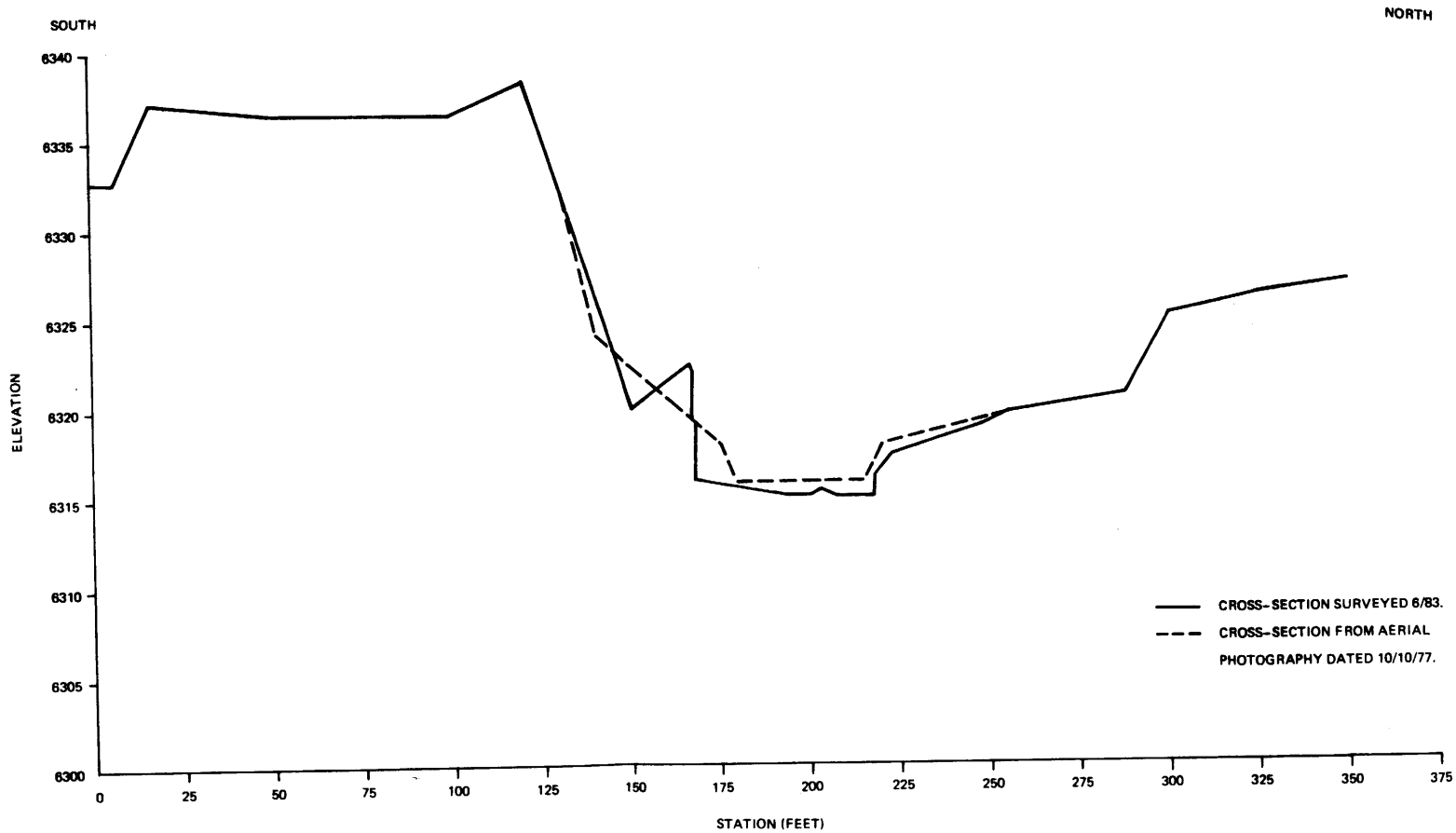
Sheet 2 of 2

EAST

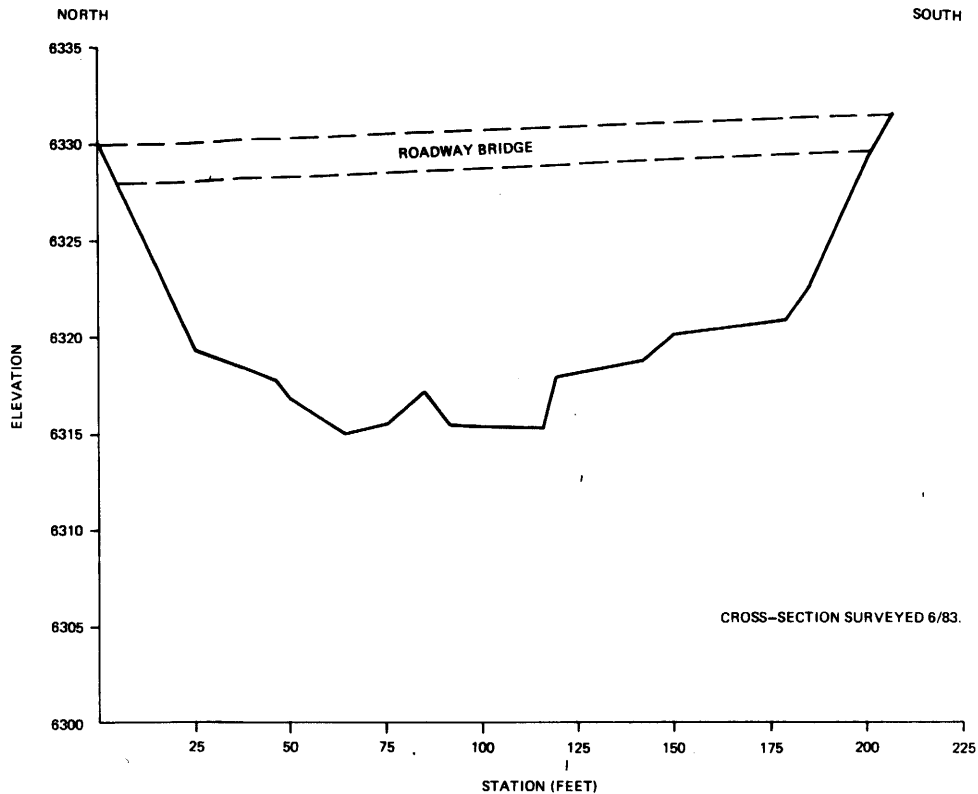
NOTE:

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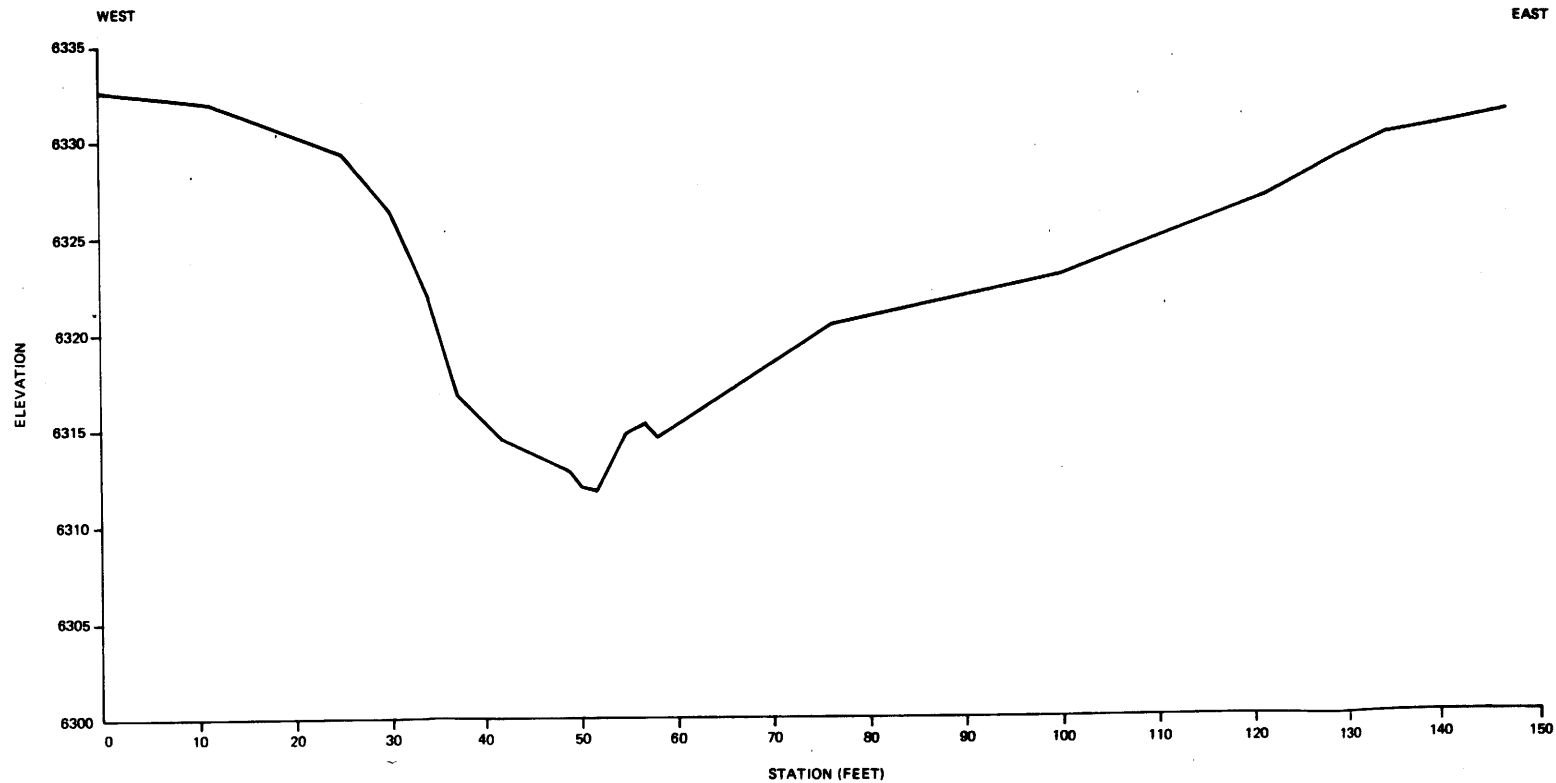
*** CROSS-SECTION 9



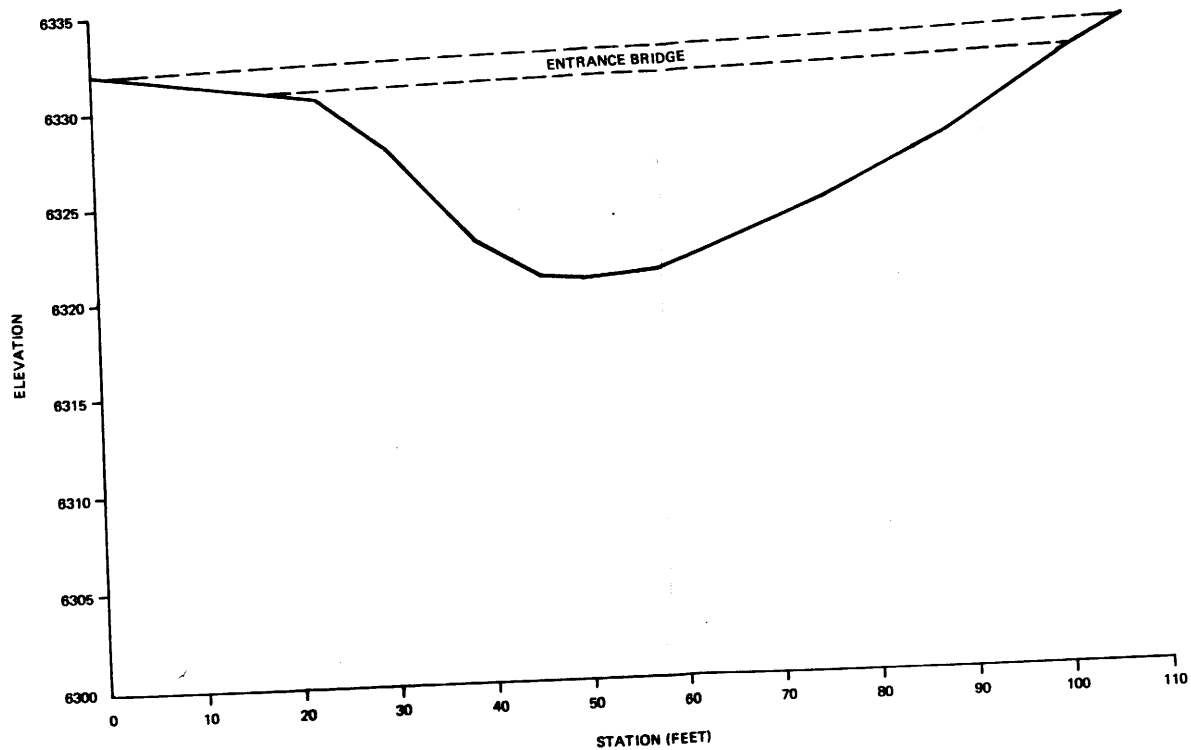
✱ ✱ CROSS-SECTION 11



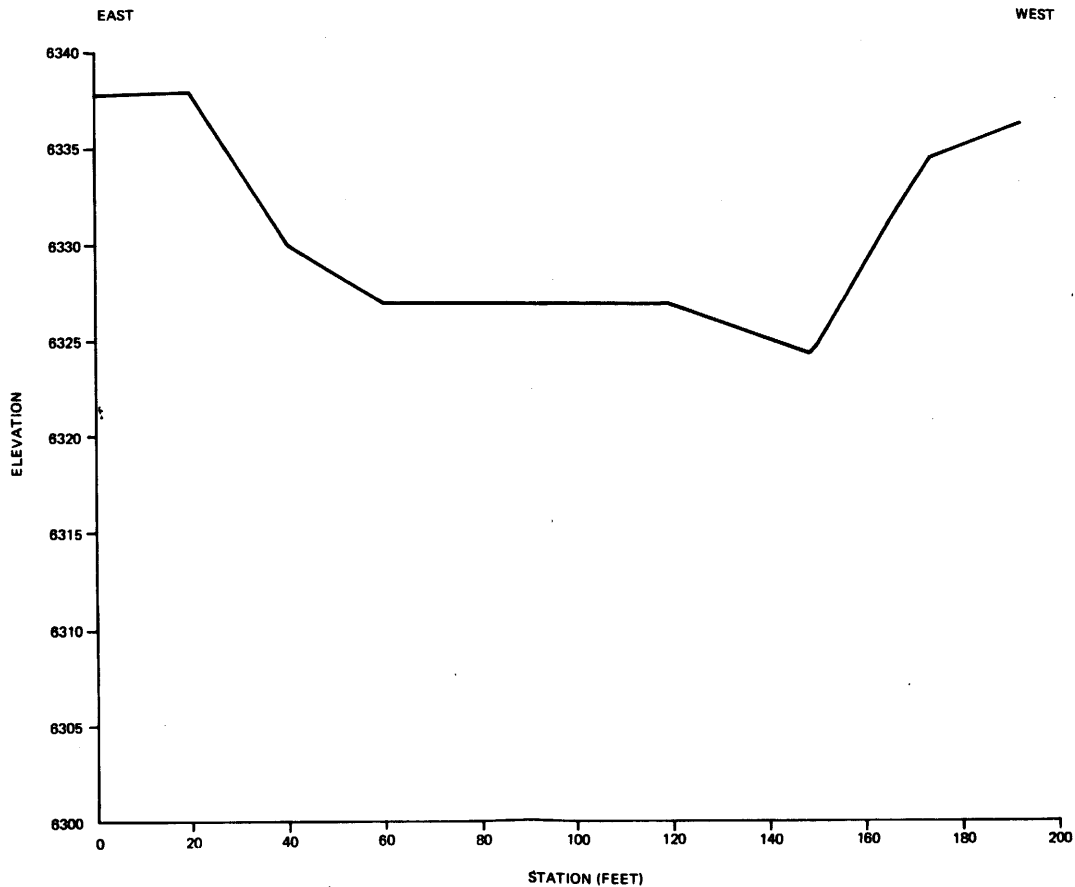
✱ ✱ CROSS-SECTION 14 (-7)



*** CROSS-SECTION 15

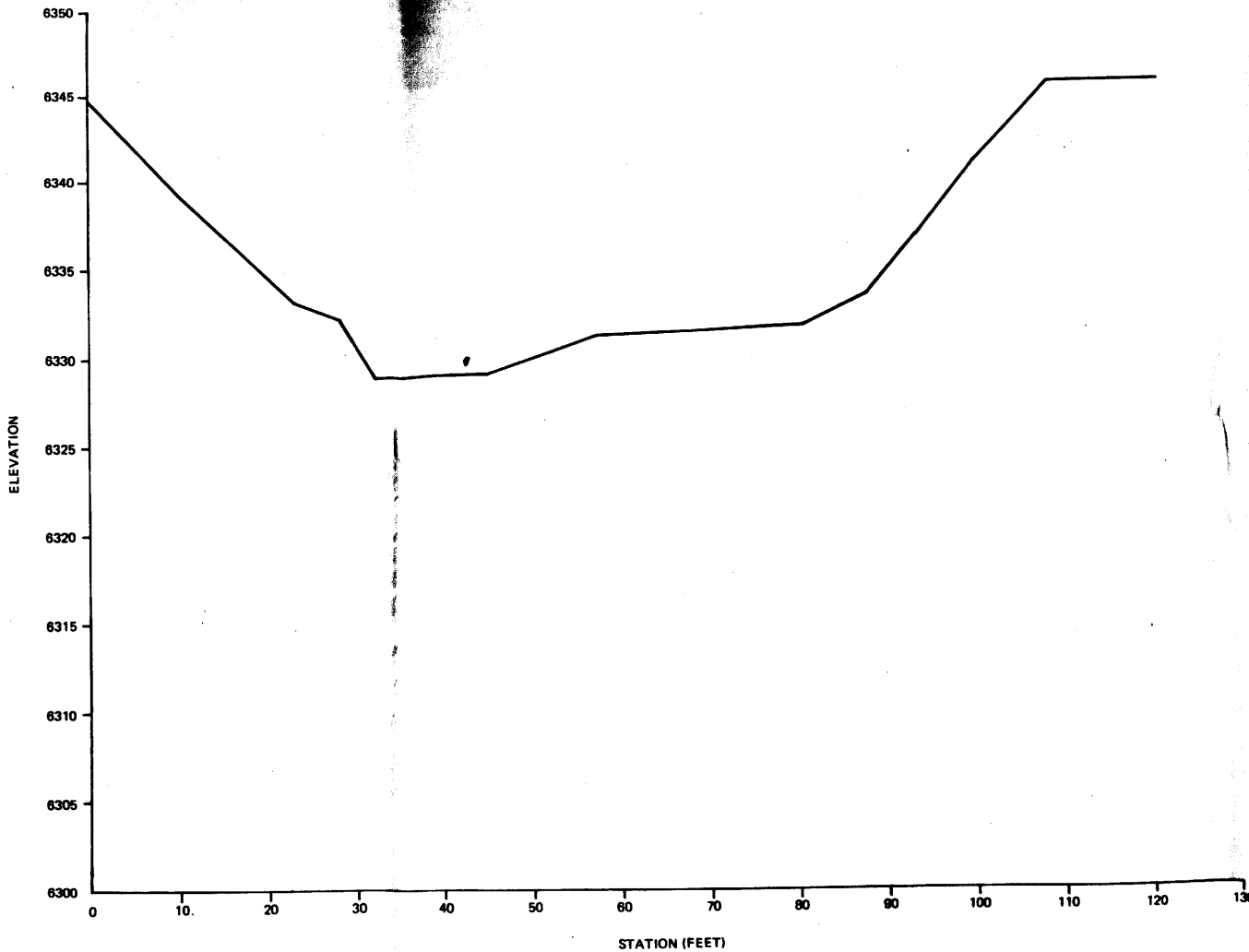


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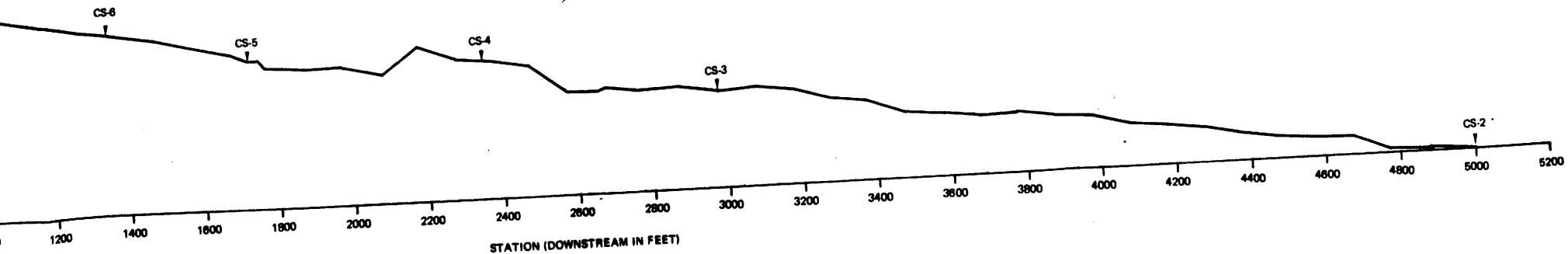


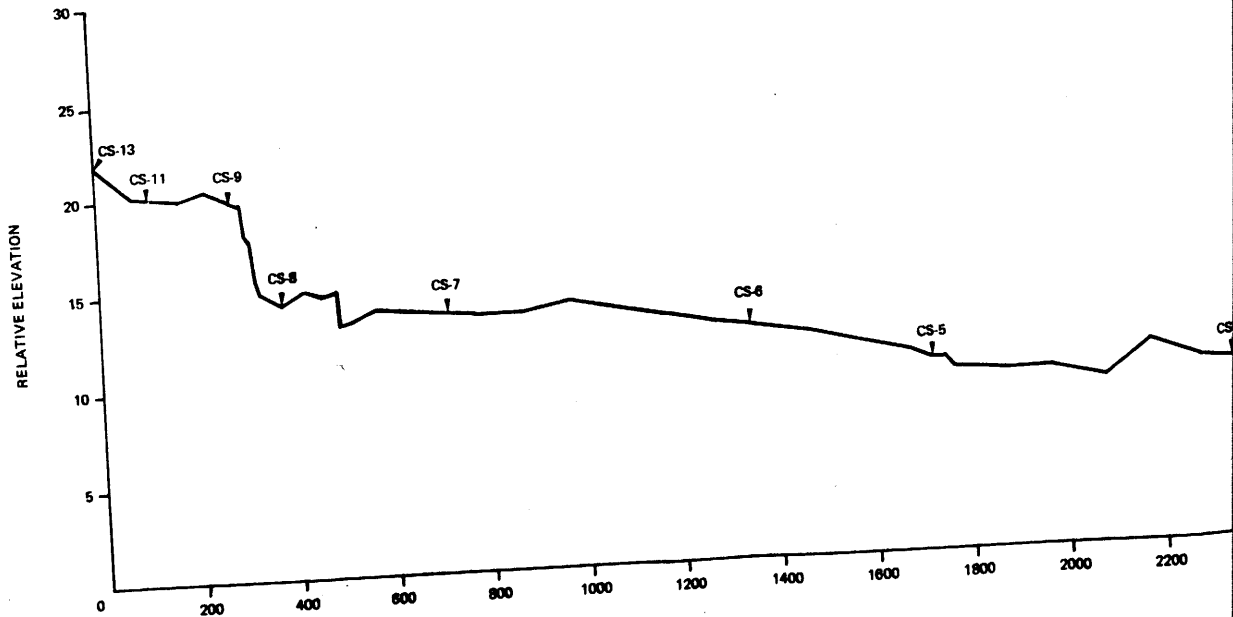
WEST

EAST



† LONG PROFILE - PUEBLO COLORADO CROSS-SECTION 1





LONG PROFILE — UPPER TRIBUTARY

