DEPTHS OF CHANNELS IN THE AREA OF THE SAN JUAN BASIN REGIONAL URANIUM STUDY, NEW MEXICO, COLORADO, ARIZONA, AND UTAH

By

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PREFACE

This is one of a series of reports prepared as part of the San Juan Basin Regional Uranium Study, which is under the leadership of the Bureau of Indian Affairs (BIA). The reports were used as source of material in the preparation of the Regional Study, which is available for public examination at BIA offices in Albuquerque, New Mexico, and Washington, D.C.

The reports listed below are a part of the series that was prepared by the U.S. Geological Survey. These reports have been open filed by the Survey and can be examined by the public at the Survey offices in Denver, Colorado; Albuquerque, New Mexico; and Reston, Virginia.

Water Use in the area of the San Juan Basin Regional Uranium Study, New Mexico, Colorado, Arizona, and Utah--Open File Report 79-1500

Surface-water Environment in the area of the San Juan Basin Regional Uranium Study, New Mexico, Colorado, Arizona, and Utah-----------------------Open File Report 79-1499

Regional Geohydrology of the San Juan Hydrologic Basin of New Mexico, Colorado, Arizona, and Utah--Open File Report 79-1498

Reconnaissance Study of Selected Environmental Impacts on Water Resources due to the Exploration, Mining, and Milling of Uraniferous Ores in the Grants Mineral Belt, Northwest New Mexico--Open File Report 79-1497

Effects of Uranium Development on Erosion and Associated Sedimentation in Southern San Juan Basin, New Mexico-----------------------------Open File Report 79-1496

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Metric Units

English units used in this report may be converted to metric units by the following conversion factors:

English	Multiply by	Metric
foot	0.3048	meter
mile	1.609	kilometer
gallons per minute (gal/min)	3.78543	liters per minute

DEPTHS OF CHANNELS IN THE AREA OF THE SAN JUAN BASIN REGIONAL URANIUM STUDY NEW MEXICO, COLORADO, ARIZONA, AND UTAH

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Abstract

During December 1977 and January 1978 about 280 measurements were made of the depths of channels (arroyos) more than 6 feet deep in the San Juan Basin area. More than half of the measurements were made at sites where channel depths had been previously measured between 1964 and 1969. Some channels in the western part of the basin had been re-measured in 1969 and in 1971.

The principal areas being dissected by arroyos are near highlands along the margins of the basin and in uplands in the northeastern part of the basin. The most severe dissection by arroyos and the deepest arroyos--commonly between 40 and 60 feet deep--are in the southeastern part of the basin. Dissection by arroyos is least in the central part of the basin near the Chaco River where most arroyos are less than 10 feet deep. Elsewhere, moderate dissection predominates with most arroyos between 12 and 40 feet deep.

Comparison of measurements made from 1964-71 with those made in 1977-78 shows that more channels in the western San Juan Basin were filling than were downcutting. Downcutting or filling was generally less than 2 feet. About two-fifths of the sites measured showed less than half a foot of downcutting or filling. Maximum downcutting was 4 feet along the

Rio San Jose in the southeastern part of the basin. Maximum filling of 7 feet was along the Chaco River at the Chaco Canyon National Monument. Along 11 other streams elsewhere in the western part of the basin, channels were filled 3 to 4.5 feet.

The few measurements made in the southeastern San Juan Basin indicate that since 1964 downcutting has predominated over filling.

Large floods during the summer of 1977 caused some change in channel depths in the southwestern part of the San Juan Basin. Some of the channels appeared to have been filled during the years prior to the cutting that occurred from the 1977 floods. At other places, flood flows aggraded (filled) channels.

The rate of erosion and arroyo formation in the entire San Juan Basin is effected by man. The southeastern part of the basin--having been occupied by man for several centuries--shows the greatest effects of man on the rate of arroyo formation. Recent urban developments, particularly near Gallup, also appear to have affected the rate of erosion and arroyo formation. In contrast, arroyos appear to be aggrading below many earth-fill dams.

In general, the effects of the petroleum, coal, and uranium exploration and development on arroyo formation have been minimal because the main trenching of the arroyos predates oil and mining operations. Some modification--degradation or aggradation--of the arroyos and local trenching of new arroyos have taken place in the area of some of the mines. Most of the observed effects from the mining operations on erosion and aggradation relate to the discharge of mine and mill water into the nearby streams.

Introduction

In December 1977 and January 1978 about 280 measurements were made of the depths of channels (arroyos) more than 6 feet deep in the area of the San Juan Basin uranium study, mainly between the south-flowing Rio Puerco[1] in New Mexico near Albuquerque, Black Creek, a tributary of the west-flowing Puerco River in Arizona, and McElmo Creek in Colorado and Utah (fig. 1). More than half of these measurements were made at sites where channel depths had been previously measured between 1964 and 1969. Some of the sites in the western part of the basin were also re-measured in 1969 and in 1971. All the measurements are shown in Plate 1 or Table 1.

The depth measurements provide baseline data useful in assessing the effects of mineral exploration, mining, and milling and other activities relating to the man's occupation of the land on the stream-channel and bottom-land environments. Most of the measurement sites are in the areas of current or projected uranium mining. Depth measurements were not made in the northeastern part of the basin, where little future uranium development is anticipated.

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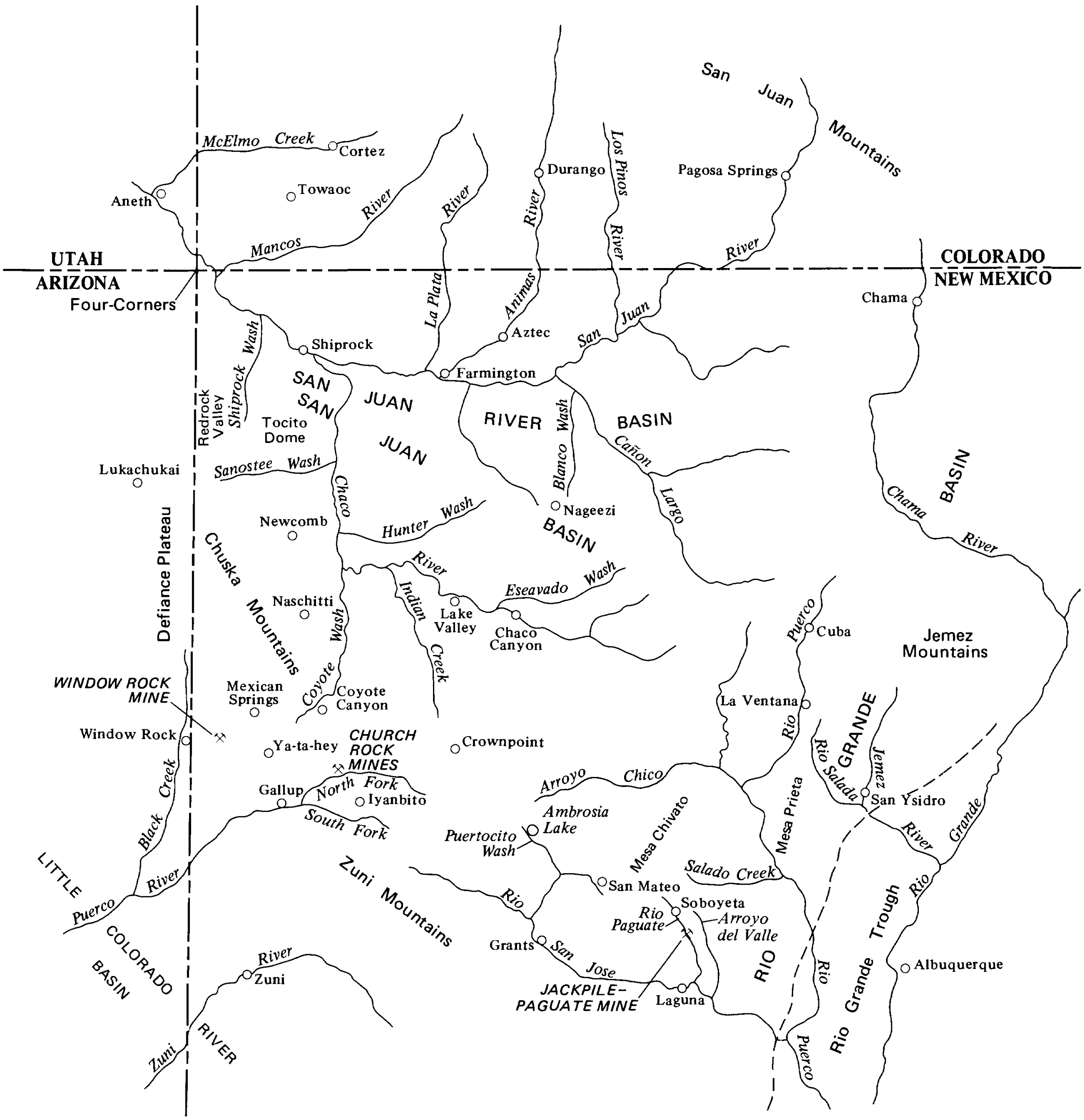
[1]Two rivers that drain parts of the San Juan Basin have the name Puerco--the Rio Puerco in the southeastern part of the basin and the Puerco River in the southwestern part.



Base from U.S. Geological Survey New Mexico (1963) and Colorado (1969) State Base maps and from Simplified Geologic and Uranium Deposit Map of San Juan Basin, U.S. Dept. of Energy, Grand Junction Office, Colorado (1977).

Figure 1.—Location of the San Juan Basin and adjoining area, New Mexico, Colorado, Arizona, and Utah.

Most of the sites measured are in alluvial valleys mainly along trunk streams such as Arroyo Chico, Blanco Wash, Sanostee Wash, Puerco River, and Black Creek that are tributaries of the San Juan River, the Little Colorado River, or the Rio Grande. At these sites stream gradients are low and the bottom land is relatively wide. The location of all sites were determined in the field using 1° X 2° topographic maps (scale 1:250,000). All sites, drainages, towns, and highways are shown in Plate 1.

Most of the streams where depth of channel measurements were made flow only after periods of significant rainfall or snowmelt. Only the Rio San Jose, Rio Salado, and parts of the Rio Puerco, Mancos River, and McElmo Creek are perennial streams. All these streams are subject to flash flooding from major thunderstorms, which are common during the summer (figs. 2 and 3).

Figure 2. Rapid runoff after a thunderstorm of a few minutes duration that occurred on September 1, 1977, near Tocito Dome. The water has a very high suspended sediment content. Such high velocity flows accelerate or can initiate arroyo cutting, especially in areas of sparse vegetation or where the vegetation has been disturbed by man. Flash runoff resulting from summer storms is typical of the San Juan Basin.

Figure 3. View upstream along Mexican Springs Wash near Mexican Springs shows the effects from a large flood that occurred after a major thunderstrom during the summer of 1977. This flood and previous large floods have built a series of gravel bars separated by low-flow channels and reaches where severe scouring occurred. Trees growing on bars that are bent in the downstream direction indicate that flood flows are relatively common along this wash. Large floods cause most of the channels deepening and arroyo cutting.

Methods

Depths of channels and heights of terraces were measured with a hand level or steel tape. For most measurements a hand level was used to measure the distance between the lowest part of the channel or thalweg and the tops of the terraces that enclose the channel (fig. 4). A steel tape was used for measurements made from bridges. Such measurements were made by dropping a steel tape from a part of a bridge such as the wood or concrete curbing or bridge floor to the lowest part of the channel. The heights of the terraces along the channel were tied into the measurement level on the bridge with a hand level. Bridge measurements were made where the bridge did not confine the channel or restrict streamflow. Measurements made with a hand level were recorded to the nearest half foot and those made with a steep tape to one-tenth of a foot.

Most measuring sites are along straight channels, where scouring, degradation or aggradation of channels during floods are at a minimum. Sites of the many terrace measurements along roads generally are in the nearest accessible straight part of the channel downstream and beyond effects on the channel caused by the road. Local channel irregularities caused by scouring, formation of bars, vegetation, or activities of man were avoided as much as possible.

Photographs of the stream channels and bordering terraces were taken at many of the sites to document the present condition of the channel and adjacent valley floors. Other photographs were taken of mining activities--such as tailings ponds and debris dumps--that are on the valley floors and near stream channels. The pictures will be valuable for comparison of present channels conditions to those of the future.

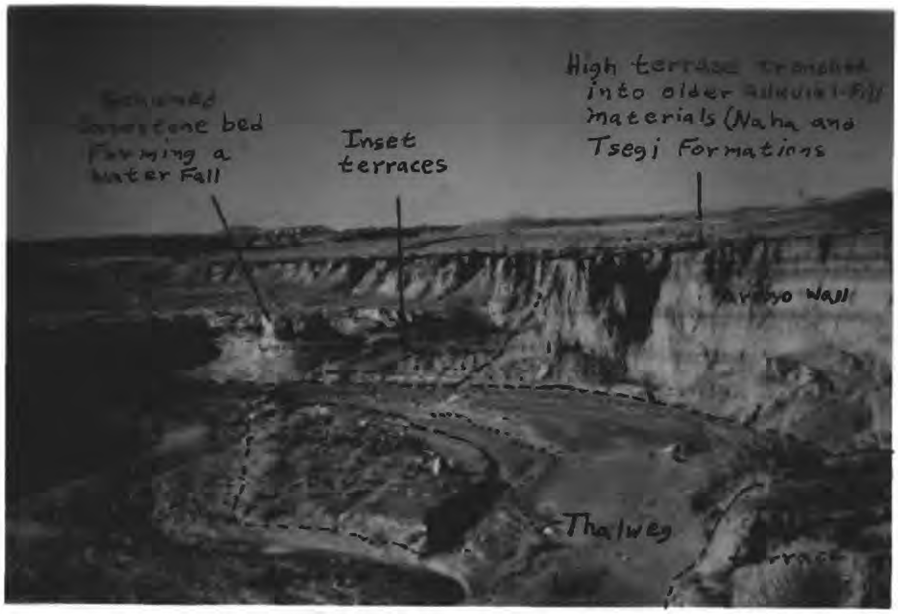


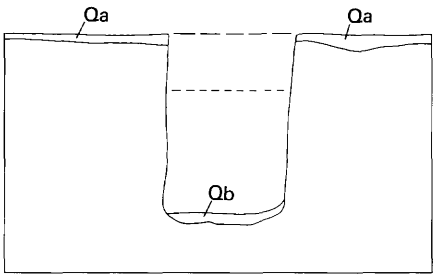
Figure 4. Arroyo of Salado Creek, a tributary of the Rio Puerco southwest of Mesa Prieta. The arroyo is 54 feet deep, which is the amount of post-1850 trenching along this stream. Inset terraces are between 3 and 10 feet high. The stream is actively cutting laterally at the bend. A ledge of sandstone forms a waterfall about 30 feet high. Large boulders on sand and gravel bar at center were eroded from the sandstone ledge.

Description of the channels

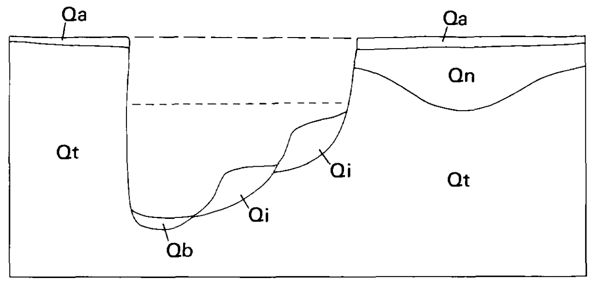
The profiles of the channels (arroyos) are "U" shaped. The banks or walls are nearly vertical, many being more than 20 feet high. Generally only one high terrace adjoins the arroyo; locally two or more high terraces are present. These terraces have been cut from alluvial materials that at one time filled the channel. At present they are seldom if ever flooded. Only the low inset terraces composed of younger alluvial fill in the confines of the arroyos are commonly flooded. The low-flow channel may occupy part or all of the floor of the arroyo depending on the development of the inset terraces. Figure 5 shows typical profiles of arroyos in the San Juan Basin.

The arroyos are excavated into unconsolidated alluvial fill that forms the bottom lands of the basin. Locally, streams have cut through the fill and are trenching the underlying sedimentary rocks. At places, buried sandstone ledges have been exhumed and form waterfalls or rapids. A few of the waterfalls are 20 to 30 feet high (fig. 4). In some places as much as 50 feet of alluvium underlies the streambeds. The alluvium exposed in the arroyo walls consists mainly of lenticular layers of mixed sand and clay. Locally, the alluvium includes beds that contain considerable amounts of organic material, immature soils, or wind-deposited sand. Gravel is a relatively minor constituent, except in alluvium deposited along drainages in highlands and on slopes flanking mesas and escarpments.

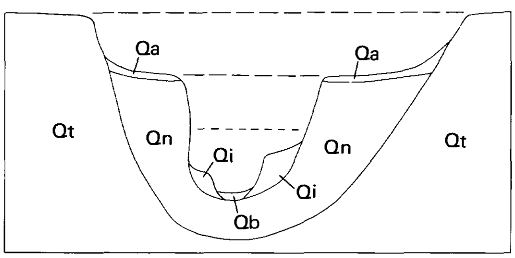
Maps showing distribution of alluvial deposits are available for northwestern New Mexico (Hunt, 1978) and for the part of San Juan Basin in the Navajo Indian Reservation (Cooley and others, 1969, pl. 3).



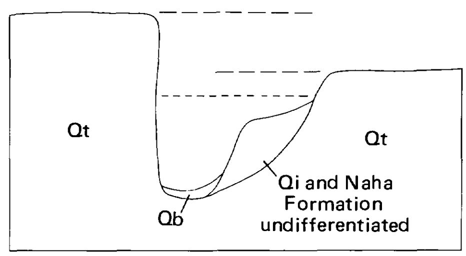
One high terrace cut from Naha or Tsegi Formations. Typical of Indian Creek and Rio San Jose



One high terrace cut from Naha or Tsegi Formations. Typical of Rio Puerco



Two high terraces cut from Naha or Tsegi Formations. Typical of Shiprock Wash at State Highway 504.



Two high terraces cut from Tsegi Formation. Typical of Sanostee Creek at U.S. Highway 666

EXPLANATION

Qb — Modern channel and bedload deposits

Qi — Alluvium (forming inset terraces) deposited in the arroyo after the main trenching event

Qa — Alluvium associated with the present period of arroyo trenching and deposited before the main trenching event

Qn — Naha Formation

Qt — Tsegi Formation

------ Height of major flood such as those that occurred along similar drainages in northeastern Arizona in 1970 (Roeske and others, 1978).

Figure 5.—Typical cross sections of arroyos in the San Juan Basin.

Synopsis of arroyo trenching and alluvial deposition

Arroyos were noted in 1840 along the Rio Puerco and perhaps other streams to the east of Mesa Chivato, where arroyo dissection has been especially severe (Bryan, 1925). During the late 19th century, most ephemeral streams and some of the small perennial streams began to rapidly deepen their channels. The channels of the large perennial streams--including the San Juan, Animas, and Jemez Rivers and Rio Grande--were little affected by the formation of the arroyos on their tributaries. In the Navajo Indian Reservation, widespread accelerated cutting did not begin until the 1880's (Gregory, 1917, p. 130-131). Only a few valleys, mainly in the south-central part of San Juan Basin and in small areas southwest of Shiprock and near Grants, have not been affected by arroyo formation.

The first event of the arroyo forming episode was deposition, principally sand and gravel, over the pre-arroyo valley floor (Cooley, 1962, p. B50; R. B. Morrison, oral commun., 1972). At most localities these deposits are the coarsest sediments present except for the modern bedload material. Generally, the deposits are less than 1 foot thick, but at many places they are 5 to 6 feet thick. In western Redrock Valley and along a few drainages near the Rio Puerco the deposits include channel fills 14 feet thick.

Deposition of the coarse sediment was followed by a period of major trenching that occurred principally before 1890 (Byran, 1925; Gregory, 1917, p. 130-131; Gregory and Moore, 1931, p. 43) when many arroyos were cut to their approximate present depths. Since 1890, the arroyos have widened--some by several hundreds of feet--although many are still less than

100 feet wide. Some sediment has been deposited in the arroyos since the main trenching event. This sediment (excluding the bedload material) mainly forms low inset terraces (figs. 4 and 5), which generally are 2 to 12 feet high. In places, root crowns of cottonwood trees and other riparian vegetation are buried in the inset terraces.

Along many drainages the arroyos have trenched alluvium that consist of two distinct deposits, that are believed by the author to be correlative with the older Tsegi Formation and the younger Naha Formation (Hack, 1942). These alluvial formations have been recognized along drainages displaying similar alluvial sequences in northeastern Arizona.

An easily identified erosion surface separates the sediments of the Tsegi Formation from the overlying Naha Formation. Channels of this old erosion surface generally are about two-thirds as deep and not as wide as the present arroyos, although in places the old channels may extend below the present arroyo beds. Along most drainages the Naha Formation filled channels excavated into the Tsegi Formation and spread over much of the adjacent bottom land. In a few drainages, however, the Naha Formation only partly filled the channels and in these drainages the Tsegi Formation forms a terrace (fig. 5). The top of the Naha Formation forms the pre-arroyo surface that was entrenched during the 19th century.

In the San Juan Basin and nearby areas the Tsegi Formation is not known to contain buried Basketmaker or Pueblo archaeological sites, however, the Naha Formation contains artifacts ranging in age from about A. D. 500 to 1300 (Basketmaker III through Pueblo I to III) (Deric

O'Brian, oral commun., 1969). Most of the Naha Formation was deposited by the end of Pueblo III time--about A. D. 1300, although some aggradation continued until terminated by the present arroyo-trenching episode.

Distribution and depths of arroyos

Principal areas of arroyos are near highlands along the margins of San Juan Basin and in uplands occupying the northeastern part of the basin. The most severe dissection and maximum depths of arroyos are in the area near the Rio Puerco and east of Mesa Chivato (fig. 6). Here, Arroyo del Valle has a maximum depth of 60 feet and the arroyo of the Rio Puerco near La Ventana and south of Mesa Prieta is about 50 feet deep (fig. 7). The smallest amount of dissection is in the central part of San Juan Basin, the area north and east of the Chaco River where streams flow in broad sand-floored channels bordered by terraces less than 10 feet high. Many streams draining the gentle slopes and alluvial lowlands south of the Chaco River have discontinuous arroyos. Some of the lowland areas remain largely undissected.

Elsewhere in the San Juan Basin generally moderate arroyo dissection predominates (fig. 6). This dissection is locally severe, especially near highlands. Depths of most arroyos in the area are between 12 and 30 feet; maximum depth is about 40 feet. The area includes broad valleys or slopes near Grants, Zuni, and Shiprock, which contain few arroyos.

Figure 6.--Map of the San Juan Basin showing generalized areas of slight to severe arroyo dissection.

1A Generally slight to moderate arroyo dissection mainly along the larger streams such as Hunter and Escavada Washes in the northern part of the lowlands occupying central San Juan Basin.
These streams have wide, shallow, sand-floored channels bordered by low terraces generally less than 10 feet high. Broad uplands between the streams are mantled by dune sand and sandy terraces and pediment deposits. These uplands have a few relatively shallow arroyos.

1B Generally slight to moderate arroyo dissection along only the main streams draining the southern part of the lowlands in central San Juan Basin. Nearly all of the few main arroyos present range between 10 and 20 feet deep. The broad alluvial flats and valley floors in the area contain only discontinuous arroyos and some areas are relatively undissected. Arroyo dissection is retarded by many earthen dams.

2A Generally moderate, locally severe, arroyo dissection along most streams draining the uplands and mountainous areas along the perimeter of San Juan Basin. Depths of arroyos vary widely, but depths along most streams are between 12 and 30 feet. Maximum depth is about 40 feet.

2B Similar to 2A except this area contains some broad slightly dissected valleys and the slightly dissected summit of Mesa Chivato. Arroyos are not as widely distributed or generally as deep as the arroyos of 2A.

3. Generally severe arroyo dissection along the Rio Puerco and some of its main tributaries and near small Hispanic and Indian villages on the eastern side of Mesa Chivato. Arroyos are as much as 51.5 feet deep along the Rio Puerco and 60 feet deep along Arroyo del Valle. Arroyos commonly are more than 25 feet deep.

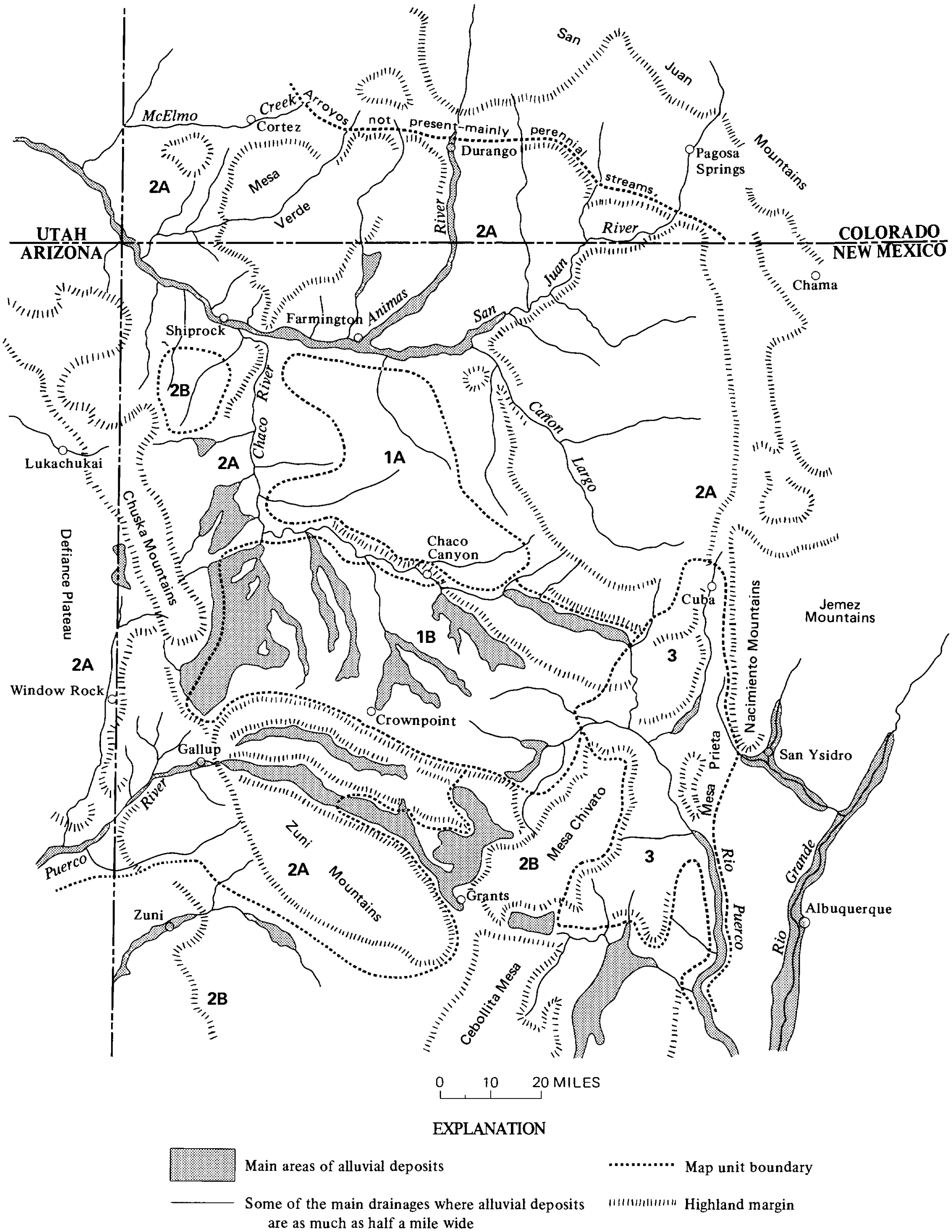


Figure 6.—Physiographic map showing generalized areas of slight to severe arroyo dissection and the main alluvial deposits.

Figure 7.--Arroyo of the Rio Puerco south of Mesa Prieta. The arroyo is trenched 50 feet below the high terrace and is as much as a quarter mile wide. It is the largest arroyo in the San Juan Basin area. According to Bryan (1925) arroyo trenching began in 1840 in the Rio Puerco drainage. The summit of the high terrace represents the pre-1840 flood plain. Dark stripes in the channel are tire tracks.

Changes in depths of channels

Comparison of channel depths in 1965-71 with depths in 1977-78 shows that more channels in the western San Juan Basin are filling than are downcutting (pl. 1, table 1). The amount of downcutting or filling was generally less than 2 feet. About two-fifths of the sites measured had less than half a foot of downcutting or filling. Maximum downcutting was 4.5 feet along a tributary to Salt Springs Wash near Naschitti (pl. 1, site 59). Three feet of downcutting also occurred near Coyote Canyon (pl. 1, site 37) partly as a result of a dam breached during a flood. A maximum of 7 feet of filling occurred in the narrow inner channel of the Chaco River in the Chaco Canyon National Monument (pl. 1. site 15). Downstream from the monument near Lake Valley (pl. 1. site 17) the Chaco River had aggraded its channel by 4 feet and at site 22 (pl. 1.), above the mouth of Indian Creek (fig. 8), the channel had aggraded about 2 feet.

Changes in depths along a single stream may differ rather widely. For example, measurements at sites 78-82 along Sanostee Wash (table 1) indicate that between 1966 and 1977 as much as 2.5 feet of downcutting and between 1.5 and 4.5 feet of filling along different reaches of the stream. Similarly, filling occurred at three places and cutting at two places along the South Fork of the Puerco River and filling occurred at three places and cutting at two places (sites 6, 8, 9, 14, and 18) along the Puerco River. No appreciable change in the channel depth occurred at site 10 on the Puerco River between 1966 and 1977.

Figure 8.--Broad aggrading channel of Chaco River at site 22 upstream of the mouth of Indian Creek. Two feet of aggradation occurred between 1966 and 1978. Subdued appearance of the channel features indicate that large flows have not occurred recently. This reach of the Chaco River is upstream of the reach affected by the floods of 1977 (see fig. 12). Cliffs on the far side of the river are of the Cliff House Sandstone.

Floods resulting from thunderstorms during the summer of 1977 caused some change in channel depths in the southwestern part of San Juan Basin (figs. 3 and 11). Such floods occurred west of Ya-ta-hey, along streams crossed by U.S. 666 between Ya-ta-hey and Sanostee Wash, near Iyanbito, and in the Indian Creek drainage between Coyote Canyon and Standing Rock. Other measurements made of the streams between Ya-ta-hey and Sanostee Wash and a few other streams in western San Juan Basin indicate that no significant change in depths of channels occurred between 1966 and 1971 (table 1).

Along the channel of Mexican Springs Wash (site 28-30, 32) and a tributary of Coyote Wash (site 42) near Coyote Canyon the floods caused 2 feet of scouring to the approximate channel depths of 1966. Both channels appear to have been aggrading prior to the 1977 floods.

The 1977 floods at Indian Creek, Coyote Wash, and other drainages caused considerable scouring and some deepening of the Chaco River channel downstream from the mouth of Indian Creek. At site 73 the river channel was deepened by 1 foot (fig. 12). In contrast, the river channel upstream from Indian Creek has aggraded and its appearance indicates a large flow has not occurred during the past several years (fig. 8).

A large sandbar was deposited at site 13 (pl. 1) on a small drainage near Iyanbito by a 1977 flood. At the site the channel was 2 feet shallower than it was in 1966. Below the downstream end of the sandbar, the channel had scoured slightly.

Considerable erosion and modification of channels were caused by floods of September 1970 in part of western San Juan Basin and areas to the west and southwest principally in Arizona (Roeske and others, 1978).

Examination of the channels and depth-of-channel measurements made in 1965-67 and 1971 by the author indicated that the maximum amount of downcutting or aggradation by streams attributed to this single flood event was generally less than 1 foot in western San Juan Basin (table 1) and as much as 4 feet in northeastern Arizona.

Data on channel filling along other drainages are shown in the following tabulation:

Channels aggraded between 1965-71 and 1977-78

By 3-3.5 feet of sediment	By 4-4.5 feet of sediment
Three drainages between Ya-ta-hey, N. Mex., and Window Rock, Ariz., sites 24, 25, and 33.	Black Creek drainage, sites 38 and 39.
Small drainage near Crownpoint, site 19.	North Fork of Puerco River, site 4.
	Salt Springs Wash, site 58.
Near Coyote Canyon, site 39.	Sanostee Wash, sites 78 and 80.
Near Naschitti, site 62.	
Hunter Wash, site 69 (fig. 9).	
Navajo (Spring) Creek near Towaoc, Colo., site 99.	

The few measurements made in southeastern San Juan Basin indicate that since the original observations in 1964-67 downcutting predominated over filling (table 1). As much as 4 feet of cutting occurred along Rio San Jose at Laguna (fig. 10) and near Mesita (pl. 1, sites 14 and 15), and 2 feet of cutting occurred along the Rio Puerco at I-40 (pl. 1, site 5) west of Albuquerque. About 2.5 feet of filling took place in the channel of Rio Salado south of La Ventana (pl. 1, site 1).

Figure 9.--View downstream of the aggrading sand-floored channel of Hunter Wash at site 69, 3 miles upstream of its confluence with the Chaco River. The amount of aggradation between 1966 and 1978 was 3 feet. If aggradation continues, the low inset terrace and small dug well used by the Navajo Indians will be buried by sand. A low-flow channel is present between the broad sandbars.

Figure 10.--Upstream view of the channel of Rio San Jose at site 14, at Laguna. Bridge is of old U.S. Highway 66. The channel is between well-developed inset terraces 3 to 5 feet high. Eroded edge of the high terrace, 36 feet high, is at lower right. The upright riparian vegetation on the inset terraces indicate that these terraces have not been inundated recently by large floods. Between 1967 and 1978 the channel was deepened 4 feet. Effects of urban development around Laguna and encroachment of riparian vegetation probably caused narrowing of the channel and its subsequent deepening. Ripples in the sand bed can be seen through the nearly clear flow of the river. At this time the stream carried little suspended sediment.

Figure 11.--Channel of an unnamed wash crossed by State Highway 56, at site 20, 11 miles northeast of Crownpoint. The channel had been aggrading prior to the 1977 summer floods. Flood flows scoured the channel to a depth of 2 feet, which was the channel depth in 1966. The high terrace is 15 feet above the bed of the wash.

Figure 12.--Downstream view of the broad channel of the Chaco River at a road crossing 10 miles northeast of Newcomb (site 73). The channel shows effects of the 1977 summer flood (see also fig. 8). The angular and steplike appearance of the sandbars were caused by flood flows. The amount of change in channel depth between 1966 and 1978 was only about 1 foot. The high terrace is about 10 feet above the channel.

Some effects of man's activities on arroyos

Any disturbance of the soil or vegetation affects erodability and the amount of sediment potentially transported from an area. Constriction of runoff by buildings, roads, railroads, ditches, and other manmade structures accelerates channeling and possible cutting of arroyos or gullies. At many places, long straight arroyo reaches have formed along roads--including old wagon roads, ditches, and stock and animal trails (fig. 13). Denuding of the natural vegetation by overgrazing, tramping around dwellings and stock corrals, or tramping by animals around wells, stock ponds, or natural watering places has increased the runoff rate and funnelled the runoff into channels--a condition which accelerates arroyo formation. Rapid runoff, particularly from thunderstorms, markedly compounds man's effects on the rate of arroyo formation. In general the effects of man's activities are most conspicuous along drainages in the narrower parts of valleys or on relatively steep slopes where runoff tends to be confined in channels. Man's effects on the rate of arroyo trenching are least in the open flats with low gradients.

The entire San Juan Basin shows the effects by man on erosion and arroyo trenching. In general, the parts of the basin showing the greatest effects of man's activities correspond with areas 2 and 3 having moderate to severe arroyo dissection (fig. 6, map units 2 and 3). Map unit 3, having the most severe arroyo trenching, has been occupied for several centuries by people living in villages or towns (fig. 14). Broad areas of the basin (principally map units 1A and 1B) generally have been occupied only by widely scattered settlements. Recent urban developments

Figure 13.--Small arroyo formed along stock trails and a dirt ranch road leading to a windmill. Arroyo is about 3 feet wide and has a maximum depth of 5 feet. Long-straight arroyos commonly result from man's activities.

Figure 14.--Accelerated erosion and arroyo formation east of Mesa Chivato at Seboyeta. Vegetation has been nearly denuded by overuse of the land near this village. Accelerated sheet erosion occurring on both slopes of this small arroyo contribute significantly to the suspended sediment load of streams.

also effect erosion and arroyo formation along some drainages. For example, continued deepening of the arroyo of the Puerco River (table 1) at Gallup (pl. 1, site 19) is partly the result of more recent urban expansion.

Earth-fill dams, are present along many drainages. Where these dams are in good condition, the arroyos appear to be aggrading. This conclusion is based on depth-of-channel measurements in Coyote Wash drainage area (table 1) and in other drainages that display rounded, sloping arroyo walls, small alluvial fans along the base of the arroyo walls, and by vegetation growing in the arroyo. Much of the fill in these arroyos is derived from the arroyo walls and from nearby bottom lands.

As the main trenching of the arroyos predates oil and mining operations the effects on arroyo formation of the petroleum, coal, and uranium exploration and development appear to be minimal. However, in the mining areas some degradation or aggradation of the old arroyos has occurred and locally some trenching of new arroyos or gullies has taken place. Major changes in vegetation also have taken place in a few arroyos. At present (1978), most of the uranium mining, with the exception of the Ambrosia Lake area, is in the areas of moderate to severe arroyo dissection of Figure 6.

Mining and milling activities that affected the depth of the arroyos were recognized at only a few localities studied in 1977-78. Affected arroyos were near the Church Rock mines, the Window Rock coal mine, and in the Ambrosia Lake area. These areas were affected by the discharge of mine and mill water into nearby stream channels. Other effects, such as the encroachment and blocking of stream channels by mine dumps and tailings ponds, the erosion of these features, and the spreading of water on the bottom lands, are discussed briefly in Part A, Supporting Document 11 (Cooley, M.E., 1979).

Water from the Church Rock mines is discharged into an unnamed tributary of the North Fork of the Puerco River. Before the mines and an associated mill were in operation, most of this tributary arroyo was about 20 to 30 feet deep. The more or less continuous discharge of mine water caused deepening of the arroyo near the mines. At one point the arroyo appears to have been deepened by approximatly 8 feet--from about 33 feet to the present depth of 41 feet (pl. 1). The amount of deepening was determined primarily from the discontinuous patches of gravel in the arroyo walls about 8 feet above the streambed. These deposits are believed to represent the depth of the arroyo prior to discharge of the mine water. Recent deepening of the arroyo is also indicated by the steep, narrow sides of the partially developed inner channel and by the absence of sand or gravel bars along the streambed.

The mine water flows along the North Fork and the main stem of the Puerco River through Gallup to beyond the Arizona State line. The flow has caused some aggradation and widening of the arroyo upstream from Gallup. Much of the sediment filling the channel has been obtained through lateral cutting and slumping of the arroyo walls (fig. 15). At site 4 (pl. 1), along the North Fork, 4 feet of filling occurred between 1966 and 1977. Some of the filling resulted from large flows during the summer of 1977. Until 1971 the channel of the Puerco River at the hogback ridges east of Gallup (site 19, pl. 1; table 1) had gradually deepened. Since 1971 about 2 feet of filling has resulted from a combination of the effects of mine water discharge, the floods of the summer of 1977,

Figure 15.--Arroyo of the Puerco River at the hogback ridges upstream from site 19 east of Gallup. Water discharged from the Church Rock mines is cutting laterally into the arroyo wall. Part of the arroyo wall is undercut near center of photograph. Two recent slumps of alluvium from the arroyo wall has locally diverted the streamflow. The arroyo is 25 feet deep and 100-150 feet wide.

and urban development near the site (fig. 15). Downstream of Gallup at sites 27 and 28 near the New Mexico-Arizona State line new highway and bridge construction probably mask the effects of the mine water discharge on changes in depth of the river channel (table 1).

Water from the Window Rock coal mine is discharged to a small unnamed tributary arroyo of Black Creek east of Window Rock, Arizona. At site 33 along State Highway 264 (pl. 1), this arroyo has deepened from 7 to 10.5 feet since 1965. The deepening is believed to have been caused primarily by the flow of mine water into the arroyo. Most other nearby arroyos had filled slightly since 1965 (table 1).

In the Ambrosia Lake area, the discharge of mine and mill water has resulted in the growth of a lush stand of cattails and tall grasses in the arroyo of Puertocito Wash that drains the area (fig. 16). The vegetation has caused sediment to accumulate in the arroyo. The sediment is derived from a large tailings pile that adjoins the creek, from erosion of the arroyo walls, and from overland flow that enters the arroyo from the adjacent bottom land. Owing to the absence of previous depth of channel measurements, the depth of the filling is not known.

Figure 16.--View upstream (north) along arroyo of Puertocito Wash that drains the Ambrosia Lake area. The arroyo is 6.5 feet deep. Mine-mill effluent supports the lush growth of cattails and tall grasses on the arroyo bed. The vegetation has resulted in accumulation of sediment in the arroyo. The sediment is derived from a tailings pile that adjoins the creek, from erosion of the arroyo walls, and from overland flow that enters the arroyo from the adjacent bottom land. The sloping arroyo walls indicate the lack of recent cutting--perhaps since the mine-mill effluent has been discharged into the arroyo.

The entire San Juan Basin shows the effects by man on erosion and arroyo trenching. In general, the parts of the basin showing the greatest effects of man's activities correspond with areas 2 and 3 having moderate to severe arroyo dissection (fig. 6, map units 2 and 3). Map unit 3, having the most severe arroyo trenching, has been occupied for several centuries by people living in villages or towns (fig. 14). Broad areas of the basin (principally map units 1A and 1B) generally have been occupied only by widely scattered settlements. Recent urban developments also effect erosion and arroyo formation along some drainages. For example, continued deepening of the arroyo of the Puerco River (table 1) at Gallup (pl. 1, site 19) is partly the result of more recent urban expansion.

Conclusions and recommendations

Principal arroyo formation occurs along the highlands along the margins of San Juan Basin and in the uplands of the northeastern part of the basin. In these areas most arroyos are between 12 and 30 feet deep. The greatest rate of surface dissection by arroyos and maximum depths of arroyos, as much as 60 feet, are in the southeastern part of the basin drained by the Rio Puerco. The smallest amount of dissection by arroyos is in the central part of the basin near the Chaco River where many streams have broad sand-floored channels generally less than 10 feet deep. Some of the broad alluvial flats south of the Chaco River contain only discontinuous arroyos.

The entire San Juan Basin shows some effects of man on erosion and trenching by arroyos. Man's activities are more conspicuous along drainages in narrower parts of valleys or on slopes where runoff tends to be confined in channels, as evidenced by continued deepening of the arroyo of the Puerco River at Gallup through 1971. The area of most severe arroyo dissection in southeastern San Juan Basin has been occupied by man for several centuries. The central part of the basin shows the least amount of arroyo dissection and affects of man. Along some drainages where earth-fill dams have been constructed arroyo floors are aggrading.

Measurements of the depths of channels between 1964-71 and 1977-78 indicate that at about two-fifths of the re-measured sites there was little or no change in channel depths. Aggradation predominated over downcutting in western San Juan Basin. In the eastern part of the basin the few data available indicate that downcutting predominated over aggradation. The maximum amount of downcutting noted was 4 feet. Maximum aggradation was

7 feet at the Chaco Canyon National Monument along the Chaco River and 4-4.5 feet of filling occurred at places along four other drainages. By far the largest volume of sediment deposited was in the wide channel of the Chaco River downstream from the National Monument to the mouth of Indian Creek. The measurements also show that cutting occurred in some reaches of Sanostee Wash and South Fork of the Puerco River while filling occurred in other reaches during the same period.

Some of the changes in depths of channels are attribute to large flood flows that occurred in the southwestern part of San Juan Basin during the summer of 1977. These floods caused aggradation along streams near State Highway 264 between Ya-ta-hey and Window Rock, and downcutting in washes near U.S. 666 between Ya-ta-hey and Sanostee Wash, near Iyanbito, in the Indian Creek drainage, and in the lower reaches of Chaco River. The floods also caused scouring of some of sediment deposited in the channels of Mexican Springs Wash and tributary washes of Coyote Wash between 1966 and 1977. The amount of scouring was about equal to the amount of sediment that had been deposited.

Most of the observed effects on changes in depth of channels from mining operations have resulted from the discharge of mine and mill water. Water from the Church Rock mines caused local arroyo deepening of as much as 8 feet. The flow from the mine together with the floods of 1977 and local urban development have caused some aggradation and widening of the arroyo of the North Fork and main stem of the Puerco River upstream from Gallup. Since 1965, water from the Window Rock coal mine is believed to be the principal cause of deepening of an unnamed tributary arroyo of Black Creek by 3.5 feet.

In the Ambrosia Lake area, mine and mill water discharge sediment in part derived from a large tailings pile has partially filled the arroyo of Puertocito Wash.

Recommendations for future investigations of arroyos and stream channels include studies of the channel geometry--the depth, width, and configuration of the channels--and of conditions of erosion and sedimentation in the arroyos near the present mines and mills, at future mine and mill sites, and at selected sites along other streams in the San Juan Basin. Particular attention should be given to changes in riparian vegetation in arroyos containing flow derived from the mining and milling operations and its effects on the channel geometry, erosion, and sedimentation. Periodic re-measuring of the depth-of-channels are needed to help determine effects from mining and milling operations, and from other activities of man in the basin. Photographic documentation of the changes in the arroyos is also needed. Lastly, information on the occurrence, distribution, and amount of discharge of large floods and of mine and mill water discharge should be compiled to provide data on flow conditions that will affect channel geometry.

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Table 1.--Heights of terraces and changes in depths of channels in the area of the San Juan Basin regional uranium study of New Mexico, Colorado, Arizona and Utah

Drainage and location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel from previous measurement 2	Downcutting since the late 19th century	Remarks
San Juan River drainage basin							
Canyon Largo drainage							
Unnamed tributary at State Highway 44; sec. 13, T. 22 N., R. 4 W.	1		4	-66		4	
			3	1-8-78	+1	3	
Unnamed tributary at State Highway 44; sec. 9, T. 22 N., R. 4 W.	2		-/4	-66		4	
		AM	-/3	1-8-78	+1	3	
Unnamed tributary at State Highway 44; sec. 1, T. 22 N., R. 5 W.	3		8	-66		8	
		Y	6	1-8-78	+2	6	
Blanco Wash drainage							
Blanco Wash at State Highway 44; sec. 36, T. 24 N., R. 8 W.	4		4/8	-66		8	
			-/7	1-8-78	+1	7	
Unnamed tributary to Blanco Wash at State Highway 44; sec. 35, T. 24 N., R. 8 W.	5		7	-66		7	
			5	1-8-78	+2	5	
Gallegos Canyon drainage							
Unnamed tributary at State Highway 44; Sec. 34, T. 26 N., R. 10 W.	6		3	-66			
			3.5	1-16-78	-.5		
Gallegos Canyon drainage south of Farmington; sec. 13, T. 26 N., R. 12 W.	7		2/4/7	7-16-66		7	
			-/-/7	1-16-78	0	7	

Drainage and location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
West Fork Gallegos Canyon; sec. 17, T. 26 N., R. 12 W.	8	A	-/3/5/8	7-16-66		8	
		A	2/3/5/8	1-16-78	0		
West Fork Gallegos Canyon; sec. 7, T. 26 N., R. 12 W.	9	A	3/5	7-16-66		5	
		A	3/4.5	1-16-78	+.5	4.5	
Animas River drainage							
Estes Arroyo tributary to Animas River; sec. 31, T. 31 N., R. 11 W.	10	A	2/5.5	9-19-66		5.5	
			-/5	1-16-78	+.5	5	
Farmington Glade north of Farmington; sec. 31, T. 31 N, R. 12 W.	11		3-4/16/18.5	9-19-66		16	
			-/-/18.5	1-16-78	0		
La Plata River drainage							
La Plata River at La Plata; sec. 3, T. 31 N., R. 13 W.	12		3/8/14	9-19-66			
			4-5.5/8/14	1-16-78	0		
McDermott Arroyo near La Plata; sec. 2, T. 31 N., R. 13 W.	13	A	4/7/18.5	9-19-66		18.5	
			4/7/-	1-16-78	0		
Westwater Arroyo near Fruitland sec. 6, T. 29 N., R. 15 W.	14	M	3/7/14	2-6-66			
		M	-/-/12	1-15-78	+2		
Chaco River drainage							
Chaco River at Chaco Canyon National Monument; sec. 13, T. 21 N., R. 11 W.	15		2/5/10/30	4-21-66		30	
			2/5/6/23	12-18-77	+7	23	
Choukai Wash north of Chaco Canyon National Monument; sec. 25, T. 22 N., R. 11 W.	16		2/15/25?	4-21-66			
			-/15/25?	12-18-77	0		

Drainage and location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Indian Creek northwest of White Rock; unsurveyed.	26		4/16 -/16	7-12-66 1-12-78	 0	16 16	Large flow in summer of 1977.
Indian Creek northwest of White Rock; unsurveyed.	27	A	5/12 7/11	7-12-66 1-12-78	 +1	12 11	Large flow in summer of 1977.
Mexican Springs Wash 4 miles northwest of Mexican Springs; unsurveyed.	28		4-5/15-16/20 -/-/19.5	9-30-66 12-16-77	 +.5	15-16	
Mexican Springs Wash northwest of Mexican Springs; unsurveyed.	29		5/7-8/17 -/-/16	9-30-66 12-16-77	 +1	17 16	
Mexican Springs Wash northwest of Mexican Springs; unsurveyed.	30		5-6/11/18 -/-/18	9-30-66 12-16-77	 0	18 18	
Mexican Springs Wash northwest of Mexican Springs; unsurveyed.	31	A A	5/7 -/4	9-30-66 12-16-77	 +3		Mainly fill above dam.
Mexican Springs Wash near Mexican Springs, unsurveyed.	32		4-6/7?/10/16 -/-/-/16	9-30-66 12-16-77	 0	16 16	Large flow in summer of 1977 appears to deepened channel by 2-3 feet below level of previous fill.
Catron Wash at U.S. 666; sec. 28, T. 18 N., R. 18 W.	33	M M	3 4	2-6-66 12-19-77	 -1	3 4	
Unnamed tributary to Catron Wash at U.S. 666 at Twin Lakes; sec. 8, T. 17 N., R. 18 W.	34		7/17.5 -/18 -/17.5	2-6-66 5-10-71 12-15-77	 -.5 +.5	17.5 18 17.5	Bedrock exposed in channel below point of measurement.

Drainage and Location (sites without state designation are in New Mexico)	Location number plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Differences in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Unnamed tributary to Catron Wash at U.S. 666 near Twin Lakes; sec. 5, T. 17 N., R. 18 W.	35		2/5/11	2-6-66		11	Large flow occurred in summer of 1977.
			-/-/12	2-15-77	-1	12	
Unnamed tributary to Coyote Wash southwest of Coyote Canyon; sec. 16, T. 17 N., R. 17 W.	36		3/6/12	7-10-66			
			-/-/12	2-15-77	0		
Unnamed tributary to Coyote Wash southwest of Coyote Canyon; sec. 8, T. 17 N., R. 17 W.	37	M	5	7-10-66		5	Dam breached by large flow.
			8	2-15-77	-3	8	
Unnamed tributary to Coyote Wash southwest of Coyote Canyon; sec. 7, T. 17 N., R. 17 W.	38	A	2/5	7-10-66		5	
		A	2/4	2-15-77	+1	4	
Coyote Creek west of Coyote Canyon; sec. 30, T. 18 N., R. 17 W.	39		17.5	7-10-66		17.5	
		A	14	2-15-77	+3.5	14	
Coyote Creek west of Coyote Wash at Coyote Canyon; sec. 19, T. 18 N., R. 17 W.	40	A	9/11	7-10-66		9	
		A	7/9	2-15-77	+2	7	
Unnamed tributary to Coyote Wash at Coyote Canyon; sec. 23, T. 18 N., R. 17 W.	41	A/M	3	7-10-66			
		A/M	2	2-15-77	+1		
Unnamed tributary to Coyote Wash near Coyote Canyon; sec. 14, T. 18 N., R. 17 W.	42		21	7-10-66		21	Large flow in 1977 appears to have deepened channel by 1-2 feet into previously laid fill.
			21.5	2-15-77	-.5	21.5	

Drainage and location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Unnamed tributary to Coyote Wash east of Coyote Canyon; sec. 16, T. 18 N., R. 16 W.	43		2/10 3/9.5	7-10-66 12-16-77	 +.5	10 9.5	
Unnamed tributary to Coyote Wash east of Coyote Canyon; sec. 16, T. 18 N., R. 16 W.	44		5 6	7-10-66 12-16-77	 -1	5 6	
Unnamed tributary to Coyote Wash east of Coyote Canyon; sec. 14, T. 18 N., R. 16 W.	45		5 4	7-10-66 12-16-77	 +1	5 4	Large flow in summer of 1977 inundated road.
Unnamed tributary to Coyote Wash east of Coyote Canyon; sec. 13, T. 18 N., R. 16 W.	46		<3 4	7-10-66 12-16-77	 >-1		
Unnamed tributary to Coyote Wash west of Standing Rock; sec. 10, T. 18 N., R. 15 W.	47		8 10	7-10-66 12-16-77	 -2	8 10	
Red Willow Wash near Tohatchi; unsurveyed.	48		2-4/6 -/6 -/10	9-29-65 5-10-71 12-19-77	 0 -		New measuring point established by Pueblo ruin because of large flow in summer of 1977.
Unnamed tributary to Red Willow Wash at U.S. 666 near Tohatchi, unsurveyed.	49		3/5/7 -/6/8.5	2-6-66 12-19-77	 -1.5		Large flow in summer of 1977.
Unnamed Tributary to Red Willow Wash at U.S. 666 near Tohatchi, unsurveyed.	50	A	-/17 -/17 3/19	2-6-66 5-10-71 12-19-77	 0 -2	17 17 19	

Drainage and location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Unnamed tributary to Red Willow Wash at U.S. 666 east of Tohatchi; unsurveyed.	51		3/12	2-6-66			Large flow in summer of 1977.
			5/12.5	12-19-77	-.5		
Unnamed tributary to Red Willow Wash at U.S. 666 east of Tohatchi; unsurveyed.	52		3/5-6	2-6-66		5-6	
			3/6	12-19-77	0	6	
Coyote Wash northeast of Tohatchi; sec. 33, T. 20 N., R. 16 W.	53	A	6	7-11-66		6	
		A	4	12-19-77	+2	4	
Unnamed tributary to Coyote Wash at Standing Rock; sec. 7, T. 18 N., R. 14 W.	54		8	7-10-66		8	
			8-9	12-19-77	-1	8-9	
Unnamed tributary to Coyote Wash at U.S. 666; sec. 4, T. 19 N., R. 17 W.	55		2/6	2-6-66		6	
			-/7	12-19-77	-1	7	
Unnamed tributary to Coyote Wash at U.S. 666; sec. 4, T. 19 N., R. 17 W.	56		2-3/5.5/7.5	2-6-66		7.5	Large flow in summer of 1977.
			3/8/10	12-19-77	-2.5	10	
Unnamed tributary to Coyote Wash at U.S. 666; sec. 21, T. 20 N., R. 17 W.	57		2/5/14	2-6-66		14	Large flow in summer of 1977.
			-/-/14	5-10-71	0	14	
			-/-/15.5	12-19-77	-1.5	15.5	
Salt Springs Wash at U.S. 666; unsurveyed.	58		3-5/7?/17	2-6-66		17	
			-/-/16.5	5-10-71	+.5	16.5	
			-/-/14.5	12-19-77	2.0	14.5	

Drainage and Location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Unnamed tributary to Salt Springs Wash at U.S. 666; unsurveyed	59		2-3/13/19.5	2-6-66			
			-/-/19.5	5-10-71	0		
			-/8.5/15	12-19-77	+4.5		
Unnamed tributary to Salt Springs Wash at U.S. 666; unsurveyed.	60		2/11 /17?	2-6-66			
			-/11 /-	5-10-71	0		
			-/11.5/-	12-19-77	-.5		
Unnamed tributary to Salt Springs Wash at U.S. 666; unsurveyed.	61		4/8.5	2-6-66		8.5	
			-/9	12-19-77	-.5	9	
Unnamed tributary to Coyote Wash at U.S. 666; unsurveyed.	62		2/4/24	2-6-66			Large flow in summer of 1977
			-/-/24	5-10-71	0		
			-/5/21	12-19-77	+3		
Unnamed tributary to Coyote Wash at U.S. 666; unsurveyed.	63		2/4/6.5	2-6-66		6.5	
			-/-/8	12-19-77	-1.5	8	
Unnamed tributary to Sheep Springs Wash at U.S. 666; unsurveyed.	64		1-3/7	2-6-66		7	
			3/7	12-19-77	0	7	
Sheep Springs Wash at Sheep Springs at U.S. 666; unsurveyed.	65		2-4/11	2-6-66		11	
			-/12.5	12-19-77	-1.5	12.5	
Unnamed tributary to Sheep Springs Wash at U.S. 666; unsurveyed.	66		2/4/16.5	2-6-66		16.5	
			-/-/15.5	5-10-71	+1	15.5	
			-/-/15.5	12-19-77	0	15.5	
Hunter Wash at Bisti (abandoned); sec. 35, T. 24 N., R. 13 W.	67		4/6	7-15-66		6	
			-/5	1-12-78	+1	5	
Unnamed tributary to Hunter Wash near Bisti (abandoned); sec. 5, T. 23 N., R. 13 W.	68	D	4/7	7-15-66		7	
			-/7	1-12-78	0	7	

Drainage and Location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Hunter Wash near Chaco River; unsurveyed.	69		5/12.5	7-11-66			
			2-3/9	1-12-78	+ 3.5		
Captain Tom Wash southwest of Newcomb; unsurveyed.	70		3/13/17	9-29-66			
			-/13/16.5	1-19-77	+.5		
Captain Tom Wash at Newcomb at U.S. 666; unsurveyed.	71		6.5/21	2-6-66			Large flow in summer of 1977.
			-/21.5	5-10-71	-.5		
			8.5/23.5	12-19-77	-2		
Brimhall Wash at Burhams; sec. 25, T. 25 N., R. 16 W.	72		2/3?/6	4-27-66		6	
			-/-/6	1-12-78	0	6	
Chaco River near Brimhall Wash; sec. 29, T. 25 N., R. 16 W.	73		2/5/9	4-27-66			Large flow in summer of 1977.
		M	-/-/10	1-12-78	-1		
Pena Blanca Arroyo at U.S. 666; unsurveyed.	74		-/7-7/10	2-6-66		7-7	
			-/-/9	5-10-71	+1		
			5/7-8/11	12-19-77	-2	7-8	
Unnamed tributary to Tocito Wash; sec. 21, T. 25 N., R. 19 W.	75		5/10/22	2-29-66			
			-/-/21	12-19-77	+1		
Tocito Wash at Tocito: sec. 17, T. 25 N., R. 18 W.	76		3-4/20/26	9-28-65		20	
			-/-/29	12-19-77	-3		
Tocito Wash at U.S. 666; sec. 12, T. 25 N., R. 18 W.	77		3-4/11	2-6-66			
			-/8	5-10-71	+3		Fill behind dam.
		AM	-/2	12-19-77	+6		Fill behind dam.
Sanostee Wash west of Sanostee; unsurveyed.	78		3-5/11/18	9-29-66			
			-/ 7/14	12-19-77	+4		

Drainage and Location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Sanostee Wash near Sanostee;	79		5-6/11/15-16	9-29-66			
sec. 6, T. 25 N., R. 19 W.			7/12/18	12-19-77	-<2		
Sanostee Wash at Sanostee;	80		2/17	9-29-66			
sec. 4, T. 25 N., R. 19 W.			-/12.5	12-19-77	+4.5		
Sanostee Wash east of Sanostee;	81		2/4/10/17	9-29-66			
sec. 1, T. 25 N., R. 19 W.			-/-/ -/18.5	12-19-77	-1.5		
Sanostee Wash at U.S. 666;	82		8/22 / 25	2-6-66			
sec. 36, T. 26 N., 18 W.			7/22.5/-	5-10-71	-0.5		
			7/21 / 24	12-19-77	+1.5		
Rattlesnake Wash near Shiprock;	83	A	2-5/8/18.5/23	7-4-65		18.5	
sec. 34, T. 30 N., R. 18 W.			-/-/-/23	5-13-69	0		
			-/-/-/22.5	5-11-71	+.5		
			-/-/-/22.5	1-13-78	0		
Salt Creek Wash near Shiprock	84		3-4/-/28	2-6-66			
at U.S. 666; sec. 12; T. 30 N.,			-/- /26.5	5-11-71	+1.5		
R. 18 |_'_		M	-/22/28	1-15-78	-1.5	22	
Unnamed tributary to Malpais	85		2/4/20	2-6-66		20	
Arroyo at U.S. 666; unsurveyed.			-/-/21.5	5-11-71	-1.5	21.5	
			-/-/21.5	1-15-78	0	21.5	
Little Shiprock Wash near	86	A	2/9	4-27-66			
Mitten Rock; unsurveyed.		M	-/10	1-13-78	+1		
Shiprock Wash near Shiprock;	87	A	5/20/23	7-4-65		20	
sec. 22, T. 30 N., R. 19 W.			-/- /22.5	5-11-71	+.5		
			-/- /21.5	1-13-78	+1		
Standing Redrock Creek at Red	88		5/7/23	4-27-66			
Rock, Ariz.; sec. 19, T. 37 N.			- /22	1-13-78	+1		
R. 5 W.							

Drainage and Location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel of channel from previous measurement 2	Downcutting since the late 19th century	Remarks
Red Wash drainage							
Red Wash at Red Rock, Ariz.; sec. 18, T. 37 N., R. 5 W.	89	M	2-3/5?/7 -/- /6	4-27-66 1-13-78	+1		
Unnamed tributary to Red Wash, Ariz.; sec. 26, T. 37 N., R. 6 W.	90	A	<3/8/13.5 -/7/11	6-6-67 1-13-78	+2.5		
Unnamed tributary to Blackhorse Creek, Ariz.; unsurveyed.	91		3-5/7/17 / 42 -/- /17.5/-	6-6-67 1-13-78	-.5		
Unnamed tributary to Cove Wash in Redrock Valley, Ariz., sec. 25, T. 37 N. R. 7 W.	92		4-6/8-9/-/22 5/8-9/17/22	6-6-67 1-13-78	0	17	
Cove Wash in Redrock Valley, Ariz., sec. 20, T. 37 N., R. 6 W.	93		5-6/10 5.5/10	6-6-67 1-13-78	0		
Red Wash west of Shiprock; sec. 10, T. 30 N., R. 20 W.	94		2-3/6/10/20 -/- / - /19 -/- / - /19.5 -/- / - /19.5	7-4-65 9-13-69 5-11-71 1-13-78	 +1 -.5 0		
Unnamed tributary to San Juan River at Bitlabito; sec. 1, T. 30 N., R. 21 W.	95		3-5 4-5	7-4-65 1-13-78	0		
Unnamed tributary to San Juan River near Bitlabito; sec. 26, T. 31 N., R. 21 W.	96		4-6/9 - /8-9	7-4-65 1-13-78	-1		
Mancos River at U.S. 666, Colo.; sec. 7, T. 32 N. R. 17 W.	97		2/5/10?/15 -/- / - /14	2-6-66 1-15-78	+1		

Drainage and Location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Cummings Creek at N. Mex.-Colo. State line at U.S. 666, Colo.; sec. 24, T. 32 N, R. 18 W.	98		2/5/12	2-6-66		12	
			-/-/10.5	5-11-71	+1.5	10.5	
			-/-/9	1-15-78	+1.5	9	
(Navajo) Spring Creek near Towaoc, Colo., unsurveyed.	99		20.5	5-9-69		20.5	
			17	1-13-78	+3.5	17	
Navajo Spring Creek at U.S. 106, Colo.; sec. 24, T. 33 N., R. 18 W.	100		7/35	7-13-66		35	
			-/35.5	5-9-69	-.5	35.5	
			-/34.5	5-11-71	+1	34.5	
			-/35	1-14-78	-.5	35	
Aztec Wash at U.S. 666, Colo., sec. 4, T. 32 N., R. 19 W.	101	A	2-5/22	7-13-66		22	
			- /22	5-9-69		22	
			- /21.5	5-11-71	+.5	21.5	
			- /21	1-13-78	+.5	21	
Unnamed tributary to San Juan River, Ariz.; sec. 25, T. 41 N., R. 30 E.	102	A	3.5	7-13-66		3.5	
		A	3	1-13-78	+.5	3	
Unnamed tributary to Todastoni Wash at Teec Nos Pas, Ariz.; sec. 27, T. 41 N., R. 30 E.	103	A	4/23	7-4-65		23	
			-/24	5-11-71	-1	24	
			-/23	1-13-78	+1	23	
<u>McElmo Creek drainage</u>							
McElmo Creek 8 miles west of Cortez, Colo., sec. 33, T. 36 N., R. 17 W.	104		7/12/21/26	5-9-69		21	
			-/-/-/25	1-13-78	+1	20	

Drainage and Location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
McElmo Creek 11 miles west of Cortez, Colo.; sec. 35, T. 36 N., R. 18 W.	105		3-4/8?/21/32 4/9/19/29.5	5-9-69 1-13-78	 +2.5	21 19	
McElmo Creek 16 miles west of Cortez, Colo., sec. 31, T. 36 N., R. 18 W.	106		5/13/18-20 5/13.5/18-20	5-9-69 1-13-78	 0	18-20 18-20	
McElmo Creek 22.5 miles west of Cortez, Colo., sec. 36, T. 36 N., R. 20 W.	107		2-4/18-20/21.5 -/- /22	5-9-69 1-13-78	 -.5	18-20	
Yellow Jacket Canyon near mouth, Utah; sec. 24, T. 39 S., R. 24 E.	108		2-3/21 4-5/24.5 4-5/24	5-9-69 5-11-71 1-13-78	 -3.5 +.5	21 24.5 24	Large flow in Sept. 1970

Drainage and Location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Differences in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Little Colorado River drainage basin							
Puerco River drainage							
North Fork near Mariano Lake; sec. 15, T. 16 N. R. 14 W.	1		2-5/15 -/17	7-10-66 12-16-77	-2	15 17	
North Fork near Pinedale; sec. 17., T. 16 N., R. 15 W.	2		20 21	7-10-66 12-14-77	-1	20 21	
Unnamed tributary to North Fork 2 mi. west of Pinedale; sec. 13, T. 16 N., R. 16 W.	3		26 29	7-10-66 12-14-77	-3	26 29	
North Fork southwest of Church Rock mine; sec. 16, T. 16 N., R. 16 W.	4		22.5 18.5	7-10-66 12-14-77	+4	22.5 18.5	Large flow in summer of 1977.
Unnamed tributary to South Fork near Continental Divide; sec. 14, T. 14 N., R. 14 W.	5		2-3/14/19? -/14/19?	2-21-66 12-18-77	0	14 14	
South Fork near Coolidge; sec. 7, T. 14 N., R. 14 W.	6	A A	13.5 12	2-21-66 12-18-77	+1.5	13.5 12	Large flow in summer of 1977 in combination with mine effluent caused aggradation.
Unnamed tributary to South Fork east of North Guam; sec. 33, T. 15 N., R. 14 W.	7		2-4/27 - /27.5	2-21-66 12-18-77	-.5	8 7	
South Fork near North Guam; sec. 26, T. 15 N., R. 15 W.	8		2-4/8/11 -/7/10	2-21-66 12-18-77	+1	7 8	
South Fork near North Guam; sec. 27, T. 15 N., R. 15 W.	9		7 8	2-21-66 12-18-77	-1	6 6	
South Fork near Ciniza; sec. 29, T. 15 N., R. 15 W.	10		1=4/6 -/ 6	2-21-66 12-18-77	0		

Drainage and Location etc.	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of meaaurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Unnamed tributary to South Fork east of Iyanbito; sec. 30, T. 15 N., R. 15 W.	11		1-4/14 4/-	2-21-66 12-18-77	0	14	Dug well on 4-foot terrace.
Unnamed tributary to South Fork at Iyanbito	12		2-5/22/28? -/23/29?	2-21-66 12-18-77	-1	22 23	
Unnamed tributary to South Fork southwest of Iyanbito; sec. 25, T. 15 N., R. 16 W.	13	A	2-3/9.5 -/7.5	2-21-66 12-18-77	+2	9.5 7.5	Measured on large sandbar formed by large flow in summer of 1977.
			-/10	12-18-77	-.5	10	Measured below large sandbar.
South Fork near Perea	14		4/8 -/10.5	2-21-66 12-18-77	-2.5	10.5	
Unnamed tributary to South Fork near Fort Wingate; sec. 28, T. 15 N., R. 16 W.	15	D D	8 8	2-21-66 12-18-77	0	8 8	
Unnamed tributary to South Fork at Fort Wingate; sec. 9, T. 14 N., R. 16 W.	16	AM A	2/6 -/5	2-21-66 12-18-77	+1	6 5	
Unnamed tributary to South Fork west of Fort Wingate; sec. 19, T. 15 N., R. 16 W.	17	D D	3 6	2-21-66 12-18-77	-3		
South Fork at Church Rock	18	M	3-5/10/19 5.5/8/17±	7-6-65 12-14-77	+2		

Drainage and Location etc.	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Puerco River at hogback east of Gallup; sec. 18, T. 15 N., R. 17 W.	19		-/20/-	?-?-46		20	Channel deepened 14 feet between 1901 and 1946 (Leopold and Snyder, 1951, fig. 2).
			5.5/22/-	7-6-65	-2	22	Aggradation caused by mine water and by urban development near site.
			6.5/23/-	5-5-69	-1	23	
			8/24/27	5-10-71	-1	24	
			-/22/25	12-14-77	+2	22	
Unnamed tributary to Puerco River 5.5 miles south of Gallup; sec. 16, T. 14 N., R. 18 W.	20		26	5-5-69		26	Measured a short distance upstream of sandstone outcrop in channel. Large flow in summer of 1977.
			26.5	5-10-71	-.5	26.5	
			27.5	12-15-77	-1	27.5	
Unnamed tributary to Defiance Draw 11 miles west of Ya-ta-hey; sec. 8, T. 16 N., R. 20 W.	21	A	4/28	7-6-65		28	Large scale slump of banks caused by large flow in summer of 1977.
			-/27.5	12-15-77	+.5	27.5	
Unnamed tributary to Defiance Draw 10 miles west of Ya-ta-hey; sec. 16, T. 16 N., R. 20 W.	22	A	22	7-6-65		22	Slumping of banks blocks channel caused by large flow in summer of 1977.
			20	12-15-77	+2	20	
Unnamed tributary to Defiance Draw 6 miles west of Ya-ta-hey; sec. 11, T. 16 N., R. 19 W.	23		-/6	7-6-65		6	
		A	-/5	12-15-77	+1	5	
Unnamed tributary to Defiance Draw 2.5 miles west of Ya-ta-hey; sec. 11, T. 16 N., R. 19 W.	24	A	2-3/20	7-6-65		20	Large flow in summer of 1977 caused aggradation.
			- /17	12-15-77	+3	17	

Drainage and Location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Unnamed tributary to Defiance Draw at Ya-ta-hey; sec. 7, T. 16 N., R. 18 W.	25	A AM	3/6 -/3	7-6-65 12-15-77	+3	6 3	Large flow in summer of 1977 caused aggradation.
Unnamed tributary to Defiance Draw 1 mile south of Ya-ta-hey; sec. 18, T. 16 N., R. 18 W.	26	A	3/17 -/17	7-6-65 12-15-77	0	17 17	
Puerco River near Arizona-New Mexico State Line; sec. 11, T. 11 N., R. 21 W.	27	D D	25/35 26/36	2-21-66 12-21-77	-1	25 26	Channel is adusting to controls along I-40.
Puerco River near Lupton, Ariz. sec. 8, T. 22 N., R. 31 E.	28		2/5/7?/20/30/37 -/-/-/-/33/40	2-21-66 5-10-71	-3	30 33	Downcutting due to Sept. 1970 flood
		M	-/-/-/-/30/37.5	12-21-77	+2.5	30	New bridge s. construction.
Squirrel Springs Wash in Todilto Park; unsurveyed.	29		5.5/8/25 -/-/25	9-30-66 12-15-77	0	25 25	
Tohdidoni Wash at Navajo; unsurveyed.	30	M	5.5/11/26 -/- /26 -/- /28	9-29-66 5-25-71 12-16-77	0 -2	26 26 28	
Unnamed tributary to Black Creek near Buell Mountain; sec. 18, T. 2 N., R. 5 W.	31		2/5 3/6	8-30-66 12-16-77	-1	6 6	
Black Creek south of Navajo; sec. 29, T. 2 N., R. 5 W.	32	A	2-3/5 -/5.5	8-30-66 12-16-77	.5	5 5.5	
Unnamed tributary to Black Creek 12.5 miles west of Ya-ta-hey; sec. 7, T. 16 N., R. 20 W.	33	A	2/5/7 -/8.5/10.5	7-6-65 12-15-77	+3.5	7 10.3	Waste water from 1 Window Rock coal mine maintains small flow (+50 gal/min 12-15-77.

Drainage and Location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Unnamed tributary to Black Creek near Window Rock, Ariz. unsurveyed.	34	A	2 /17.5	7-6-65		17.5	
			- /19.5	5-5-69	-2	19.5	
			- /19	5-25-71	+.5	19	
			- /19.5	12-15-77	-.5	19.5	
Unnamed tributary to Black Creek near Window Rock, Ariz.; sec. 17, T. 26 N., R. 31 E.	35	A	2-5/22	7-6-65		22	Trash and old car bodies cause some aggradation.
			- /20	12-15-77	+2	20	
Black Creek near Window Rock, Ariz.; sec. 13, T. 26 N., R. 30 E.	36	M	6/8	7-6-65		8	
			- /7.5	5-5-69	+.5	7.5	
			- /7.5	5-25-71	0	7.5	
			- /6.5	12-15-77	+1	6.5	
Black Creek 8 miles south of Window Rock, Ariz.; sec. 14, T. 25 N., R. 30 W.	37		8	11-22-66		8	
			10	5-24-71	-2	10	
			12	12-15-77	-2	12	
Unnamed tributary to Black Creek 12.5 miles south of Window Rock, Ariz.; sec. 14, T. 24 W., R. 30 E.	38	A	2.5/21.5	11-22-66			
		A	-/17	12-15-77	+4.5		
Black Creek 16.5 miles south of Window Rock, Ariz.; sec. 26, T. 24 N., R. 30 E.	39		17.5	11-22-66		17.5	Downcutting due to Sept. 1970 floods.
			22	5-21-71	-4.5	22	
			18	12-15-77	+4	18	
Rio Pescado southeast of Ramah; sec. 1, T. 10 N., R. 16 W.	40		2/6/-	7-15-67		6	Channel filled and newly excavated.
		D	-/4.5/7.5	12-15-77	+1.5	4.5	
Unnamed tributary of Rio Pescado west of Ramah; sec. 3, T. 10 N., R. 16 W.	41	AM	4	7-15-67		4	
		A	4	12-15-77	0	4	

Drainage and location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Rio Pescado west of Ramah; sec. 12,	42		5/11/22	7-15-67			
T. 10 N., R. 17 W.			-/-/22	12-15-77	0		
Rio Nutria east of Zuni; sec. 36,	43		21	5-5-69		21	
T. 11 N., R. 18 W.			21	12-15-77	0	21	
Zuni River near Zuni; sec. 26,	44	Y	2/14	7-10-66		14	
T. 10 N., R. 19 W.			-/14	12-15-77	0	14	

Drainage and Location etc.	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Rio Grande drainage basin							
Rio Salado drainage							
Rio Salado south of La Ventana; unsurveyed.	1		35.5 33	10-12-64 1-6-78	+2.5	35.5 33	Large flow in summer of 1977 caused some cutting.
Penasco Arroyo west of San Ysidro; unsurveyed	2		28 28.5	10-12-64 1-6-78	-.5	28 28.5	
Rio Puerco drainage							
La Jara Creek at Cuba; sec. 20, T. 21 N., R. 1 W.	3		7/30/35 -/29/34	10-12-64 1-6-78	+1	30 29	
Senorita Creek south of Cuba; sec. 21, T. 20 N., R. 1 W.	4		31 31	10-12-64 1-6-78	0	31 31	
Rio Puerco at I 40; sec. 4, T. 9 N., R. 1 W.	5		5/37.5 13/39.5	10-16-64 12-14-77	-2	37.5 39.5	Narrowing and perhaps deepening of inner channel due to discharge of sewage effluent and growth of riparian vegetation
Unnamed tributary to Bluewater Creek northwest of Thoreau; sec. 18, T. 14 N., R. 13 W.	6		6/17 -/16	2-21-66 12-18-77	+1	17 16	
Unnamed tributary to Bluewater Creek northeast of Thoreau; sec. 26, T. 14 N., R. 13 W.	7		3/6/10 -/8/10	4-21-66 12-18-77	0	10 10	
Unnamed tributary to Bluewater Creek near San Antonio Spring; sec. 20, T. 14 N., R. 12 W.	8		3/13 -/14	4-21-66 12-18-77	-1	13 14	

Drainage and Location etc.	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Unnamed tributary to Bluewater Creek at Smith Lake; sec. 17, T. 15 N., R. 12 W.	9	A A	4 3.5	4-21-66 12-18-77	+.5	4 3.5	
Unnamed tributary to Bluewater Creek 3 miles south of Smith Lake; sec. 32, T. 15 N., R. 12 W.	10	A A	11/18.5 -/14	4-21-66 12-18-77	+4.5		Measured above reservoir.
Unnamed tributary to Bluewater Creek 4 miles south of Smith Lake; sec. 5, T. 14 N., R. 12 W.	11	A	5 5	4-21-66 12-18-77	0	5 5	
Rio San Jose at McCartys; sec. 28, T. 10 N., R. 8 W.	12	AM AM	6 6	7-15-67 1-18-78	0		
Unnamed tributary to Rio San Jose near Cubero; sec. 25, T. 10 N., R. 7 W.	13		3-4/24/33 6-7/25/34	7-15-67 1-18-78	-1	24 25	
Rio San Jose at Laguna; sec. 4, T. 9 N., R. 5 W.	14		2-4/5-6/18/32 -/- /22/36	7-15-77 1-18-78	-4	18 22	
Rio San Jose at I 40; sec. 20, T. 9 N., R. 4 W.	15		4/8/18 -/12/22	2-20-66 1-18-78	-4		
Rio San Jose near Los Lunas Junction; sec. 31, T. 9 N., R. 3 W.	16		4/10± 6/10±	2-20-66 1-18-78	0		

Drainage and location (sites without state designation are in New Mexico)	Location number on plate 1	Condition of Channel 1	Height of terrace in feet above streambed 1	Date of measurement	Difference in depth of channel in feet from previous measurement 2	Downcutting since the late 19th century	Remarks
Chaco River near Lake Valley sec. 25, T. 22 N., R. 13 W.	17		2-3/14 2/10	7-15-66 1-12-78	+4		
Unnamed tributary draining to Lake Valley south of Crownpoint; sec. 16, T. 16 N., R. 12 W.	18		2/8.5 -/8	4-21-66 12-18-77	+.5	8.5 8	
Unnamed tributary draining to Lake Valley near Crownpoint; sec. 29, T. 17 N., R. 12 W.	19	M M	3.5/10 -/7	7-12-66 12-18-77	+3	10 7	
Unnamed tributary draining to Lake Valley at State Highway 56 northeast of Crownpoint; sec. 17, T. 18 N., R. 11 W.	20		4-5/13 -/15	4-21-66 12-18-77	-2	13 15	
De-na-zin Wash north of Lake Valley; sec. 14, T. 23 N., R. 13 W.	21		2-3/5 2/4	7-15-66 1-12-78	+1	5 4	
Chaco River northwest of White Rock; unsurveyed	22		2/6/8 -/4/6	7-12-66 1-12-78	+2		
Unnamed tributary to Indian Creek southeast of Standing Rock; sec. 35, T. 18 N., R. 14 W.	23		11/16? -/16	7-10-66 12-16-77	0		
Unnamed tributary to Indian Creek near White Rock; sec. 6, T. 21 N., R. 13 W.	24		4/7 3/5.5	7-11-66 1-12-78	+1.5	7 5.5	Large flow in 1976(?)
Unnamed tributary to Indian Creek near White Rock; unsurveyed.	25		2-3/11 -/11	7-12-66 1-12-78	0	11 11	