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Reversal of Erosion Cycle and Climatic Change

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Successive surveys of the cross section of ephemeral channels in New Mexico over a period of 15 years, 1960-1975, show that arroyos that were actively eroding early in the century have reversed the trend and are alluviating. This appears to be associated with the worldwide cooling trend that began about 1940. If the inference proves to be correct, it is significant hydrologically, for it provides some specific knowledge of the climatic conditions associated with the alternate periods of valley erosion and valley alluviation that created the widespread terraces of the semiarid West.

If there is any single question in hydrology in greatest need of an answer, it might be this: How great a change in what climatic factors is needed to change by a measurable amount production of water and sediment from a basin?

With a plethora of records available on streamflow and precipitation, with good maps and photographs of vegetal cover, and with modest but increasing knowledge of sediment yield, one might suppose that correlation techniques would quickly answer this apparently simple question. The difficulty lies in the areal and temporal variance in all the parameters and the feedback mechanisms operating to ameliorate the effects imposed by climatic variation. As an example of the latter it may be noted that any increase in precipitation induces greater vegetal growth, increasing transpiration losses and providing additional protection of soil against erosion.

It is probable that the question as stated cannot be answered, except for particular small areas, and these may not be representative of any region. Furthermore, any time trends are likely to be so confounded by actions of man that the effect of climate alone cannot be separated. The small but nevertheless important net of benchmark watersheds and benchmark precipitation gauges measured, respectively, by the U.S. Geological Survey and the Weather Bureau may ultimately provide answers for selected localities, but so far the records are short and analyses have not been made.

It could be asked why the question is important. The answer might well be stated as two assertions: (1) The landscape abounds with evidence of climatic changes in the Holocene, especially in the widespread existence of terraces or abandoned flood plains of rivers, and (2) the effect of climatic change on hydrologic functioning is identical with effects brought about by activities of man.

The first assertion is common knowledge resulting from geologic, stratigraphic, and archaeologic studies. The alternation of erosion and deposition by streams resulting in the presently observed valley fills, terraces, and gullies has had especially important economic consequences in the semiarid lands of the American Southwest. The sequence of climatic events and the physiographic results were first postulated by Kirk Bryan in a series of papers later corroborated and expanded by his students. This has been called the alluvial chronology of southwestern valleys.

The alluvial chronology associates observed alternations of valley filling (aggradation) and valley erosion (degradation) with climatic change. The stratigraphic and paleontologic evidence suggests that erosion of the valley alluvium was associated with a climate relatively arid and thus logically, aggradation or valley alluviation occurred in a climate relatively cool and moist. This inference derives from the existence of pedocalic soils and paleosols associated with the surface of the older alluvium, and the sand dunes associated with the trenching of that alluvial surface.

But the evidence is inferential and further proof is needed. As long as this remains a hypothesis, the relation of climatic change to hydrologic process also remains in a state of uncertainty.

Now consider the second assertion. Grazing by stock decreases grass cover and induces erosion. Trampling by livestock enhances this tendency. Clearing of forests may have the same tendency. In the first third of this century there was a lively discussion in the scientific literature about the cause of the observed valley trenching (gully formation) that affected myriad alluvial valleys in the southwestern United States in an erosion epicycle that began about 1880 AD and had not yet run its course in 1920. There were many who ascribed this epicycle of gully erosion to the activities of man, especially overgrazing by stock. A few geologists, especially Kirk Bryan, pointed out that similar epicycles of erosion had occurred in the same area before the advent of man, and that the basic cause was most probably climatic. "Overgrazing thus becomes merely the trigger pull which timed the arroyo cutting in the thirty years following 1880" (Bryan, 1940, p. 231).

Though details of stratigraphy vary from one locality to another the features of importance to the present discussion are exemplified by the valley deposits and their morphology in the vicinity of Santa Fe, New Mexico, illustrated in Fig. 1. The present valley flat is the top surface of the Coyote Terrace (Leopold, Emmett, and Myrick, 1966) shown in the figure. The Coyote Terrace deposits contain charcoal dated by ^{14}C as 2800 ± 250 years BP and a comparable site 4 miles away provided a date of 2230 ± 250 years. The upper layers of these terrace deposits contain artifacts. It is reasoned, then, that the deposition resulting in the present wide valley flat was in progress through the later part of the Holocene and extended into the pottery-making period of paleo-Indian culture of pre-Columbian time, say until 1100 AD.

There followed a period of gully formation or valley trenching that dissected the Coyote deposits, with gullies cutting down to bedrock in many places. This was followed by alluviation that partly filled the arroyos and a new flood plain was formed at the level of the top of the low terrace in Fig. 1.

This valley level was subsequently trenched by a widespread system of arroyos or gullies in the well-known

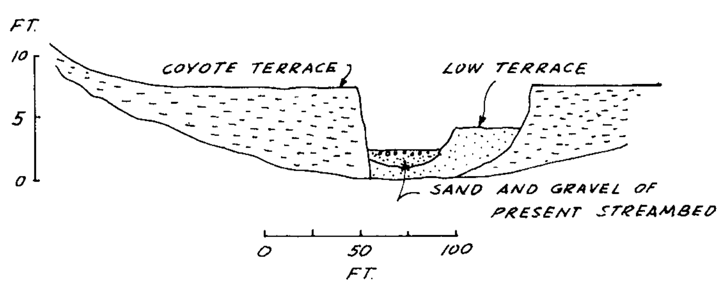

FIG. 1. Diagrammatic cross section through typical valley exhibiting the Coyote Terrace and associated features, near Santa Fe, New Mexico.

erosion epicycle that began late in the 19th century and accounts for the trenches now observed throughout the Southwest.

The erosion period that took place within the span 1100–1400 AD was clearly not related to man's activities and is considered to be climatic in origin. The erosion in the late 1800's and continuing in the first half of the 20th century was exacerbated by man, especially overgrazing. Many students of the subject (Thornethwaite *et al*, 1942) considered that erosion epicycle due entirely to overgrazing, for the precipitation record showed no significant change in mean annual amount. Leopold (1951) showed, however, that the intensity of individual rains had a secular variation. The period during which 19th century erosion began and was most rampant was characterized by more frequent heavy rains and a deficiency of light rainfalls.

There is, unfortunately, no generally accepted index either of climate or of erosional activity that applies to the question at hand. In the climatic record there is such a plethora of data that variance among areas and climatic parameters tends to hide general trends. Nevertheless, despite local variations, a trend toward decreasing river discharge throughout the first half of the present century seems to characterize most river basins in the United States. Examples of the trend are readily available. A graphical presentation can be seen in Leopold (1974, pp. 131–132). In climatic parameters, droughts of the 1950's and the change in hurricane paths on the Atlantic coast are aspects that impinge on common experience. Mitchell (1963) has shown that the mean global temperature has risen during the first half of the 20th century with a cooling trend beginning in the 1940's. These records and ^{18}O measurements from an ice core from Greenland led Broecker (1975) to predict a progressive cooling during the rest of the century, after which the increasing CO_2 content of the atmosphere will overcompensate for the natural cooling and cause global temperatures to rise dramatically. The cooling trend beginning at midcentury is becoming increasingly apparent from several kinds of observations.

Against this generalized sketch of climatic trends one would wish to compare a record of changes in alluvial action. Records of the latter are so few that any sequential observation through time, however limited in scope, is probably worthy of consideration.

There are a few places in New Mexico where I have made successive observa-

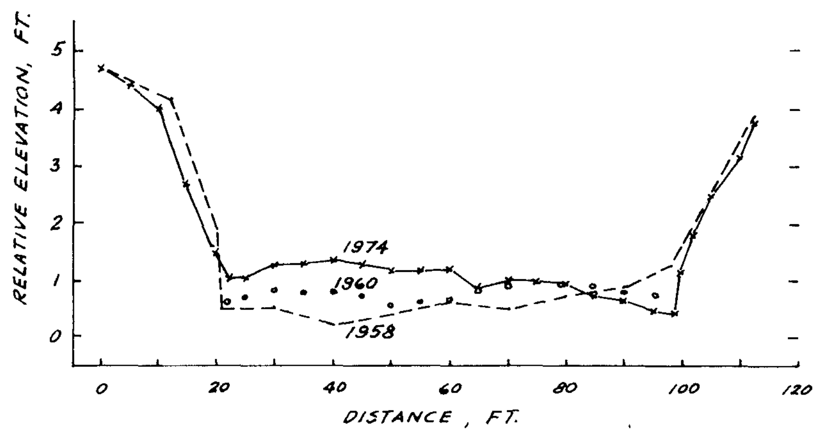

FIG. 2. Change in cross section of Arroyo de los Frijoles, near Santa Fe, New Mexico, between 1958 and 1974, at Section 6, drainage area 2.8 sq miles.

tions of channel change over periods varying from 7 to 15 years. They consist of three kinds of observations: channel cross sections, gully headcut retreat or progress uphill, and sheet erosion measured by protrusion of nails originally driven flush with the ground. Observations are all in areas typical of the alluvial valleys that experienced the successive periods of alluviation and valley trenching described earlier. The observations near Santa Fe are on land that has had either light grazing or no grazing for three decades.

The working hypothesis follows Bryan's idea that periods of erosion are relatively arid, and, as elaborated by Leopold (1951), may not have lower annual rainfall but that the relative aridity is marked by a smaller proportion of low intensity rains and a larger proportion of intense storms. In the areas observed, gully formation was rampant in the late 19th and early 20th centuries. The general trend toward a cooler climate, though not explicitly demonstrated for the New Mexico area, would suggest that the gullying process would slow or cease and be replaced by alluviation and gully filling by deposition.

Figure 2 shows one of many cross sections of the channel of Arroyo de Frijoles, a tributary to Rio Santa Fe, 5 miles NW of the city of Santa Fe, New Mexico. Detailed descriptions of locations of all sites mentioned here are shown in Leopold, Emmett, and Myrick (1966). This section has aggraded nearly a foot in the period 1958–1974, with a larger amount deposited in the 2 years, 1958–1960 than in the 14 years 1960–1974.

Figure 3 shows the elevation of the channel centerline as a function of time, for five surveyed cross sections of Coyote C. Arroyo, an ephemeral tributary to a system draining into the Rio Grande. It is located about 7 miles NW of Santa Fe.

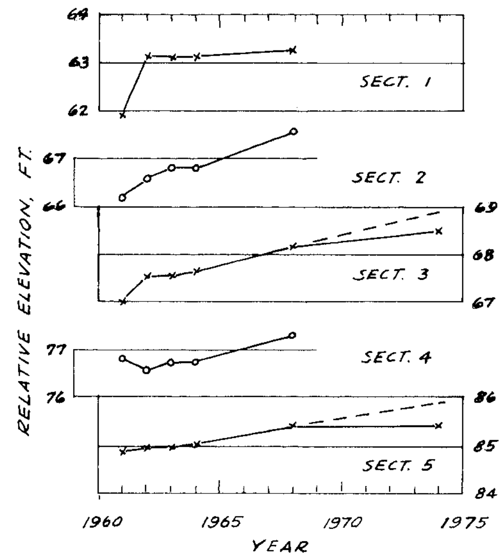

FIG. 3. Elevation of channel centerline as a function of time, five cross sections of Coyote C. Arroyo, near Santa Fe, New Mexico, drainage area about 40 acres. Dashed line suggests elevation if early trend continued.

At all sections the bed elevation rose 0.5 to 1.4 ft between 1961 and 1968. For sections 3 and 5, data are available for 1974 as well. In this additional 6 years, the bed rose an additional 0.1 to 0.3 ft. The rate of aggradation was slower than that characterizing the previous 7 years.

The next piece of information, shown by the upper part of Fig. 4, is the rate of headcut retreat of two vertical-walled arroyo heads. The graph shows the up-valley migration measured as the distance between a monument and the lip of the vertical drop. The two headcuts are in different drainages, about 4 miles apart. In the period 1959–1968 each moved rather uniformly at a rate of about 2 ft/year. Both advanced at a smaller rate, about 0.9 ft/year, in the period 1968–1974.

The third observation concerns the rate of sheet erosion measured as the progressive exposure of nails driven originally flush with the ground surface. An area of hillslope and rill was covered with a

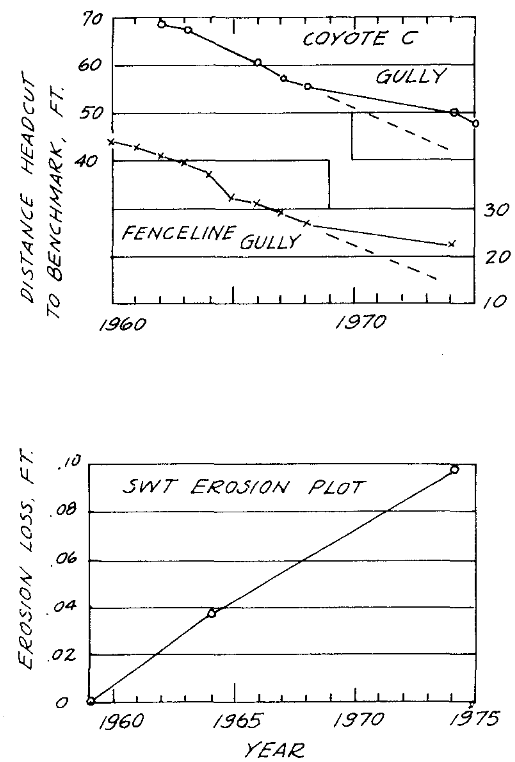

FIG. 4. *Upper:* Position of vertical head cut of gully relative to a monumented bench mark as a function of time, for two gully heads near Santa Fe, New Mexico. Dashed line suggests position of gully head had early trend continued. *Lower:* Cumulative erosion loss averaged for 61 nails in a plot at Slopewash Tributary, Arroyo de los Frijoles, as a function of time, near Santa Fe, New Mexico.

rectangular grid of 61 nails at 5-ft spacing. The progressive exposure of the nails, as sheet erosion lowered the surface, measures erosion rate. The data plotted in the lower part of Fig. 4 represent mean cumulative erosion as a function of time. Between 1959 and 1964 the mean was 0.008 ft/year and between 1964 and 1974 it was 0.006 ft/year. This nail grid is located on Slopewash Tributary to Arroyo de los Frijoles, 4 miles SE of the Coyote C. Arroyo discussed above.

The fourth observation is the change of channel cross section across North Rio Chaco at the Chaco Canyon National Monument, New Mexico. This is about 120 miles WNW of the Santa Fe localities discussed above. The stream at this place drains about 200 square miles.

The arroyo has constricted its active width by the building of a considerable bar of silt on the right bank. Though the thalweg is at about the same elevation the net change during the 13-year period is alluviation (Fig. 5).

The data show that the arroyo filling has progressed continuously at least since 1961. The rapid erosion of vertical-walled gullies devoid of vegetation so obvious in northern New Mexico and Arizona during the 1930's has been re-

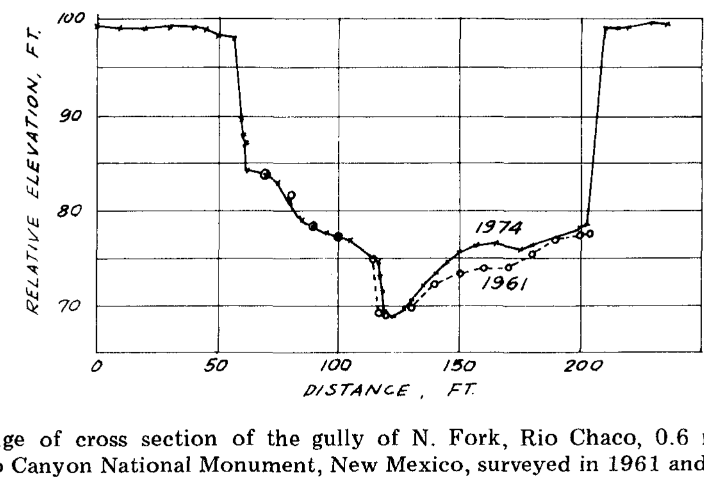

FIG. 5. Change of cross section of the gully of N. Fork, Rio Chaco, 0.6 miles upstream of museum, Chaco Canyon National Monument, New Mexico, surveyed in 1961 and 1974.

placed by deposition. The measurements are strengthened by the general observation that formerly vertical walls of many arroyos have become rounded and partly vegetated.

All three types of data show a reduction in rate of these changes during the last decade. Alluviation, headcut retreat, and sheet erosion have been slower in the 1968–1975 period than in the previous 7 years.

No forecast can be made from these observations. They do, however, tend to confirm the early hypothesis of Kirk Bryan that a climatic trend toward cooler and wetter conditions such as that experienced in the United States since 1940 is associated with valley alluviation.

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