Warner, R. F. 1994. A theory of channel and floodplain responses to alternating regimes and its application to actual adjustments in the Hawkesbury River, Australia. In Kirkby, M. J. (ed.) *Process Models and Theoretical Geomorphology*, Wiley, Chichester, 173-200.

Warner, R. F. 1995. The role of stormwater management in urban rivers. Paper presented at International Association of Geomorphologists Regional Congress, Singapore.

Warner, R.F. 1996. Do we really understand our rivers? Or rivers in the pooh - semper in excreta. *Australian Geographical Studies*, 34:3-17.

Warner, R.F. and G. Pickup. 1978. Channel changes in the Georges River between 1959 and 1973/76 and their implications. Report for Bankstown Municipal Council, 84 pp.

Warner, R.F. and D.I. Smith. I. 1979a. The use of fluorometric tracers to study effluent movement in the Georges River, New South Wales, Australia. *Proceedings 10th New Zealand Geographical Society and 49th ANZAAS Congress*, 48-53.

Warner, R.F. and D.I. Smith. 1979b. The simulation of effluent movement in the tidal Georges River, New South Wales, Australia, using the dye tracer Rhodamine W.T. Report for New South Wales State Pollution Control Commission, 75 pp.

Warner, R. F., E.J. McLean, and G. Pickup. 1977. Changes in an urban water resource, an example from Sydney, Australia. *Earth Surfaces Processes*, 2:29-38.

Wolman, M.G. 1967. A cycle of sedimentation and erosion in urban river channels. *Geografiska Annaler*, 49A:385-395.

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ARROYO CHANGES IN SELECTED WATERSHEDS OF NEW MEXICO, UNITED STATES

Allen C. Gellis and John G. Elliott[1]

ABSTRACT

Whether climate, land use, or intrinsic variables is the main control of arroyo incision in the American west has been debated for more than a century. The climatic position for example, has maintained that periods of low rainfall followed by intense storm activity promotes arroyo incision. Average annual rainfall intensity for Santa Fe, New Mexico, shows more frequent high-intensity rainfall events in the period 1868 to 1880 and an increase in rainfall intensity beginning about 1967. This precipitation data could indicate that conditions are similar to the late 1800s when a period of incision occurred; although precipitation records at Santa Fe are not representative of the entire American west. By contrast, recent studies in the American Southwest indicate that many arroyos currently are aggrading. The Rio Puerco, New Mexico, incised around 1885 and, based on aerial photographic comparisons and replicate surveys, the arroyo is continuing to evolve. Inner-channel width-to-depth ratios have decreased since 1977, and the inner floodplain has aggraded 0.3 to at least 1.0 meter by overbank deposition. In one cross section the channel-bed elevation increased 2.55 meters (m), the inner-channel width decreased from 40.6 m to 23.4 m, and the cross-sectional area decreased by 125 square meters (m^2) from 1936 to 1995. Results of resurveys between 1992 and 1994 of 85 channel cross sections in three arroyos near Zuni, New Mexico, indicated that 72 percent of the cross sections are aggrading. This apparent discrepancy may be related to the intrinsic thresholds of arroyo systems, since the modern arroyos examined here are at a different stage of their development than they were in the late 1800s.

KEYWORDS

Arroyo changes, climate, watersheds, high-intensity rainfall events

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1. INTRODUCTION

Arroyos are channels incised into valley alluvium that can be tens to hundreds of meters wide and several meters to tens of meters deep. An episode of arroyo incision that occurred in the late 1800's in the American west has intrigued geomorphologists for more than a century. A widespread debate about the cause of this incision centered on climate change, land use, and more recently, intrinsic geomorphic conditions. This debate was litigated when the Zuni Tribe of New Mexico sued the United States government in the 1970s, claiming that mismanagement of their land, overgrazing, and timber harvesting led to erosion, of which arroyo incision was part (Landon, 1990).

The position that climatic change causes arroyo incision postulates a relation between changes in precipitation frequency and storm intensity and changes in erosion. For example, periods of low rainfall that are followed by intense summer storm activity may provide the impetus for arroyo incision (Leopold, 1951; Cooke, 1974; Balling and Wells, 1990). Analysis of climatic records in Santa Fe, New Mexico, by Leopold (1951) indicated that the period 1850 to 1880 was characterized by a decrease in low-intensity rainfall and by an increase in high-intensity rainfall. Frequent low-intensity rainfall sustains vegetative growth, but low-intensity rainfall was deficient between 1850 and 1880. High-intensity rainfall which was above average in the late 19th century resulted in rapid runoff and promoted erosion. Schoenwetter and Dittert (1968) noted that periods of erosion are characterized by a summer moisture regime where most annual precipitation falls during a long summer of intense thunderstorms, whereas periods of alluviation are characterized by a winter moisture regime where precipitation accumulates as snow, runs off slowly, and infiltrates more readily. Leopold and others (1966) suggested that arroyo incision is associated with increasing aridity and aggradation with increasing humidity.

The position for climate as a control on arroyo incision is strongly supported by several Quaternary incision/aggradation cycles in the Western United States that have been documented in the literature (Leopold and Snyder, 1951; Cooley, 1962; Cooke and Reeves, 1976; Hall, 1977; Waters, 1985). Because changes in land use could not have caused incision episodes prior to human habitation, climate seems to be a logical explanation.

The position that land use causes arroyo incision has centered on human activities such as overgrazing, farming, and timber harvesting, which reduce vegetative cover and infiltration rates (Thornwaite and others, 1942; Antevs, 1952; Cooke and Reeves, 1976). These activities promote increases in surface runoff or channelization of streamflow, which can initiate arroyo

incision. Land-use practices may have been a factor in at least one episode of pre-19th century arroyo incision. Judd (1964) theorized that residents of Pueblo Bonito in New Mexico may have inadvertently concentrated Chaco River flows in the center of the valley where these flows converged to form a 12th century arroyo.

A third position is that arroyo incision is intrinsic or has a natural cyclicity (Schumm and Hadley, 1957; Patton and Schumm, 1975). Aggradation over time causes the valley gradient to steepen until a threshold slope is exceeded and the valley incises. This argument contends that arroyo incision would occur regardless of climatic or land-use changes, although climate and human activities might affect the timing of incision and aggradation. In other words, alluvial valleys in the late 1800s were ready to incise.

This paper discusses arroyo formation and evolution, and describes recent arroyo changes in the southwestern United States based on field observations and information presented by other investigators. Analyses of geomorphic and climatic data are presented to determine possible links between arroyo changes and climate.

2. ARROYO CHANGES IN THE HISTORICAL RECORD

2.1. Arroyo Evolution

Sufficient time has passed since arroyo incision began in the late 19th and early 20th century to observe a pattern of change in arroyo morphology. Arroyos initially are formed by vertical incision of a streambed, by upstream migration of headcuts, or by coalescing of discontinuous gullies. Following initiation, the maximum depth of an arroyo is quickly attained (Leopold and Miller, 1954). Removal of valley fill continues by lateral erosion of valley alluvium rather than by continued downcutting.

Through time, the morphology of arroyos in larger watersheds evolves as it responds to changes in upstream erosion and sediment delivery. Parker (1977) observed the evolution of arroyo-like features in a rejuvenated watershed in an experimental flume. As headcuts and the locus of sediment production advanced up tributaries, sediment delivered to the lower main-stem reach increased geometrically and exceeded the transport capacity of the channel. Deposition, braiding, and channel widening resulted as the channel aggraded within the incised reach.

Elliott (1979) and Gellis and others (1991) documented channel changes in arroyos and termed these changes arroyo evolution. Arroyo evolution involves sequential channel deepening, widening, inner floodplain formation, and, in larger arroyos, channel pattern adjustment. These arroyo changes generally proceed over time from the mouth of arroyos to upstream reaches. Leighly (1936) and Cooke and Reeves (1976) noted a general tendency for creation of a new channel and floodplain within an arroyo. Concurrent with these arroyo changes is a decrease in the amount of sediment delivered from the watershed as sediment is deposited in the arroyo (Gellis et al., 1991; Gellis, 1992). Annual suspended-sediment concentrations at the U.S. Geological Survey streamflow-gaging station Rio Puerco near Bernardo, New Mexico, have decreased from greater than 0.13 to less than 0.06 metric ton per cubic meter of runoff from 1948 to 1994 (Fig. 2.1).

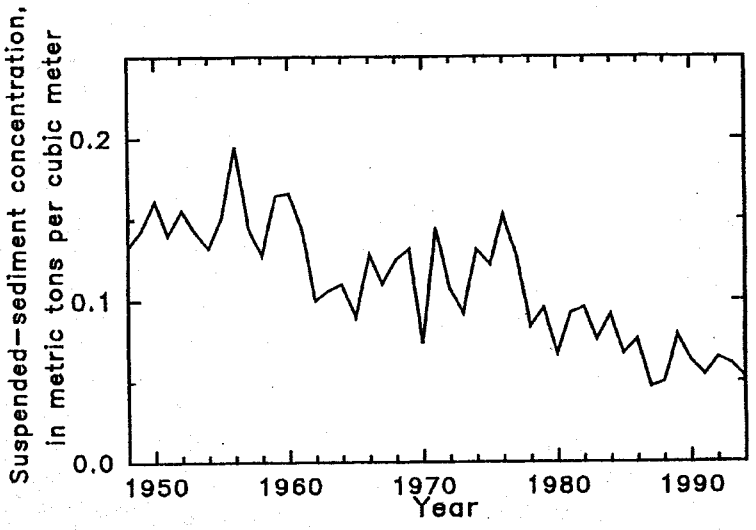

Fig. 2.1. Suspended-sediment concentration, 1948-1994, Rio Puerco near Bernardo, New Mexico.

Elliott (1979) described a five-stage sequence of arroyo cross-section and channel pattern evolution for the Rio Puerco. Presently (1996), reaches of the lower Rio Puerco are exhibiting relatively stable channel patterns and inner floodplain vegetation growth. However, a general decrease in channel width-to-depth ratios and overbank floodplain aggradation observed in 1994 and 1996 in the lower reaches suggests that Rio Puerco evolution is continuing.

Morphologic evolution similar to that of arroyos was observed in incised channels in the southeastern United States (Schumm and others, 1984; Simon, 1989). Schumm and others described a five-stage model of channel evolution from disequilibrium to stability for Oaklimeter Creek, Mississippi. In this model, attainment of channel stability involved a reduction in slope and an increase in width after incision. For the wide, gently-sloping stream, unit stream power decreased and the channel aggraded. Sinuosity changes and vegetation establishment in the channel caused further vertical accretion. Although Schumm and others (1984) were describing incised channels in Mississippi, similar channel morphologic trends are observed in arroyos of the southwestern United States.

Gellis (1988) developed a seven-stage arroyo evolution model based on studies in northeastern Arizona (Fig. 2.2). The arroyo is formed

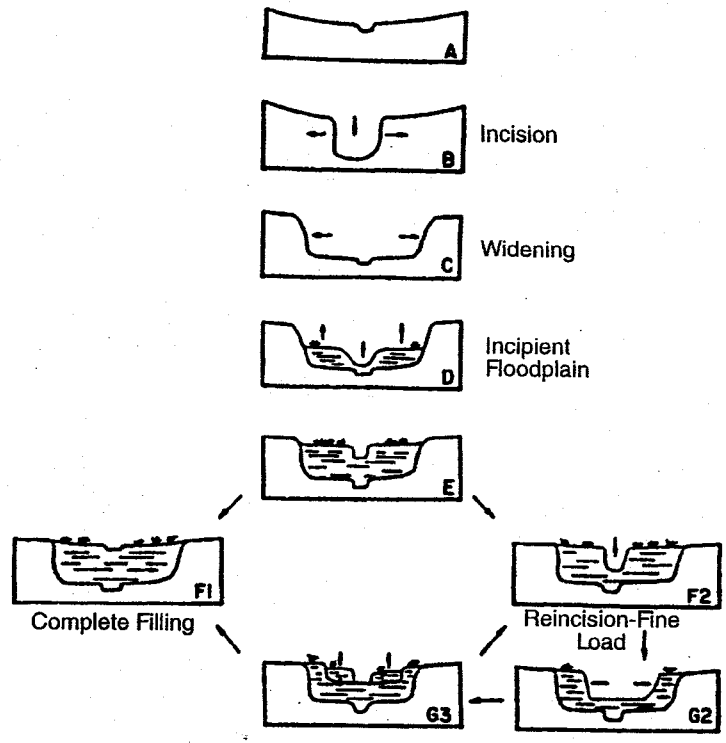

Fig. 2.2. Sequence of cross sections illustrating arroyo evolution.

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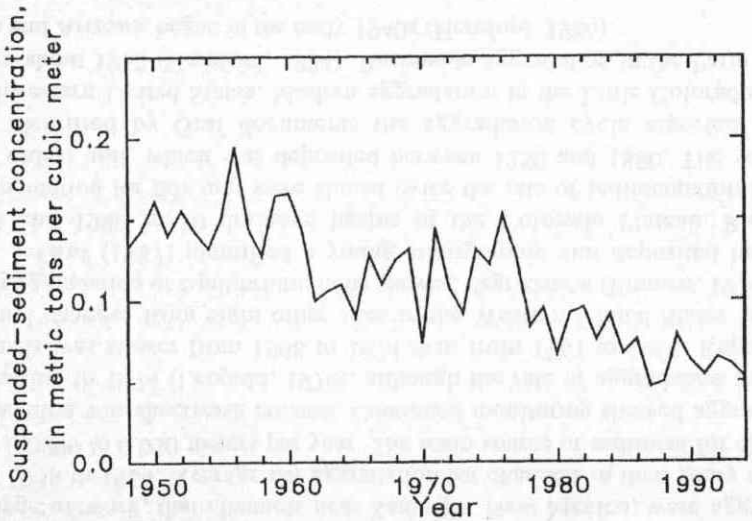

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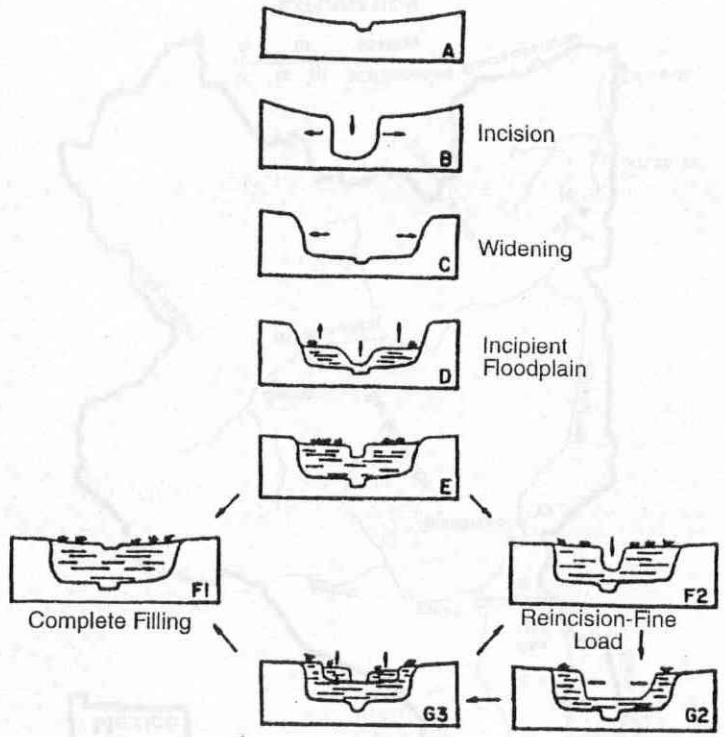

Fig. 2.2. Sequence of cross sections illustrating arroyo evolution.

by the upstream migration of a headcut. Width-to-depth ratios at the top of the channel cross section are typically lower in reaches immediately downstream from the headcut than in reaches upstream from the headcut where the channel has not yet deepened.

2.2. Recent Aggradation

Several researchers have presented evidence suggesting widespread arroyo aggradation in the Western United States in the 20th century. Leopold and others (1966) concluded, in their study of sediment sources in an ephemeral drainage network, that channels near Santa Fe, New Mexico, were aggrading from 1958 to 1964. Average net aggradation for channels in their study ranged from 0.0009 to 0.030 meters per year. The main source of sediment for channel aggradation was sheetwash erosion. Continued monitoring showed aggradation continuing to 1974 (Leopold, 1976), although the rate of aggradation in these channels was slower from 1968 to 1974 than from 1961 to 1968. Reports on channel changes from eight other sites in the Western United States showed either aggradation or equilibrium; none showed degradation (Emmett, 1974).

Graf (1987) identified a young stratigraphic unit deposited between 1943 and 1980 in 10 drainage basins of the Colorado Plateau. Rates of sedimentation for this unit were almost twice the rate of sedimentation for the next oldest unit, which was deposited between 1250 and 1880. The younger unit identified by Graf documents the aggradation cycle reported in the southwestern United States. Modern aggradation in the Little Colorado River began about 1952 (Hereford, 1984). Basinwide aggradation in the Paria River, Utah and Arizona, began in the early 1940s (Hereford, 1986).

2.3. Rio Puerco, New Mexico

The Rio Puerco in central New Mexico is a tributary of the Rio Grande with a drainage area of 15,180 km^2 (Fig. 2.3), and is an arroyo that formed in the 1880s (Bryan and Post, 1927). Evidence of several earlier cut-and-fill cycles is preserved in the Quaternary valley fill of the Rio Puerco.

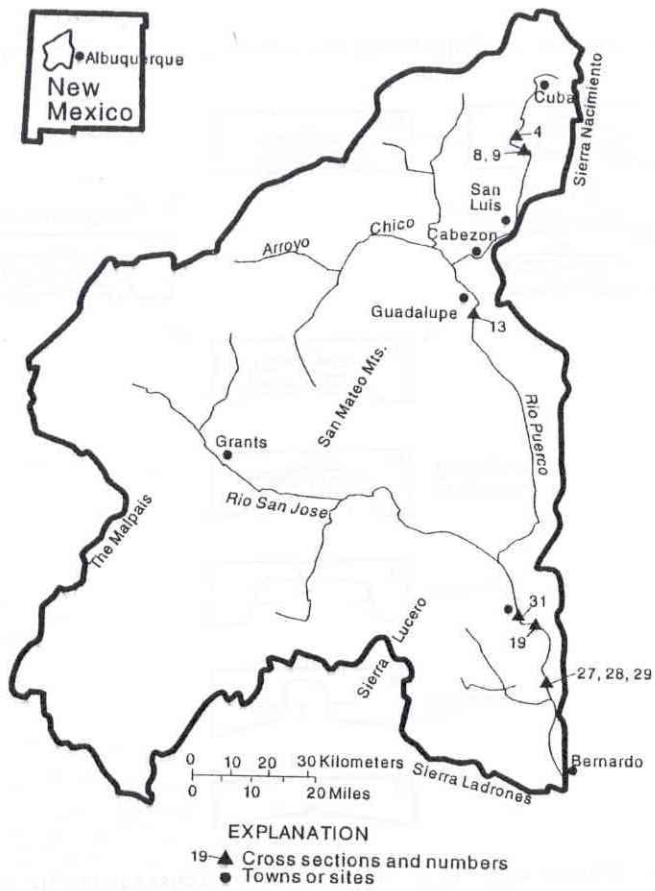

Fig. 2.3. Rio Puerco watershed, New Mexico, and location of resurveyed cross sections.

The most recent cutting cycle in the Rio Puerco occurred after European descendants settled the valley. Prior to 1885, the Rio Puerco flowed through a discontinuous arroyo, as much as 6 meters deep in places, but elsewhere with inconspicuous banks. The valley in non-incised reaches was inundated by flood flows and supported a fairly continuous plant cover and several agriculturally based communities. A combination of climatic, hydrologic, and anthropogenic factors caused the Rio Puerco to incise in the late 1880s (Elliott, 1979). Bryan (1928) dated the incision at various locations

in the Rio Puerco Valley by the abandonment of several communities and concluded that arroyo incision progressed headward from the confluence with the Rio Grande. The entire length of the Rio Puerco had incised by 1928 (Bryan, 1928), and approximately 4.87 x 10^8 m^3 of valley alluvium had eroded as the arroyo formed (Bryan and Post, 1927).

Change in the Rio Puerco has continued since the Bryan and Post (1927) study, documented by several replicated cross-section surveys and aerial photographs. Since 1885, the Rio Puerco has widened and now can be described at two scales: (1) at the scale of the entire arroyo width, and (2) at the scale of the inner channel (Fig. 2.4). The arroyo is tens to hundreds of meters wide between the two highest terrace scarps, which are remnants of the pre-19th century valley floor. Flood flows no longer occupy the entire arroyo width. An inner channel, meters to tens of meters wide, and an inner floodplain have developed on the arroyo floor (Fig. 2.4).

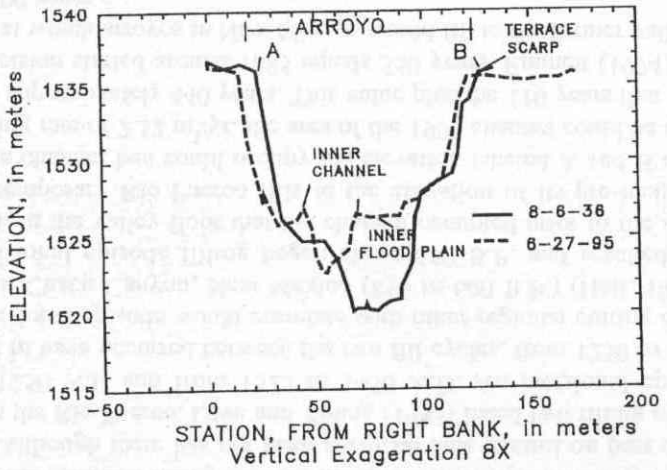

Fig. 2.4. Resurvey of Kirk Bryan's 1936 Rio Puerco cross section downstream from Highway 6, near Los Lunas, New Mexico, showing aggradation and channel morphologic terms.

Elliott (1979) analyzed arroyo and inner-channel characteristics measured from aerial photographs taken in 1935, 1953, and 1954 and from 29 inner-channel cross sections in the upper, middle, and lower reaches of the Rio Puerco surveyed in 1977 and 1978. In the late 1970s, specific reaches of the Rio Puerco could be identified as displaying one of two general morphologies

on the basis of geomorphic and sedimentologic variables. The upper reaches of the channel were characterized by Type I morphology: the inner channel typically had a sandy bed, a high width-to-depth ratio, unstable and poorly defined banks, and a laterally shifting channel pattern that was actively eroding valley fill. The middle and lower reaches of the channel were characterized by Type II morphology: the inner channel typically had a silt- and clay-rich bed and banks, a relatively low width-to-depth ratio, steep banks, and a relatively stable channel pattern. In the 1935 aerial photographs, all reaches of the Rio Puerco were characterized by Type I morphology (Elliott, 1979).

The change from Type I to Type II morphology in the middle and lower reaches of the Rio Puerco between the 1930s and the 1970s reflected the development and stabilization of a floodplain within the 19th century terrace scarps. Evidence of this floodplain development in the middle and lower arroyo reaches between the middle 1930's and the late 1970s included channel-width reduction and pattern stabilization, dense vegetation encroachment, and overbank sedimentation. Floodplain development and channel stabilization appeared to be progressing from downstream to upstream (Elliott, 1979).

Several of Elliott's arroyo reaches were resurveyed by the authors in November 1994 and June 1996 to assess arroyo, inner-floodplain, and inner-channel changes since the late 1970s (Fig. 2.3). The Guadalupe reach (cross section 13), below the confluence of Arroyo Chico and a reach south of Cuba (cross sections 8 and 9) were characterized by Type I morphology in 1977 and continued to display Type I morphology in 1994. These reaches were characterized by wide and shallow inner-channel cross sections, lateral inner-channel instability within the arroyo, and an increase in arroyo width by lateral erosion into the Quaternary valley fill. No vertical aggradation was indicated within the arroyo, nor was there evidence that Type II characteristics were beginning to succeed Type I characteristics in these reaches. However, a reach south of Cuba (cross section 4) had changed significantly since 1977. The inner-channel width had decreased by 36 percent, and a vegetated inner floodplain had developed on the right side of the previously braided streambed. This reach appeared to be in transition from a Type I to a Type II morphology.

Two reaches in the lower Rio Puerco (cross section 19; cross sections 27, 28, and 29) that were characterized by Type II morphology in 1977 continue to display Type II morphology (Fig. 2.3). These reaches had narrow and deep, well-defined inner channels and vegetated inner floodplains; however, two significant changes were observed. Channel width-to-depth ratios had decreased since 1977 and the inner floodplain had aggraded 0.3 to 1.0 meter by overbank deposition.

Cross section 31 (Fig. 2.4) in the middle Rio Puerco downstream from Highway 6 west of Los Lunas, was originally surveyed on August 6, 1936, by Kirk Bryan and was resurveyed on June 27, 1995. The cross section is located at river km 67.6 (river distance measured upstream from km 0 at the mouth) and 830 m downstream from the railroad crossing near Highway 6. Two steel bars from the original survey were found on the left bank, substantiating good elevation control at this cross section. Comparison of the two surveys indicates that the Rio Puerco streambed has aggraded 2.55 m, and the inner channel has narrowed from a width of 40.6 m in 1936 to 23.4 m in 1995 (Fig. 2.4). The area of the cross section defined from the top edge of the left terrace scarp to the top edge of the right terrace was 1,064 m^2 in 1936 and 939 m^2 in 1995. The rate of cross-sectional filling between these two surveys is 2.12 m^2/yr.

Although there has not been adequate date control on past cut-and-fill cycles in the Rio Puerco, Love and Young (1983) listed two filling cycles from 900 to 1250 A.D and from 1325 to 1450 A.D. An incisional episode was assumed to have occurred between the two fill cycles, from 1250 to 1325 A.D. This incisional episode would correlate with other regional cutting dates, such as that in Chaco Canyon, New Mexico (850 to 600 B.P.) (Hall, 1977). After this incisional episode filling began about 650 B.P. and reached the same elevation in the valley floor that the channel occupied prior to the incision. If the contemporary Rio Puerco fills to the elevation of its pre-incision valley floor, the channel bed could occupy the elevation labeled A and B in Fig. 2.4. At a filling rate of 2.12 m^2/yr, the area of the 1995 channel could be completely filled in approximately 440 years. This value plus the 110 years that has passed since incision started around 1885 equals 550 years. Emmett (1974) estimated the rate at which arroyos in New Mexico would fill to the former valley floor at 200 to 700 years.

2.4. Zuni River, New Mexico

The Zuni River at the Arizona-New Mexico border drains an area of 3,403 km^2 (Fig. 2.5a) and is a tributary of the Little Colorado River. Arroyos on the Zuni Reservation that drain into the Zuni River incised between 1905 and 1920 (Balling and Wells, 1990). Changes in 85 monumented channel cross sections were examined in three subbasins of the Rio Nutria, a tributary of the Zuni River, between January 1992 and December 1994 (Fig. 2.5b). Drainage areas of the three subbasins are Y-Unit Draw, 24.55 km^2; Benny Draw, 3.0 km^2; and Conservation Draw, 6.40 km^2.

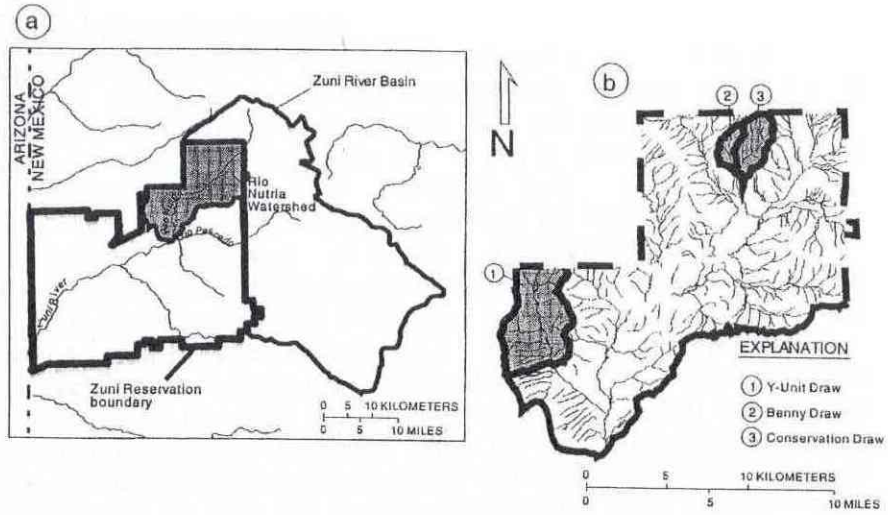

Fig. 2.5. (a) Location of major watersheds of the Zuni River Basin on the Zuni Reservation; (b) Location of subbasins in the Rio Nutria watershed.

Results of Zuni Reservation channel resurveys of 85 cross sections indicated that 72 percent of cross sections are aggrading and that 52 percent show a decrease in cross-sectional area. More cross sections show an increase in cross-sectional area (n=41) than show scour (n=23) because some cross sections that are aggrading are also increasing in cross-sectional area. For all cross sections, 43 percent are aggrading but are also increasing in cross-sectional area because of an accompanying increase in width.

In the Zuni study area, most arroyos are aggrading and widening. This may indicate that most resurveyed cross sections are in Stage C to E (Fig. 2.2).

2.5. Discussion

Case studies and previously published work support the conclusion that many channels that were incised starting in the late 19th century and early 20th century are currently aggrading. Since incision, many arroyos continue to evolve. The sequential stages of arroyo evolution--channel deepening, channel widening, floodplain formation, and the establishment of vegetation--generally proceed upstream through the watershed and ultimately lead to channel aggradation and reduced sediment yields. Therefore, channel aggradation

observed in channels in the Western United States may be due in part to arroyo evolution.

3. RECENT PRECIPITATION TRENDS

Hack's (1942) climatic interpretations of arroyo cut-and-fill cycles suggested that aggradation occurs during wet periods and incision during dry periods. This generalization of cut-and-fill cycles has continued to the present (Leopold, 1994). Based on climatic variations during the most recent arroyo cutting episode (1880-1920), a further assumption for channel cutting is that following dry periods, a high frequency of high-intensity rainfall events occurred that ultimately lead to channel incision (Leopold, 1951; Balling and Wells, 1990).

Leopold (1951) analyzed precipitation records at Santa Fe that extended back to 1849. Only records extending back to 1868 could be obtained and were reanalyzed by the authors in this paper. No trend was detected in average annual rainfall (Leopold, 1951) (Table 3.1). The average annual

Table 3.1. Average frequency, in days per year, of rains of various sizes during six time periods.

Time Period	Average number of days having rainfall of indicated amount			
	Daily Rainfall Less than 2.7 mm (days)	Daily Rainfall 12.7 - 25.4 mm (days)	Daily Rainfall Greater than 25.4 mm (days)	Mean Annual Rainfall (mm)
1868-1880	68.1	4.6	2.1	345
1881-1910	82.2	5.5	1.1	360
1911-1930	83.0	5.4	1.2	364
1931-1950	76.6	4.8	1.1	357
1951-1970	63.5	5.3	1.4	350
1971-1993	58.6	5.2	1.6	355

frequency of daily rainfall in three classes, less than 12.7 mm, 12.7 to 25.4 mm, and greater than 25.4 mm, was calculated for selected time periods from 1868 to 1993. The data showed an increase in frequency in the less than 12.7 mm class from the period 1868-1880 to the time periods spanning 1881-1930 (Table 3.1). The frequency of daily rainfall greater than 25.4 mm decreased after 1880. After 1930 the frequency of daily rainfall in the less than 12.7 mm class decreased, and after 1950 daily rainfall in the greater than 25.4 mm class

increased slightly. According to Leopold (1951), vegetation utilizes low-intensity rainfall. Periods characterized by low-intensity rainfall tends to be associated with an increase in vegetation density and a decrease in erosion (Leopold, 1951), assuming no change in land use. Conversely, high-intensity rainfall tends to be associated with increased runoff and erosion. From 1868 to 1880 low-intensity rainfall occurred relatively infrequently and high-intensity rainfall occurred slightly more frequently (Leopold, 1951); therefore climatic conditions in the southwestern United States may have been conducive to the widespread arroyo incision that occurred in the late 19th and early 20th century. Analysis of the climatic record by Leopold in 1951 led him to conclude that arroyo incision occurred during periods of aridity.

Leopold and others (1966) calculated average rainfall intensity by dividing annual rainfall by the number of days having rainfall in that year. For a constant annual precipitation, higher values of average rainfall intensity would indicate that annual rainfall fell in fewer days, presumably with a greater intensity that could have resulted in accelerated erosion. A plot of average annual rainfall intensity (Fig. 3.1) shows more intense rainfall in the period 1853-1880 that may have led to late 19th century arroyo incision. Based on the manner in which Leopold (1951) and Leopold and others (1966) interpreted average annual rainfall intensity, rainfall since 1967 may indicate that climatic factors are favorable for arroyo incision in the southwestern United States.

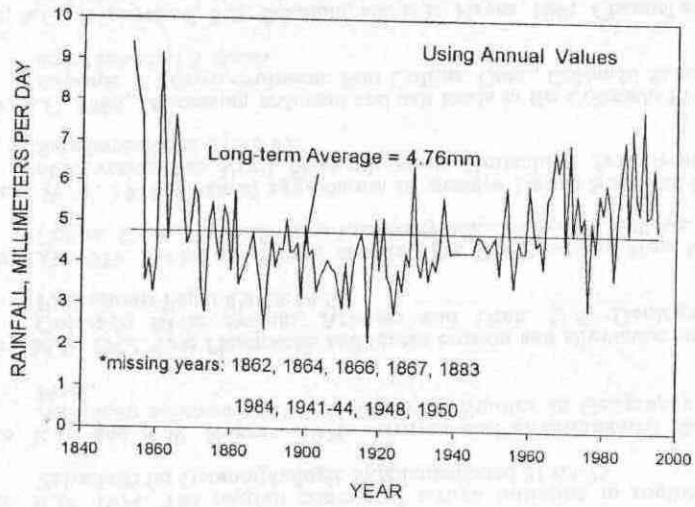

Fig. 3.1. Average annual rainfall intensity, Santa Fe, New Mexico, 1853-1993.

4. SUMMARY AND CONCLUSIONS

Recent studies in the southwestern United States indicate that many incised channels are aggrading. Graf (1987) indicated aggradation beginning about 1940. Studies of the Rio Puerco and Zuni River tributaries suggest inner floodplain aggradation within arroyos that developed in the late 19th and early 20th centuries. Beginning about 1930, climatic records at Santa Fe, New Mexico, show a decrease in the frequency of low-intensity rainfall, the type of rainfall associated with increased vegetation growth and channel aggradation. Average annual rainfall intensity increased and has generally remained above normal since 1967. The decrease in frequency of low-intensity rainfall at Santa Fe indicates that climatic conditions may be suitable for a period of degradation, contrary to onsite evidence from the Rio Puerco and Zuni River tributaries. Because precipitation records for Santa Fe may not be representative of the entire southwestern United States, the conclusion remains tentative pending climatic analysis for other areas.

The arroyo incision in the late 19th and early 20th century may have involved climate change as a triggering mechanism. Valleys in the southwestern United States had filled since an earlier cutting episode 400-800 B.P. and probably were at the threshold of incision in the late 19th century. Evidence that arroyos currently are aggrading may suggest that the initiation of later-stage aggradation in arroyos is partially controlled by intrinsic conditions. These intrinsic conditions are determined by hydraulic properties related to channel geometry and the stage of arroyo evolution. Although climate may have been the triggering mechanism for arroyo incision that began in the late 19th century, climate may not be the main factor in channel aggradation. Intrinsic conditions determined by hydraulic properties related to channel geometry and the stage of arroyo evolution may be a major influence on channel aggradation, whereas climate may exert a major influence on the rate at which channels aggrade. The preliminary conclusions in this paper are based on initial data and further data sets and interpretations are forthcoming.

5. REFERENCES

Antevs, E. 1952. Arroyo-cutting and filling. Journal of Geology, 60:375-378.

Balling, R.C. and S.G. Wells. 1990. Historical rainfall patterns and arroyo activity within the Zuni River drainage basin, New Mexico. Annals of the American Geographers 80:603-617.

Bryan, K. 1928. Historic evidence of changes in the channel of the Rio Puerco, a tributary of the Rio Grande, New Mexico. Journal of Geology 36:265-282.

Bryan, K. and G. Post. 1927. Erosion and control of silt on the Rio Puerco, New Mexico. Unpublished Report to the Chief Engineer, Middle Rio Grande Conservancy District, Albuquerque, New Mexico.

Cooke, R.U. 1974. The rainfall context of arroyo initiation in southern Arizona. Zeitschrift fur Geomorphologie Supplementband 21:63-75.

Cooke, R.U. and R.W. Reeves. 1976. Arroyos and environmental change in the American southwest. Oxford Research Studies in Geography. Clarendon Press.

Cooley, M.E. 1962. Late Pleistocene and recent erosion and alluviation in parts of the Colorado River system, Arizona and Utah. U.S. Geological Survey Professional Paper 450-B:48-50.

Elliott, J.G. 1979. Evolution of large arroyos; The Rio Puerco of New Mexico. Fort Collins, Colo., Colorado State University, unpublished M.S. thesis.

Emmett, W.W. 1974. Channel aggradation in western United States as indicated by observations at Vigil Network sites: Zeitschrift fur Geomorphologie Supplementband 21:52-62.

Gellis, A.C. 1988, Decreasing sediment and salt loads in the Colorado River basin--A response to arroyo evolution: Fort Collins, Colo., Colorado State University, unpublished M.S. thesis.

Gellis, A.C., R. Hereford, S.A. Schumm, and B.R. Hayes. 1991, Channel evolution and hydrologic variations in the Colorado River basin--Factors influencing sediment and salt loads. Journal of Hydrology 124:317-344.

Gellis, A.C. 1992, Decreasing trends of suspended-sediment loads in selected streamflow stations in New Mexico: New Mexico Water Resources Research Institute Report 265:77-93.

Graf, W.L. 1987, Late Holocene sediment storage in canyons of the Colorado Plateau. Geological Society of America Bulletin 99:261-271.

Hack, J.T. 1942. The changing physical environment of the Hopi Indians of Arizona. Peabody Museum Papers 35:1.

Hall, S.A. 1977. Late Quaternary sedimentation and paleoecologic history of Chaco Canyon, New Mexico. Geological Society of America Bulletin 88:1593-1618.

Heede, B.H. 1977, Case study of a watershed rehabilitation project: Alkali Creek, Colorado: U.S.D.A. Forest Service Research Paper RM-189.

Hereford, R. 1984, Climate and ephemeral-stream processes--Twentieth-century geomorphology and alluvial stratigraphy of the Little Colorado River, Arizona. Geological Society of American Bulletin 95:654-668.

Hereford, R. 1986, Modern alluvial history of the Paria River drainage basin, Southern Utah. Quaternary Research 25:293-311.

Judd, N.M. 1964. The architecture of Pueblo Bonito, Smithsonian Miscellaneous Collections 147:1.

Landon, S. 1990. Eroding a way of life. Albuquerque Journal, July 1, 1990, p. 1, SectionF.

Leighly, J. 1936. Meandering arroyos of the dry southwest. Geographical Review 36:270-282.

Leopold, L.B. 1951. Rainfall frequency--An aspect of climatic variation. American Geophysical Union Transactions 32:3:347-357.

Leopold, L.B. 1994. A view of the river. Harvard University Press.

Leopold, L.B. and C.I. Snyder. 1951. Alluvial fills near Gallup, New Mexico. U.S. Geological Survey Water-Supply Paper :1110-A.

Leopold, L.B. and J.P. Miller. 1954. A postglacial chronology for some alluvial valleys in Wyoming.U.S. Geological Survey Water-Supply Paper :1261

Leopold, L.B., W.W. Emmett, and R.M. Myrick. 1966. Channel and hillslope processes in a semiarid area, New Mexico. U.S. Geological Survey Professional Paper :352-G.

Leopold, L.B. 1976, Reversal of erosion cycle and climatic change. Quaternary Research 6:557-562.

Love, D.W. and J.D. Young. 1983, Progress report on the late Cenozoic geologic evolution of the lower Rio Puerco. New Mexico Geological Society Guidebook, 34th field conference, Socorro Region II.

Parker, R.S. 1977. Experimental study of drainage basin evolution and its hydrologic implications. Hydrology Papers, Colorado State University, Fort Collins, Colorado 90:58.

Patton, P.C. and S.A. Schumm. 1975. Gully erosion, northwestern Colorado--A threshold phenomenon. Geology 3:88-90.

Schoenwetter, J. and A.E. Dittert. 1968. An ecological interpretation of Anasazi settlement patterns. The Anthropological Society of Washington, Anthropological Archaeology in the Americas:41-66.

Schumm, S.A. and R.F. Hadley. 1957. Arroyos and the semiarid cycle of erosion. American Journal of Science 25:161-174.

Schumm, S.A., M.D. Harvey, and C.C. Watson. 1984, Incised channels: Littleton Press, Littleton, Colorado.

Simon, A. 1989, A model of channel response in disturbed alluvial channels. Earth Surface Processes 14:11-26.

Thornwaite, C.W., C.F.S. Sharpe, and E.F. Dosch. 1942, Climate and accelerated erosion in the arid and semiarid southwest, with special reference to the Polacca Wash drainage basin, Arizona. U.S. Department of Agriculture Technical Bulletin 808.

Waters, M.R. 1985, Late Quaternary alluvial stratigraphy of Whitewater Draw, Arizona--Implications for regional correlation of fluvial deposits in the American Southwest. Geology 13:705-708.

CHANNEL INSTABILITY IN THE LOESS AREA OF THE MIDWESTERN UNITED STATES: A COMBINATION OF ERODIBLE SOILS AND HUMAN DISTURBANCE

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ABSTRACT

The loess area of the midwestern United States contains thousands of miles of unstable stream channels that are undergoing systemwide channel-adjustment processes as a result of (1) modifications to drainage basins dating back to the turn of the 20th century: land clearing and poor soil-conservation practices, which caused the filling of stream channels, and consequently (2) direct, human modifications to stream channels such as dredging and straightening to improve drainage conditions and reduce the frequency of out-of-bank flows. Today, at the turn of the 21st century, many of these channels are still highly unstable and threaten bridges, other structures, and land adjacent to the channels. The most severe, widespread instabilities are in western Iowa where a thick cap of loess and a lack of sand- and gravel-sized bed sediments in many channels hinders downstream aggradation, bed-level recovery and the consequent reduction of bank heights, and renewed bank stability. In contrast, streams draining west-central Illinois, east-central Iowa, and other areas where the loess cap is relatively thin and there are ample supplies of sand- and gravel-sized material, are closer to recovery. Throughout the region, however, channel widening by mass-wasting processes is the dominant adjustment process.

KEYWORDS

Channel instability, erodible soils, channel degradation

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