Appendix 4b - Río Puerco

Rio Puerco Online
http://climchange.cr.usgs.gov/rio_puerco/

Rio Puerco Online

The Arroyo Cycle and Climate

The arroyo cycle and climate change are of scientific and practical interest. The Rio Puerco Basin, New Mexico, is an area of historic arroyo incision, long-term geomorphic investigation, and ongoing land management issues. This website comprises earth science and historical perspectives of the Rio Puerco Basin, and data and models that can be used to help predict responses to future changes of climate and landuse.

For more information and further reading, please see:

- Erosion in the Rio Puerco: Geography and Processes
- The Rio Puerco Arroyo Cycle and the History of Landscape Changes
- The Arroyo Problem in the Southwestern United States

Impacts of the late 19th century arroyo incision, and subsequent sediment aggradation, can be documented through repeat photography. Historic photos from selected locations in the basin were obtained from the USGS photo archive in Denver, CO. Repeat photography was done by Scott Aby in 1998. We welcome any contributions to this historic archive.

Erosion Rates and Sediment Monitoring

One cannot talk about the Rio Puerco without talking about sediment. The USGS in conjunction with other federal and state agencies and Universities has established methods and sites for monitoring sediment yields in the Puerco. Allen Gellis has summarized the history of gaging and sediment collection and is developing a sediment budget for the Rio Puerco. Gaging of the main stem and tributaries, such as Arroyo Chavez, allows for comparison of sediment yields over various spatial and temporal scales.

Cosmogenic isotopes ^{10}Be and ^{26}Al provide evidence for upland erosion rates and residence time of sediment in temporary storage on hillslopes and low-order stream alluvium. Sampling and analysis are being conducted by Paul Bierman at the University of Vermont.

Past Climate and Cycles of Change

The late Quaternary record dated by ^{14}C provides evidence for climate change over the past 30,000 years. Within that time, intervals as short as a few hundred years, such as the Medieval Warm Period and Little Ice Age, can be distinguished.

Tree ring records provide a 2000 year record of rainfall cycles for the western part of the basin. Records from the El Malpais National Monument have been studied recently by Henri Grissino-Mayer.

Over ten thousand archeological sites are known to exist in the Rio Puerco Basin, ranging in age from paleoindian (9,500 to 9,000 BC) to 19^{th} and 20^{th} century historic settlements. These sites can aid in the understanding of population dynamics, settlement pattern analyses, and provide clues to landscape and environmental changes.

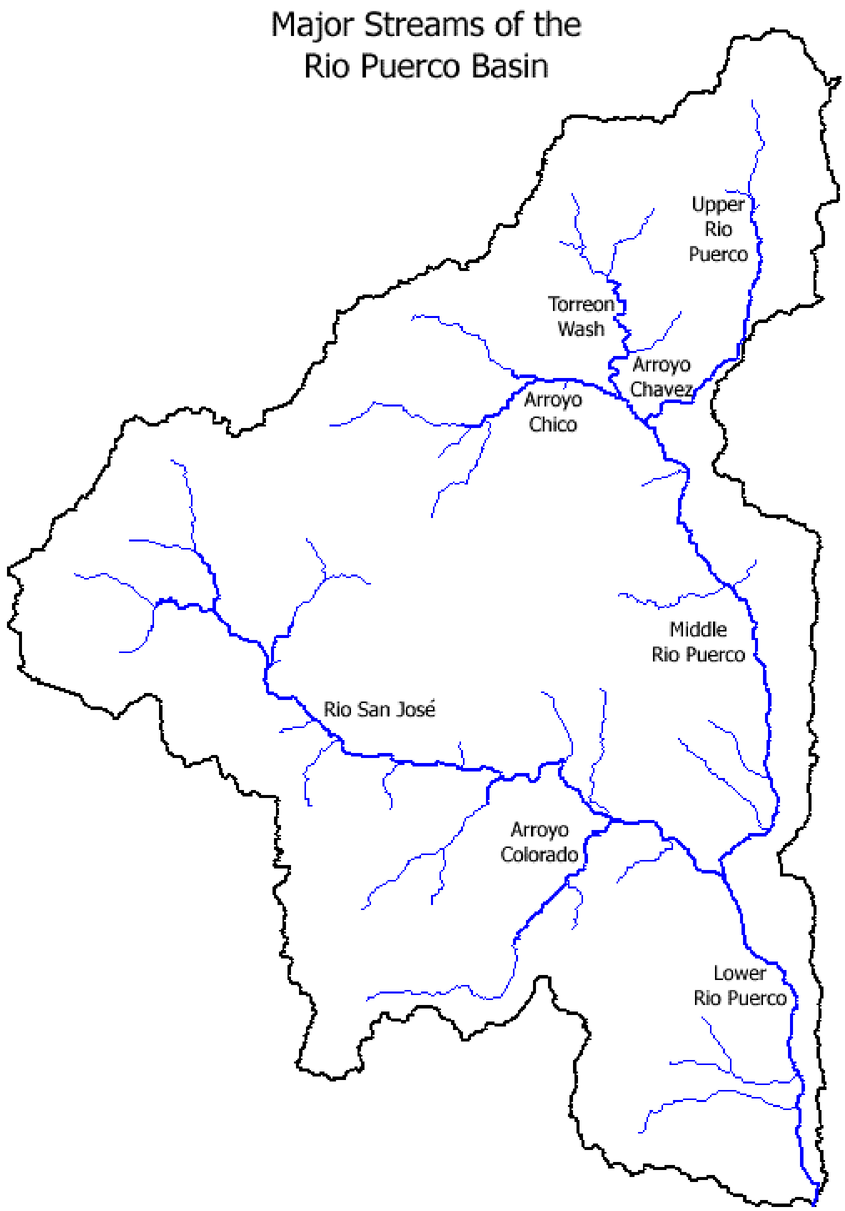
Data sets for the project are being prepared for online distribution at the Rocky Mountain Mapping Center. Browse the Online Data Library for GIS coverages and aerial photos that are available for downloading and viewing.

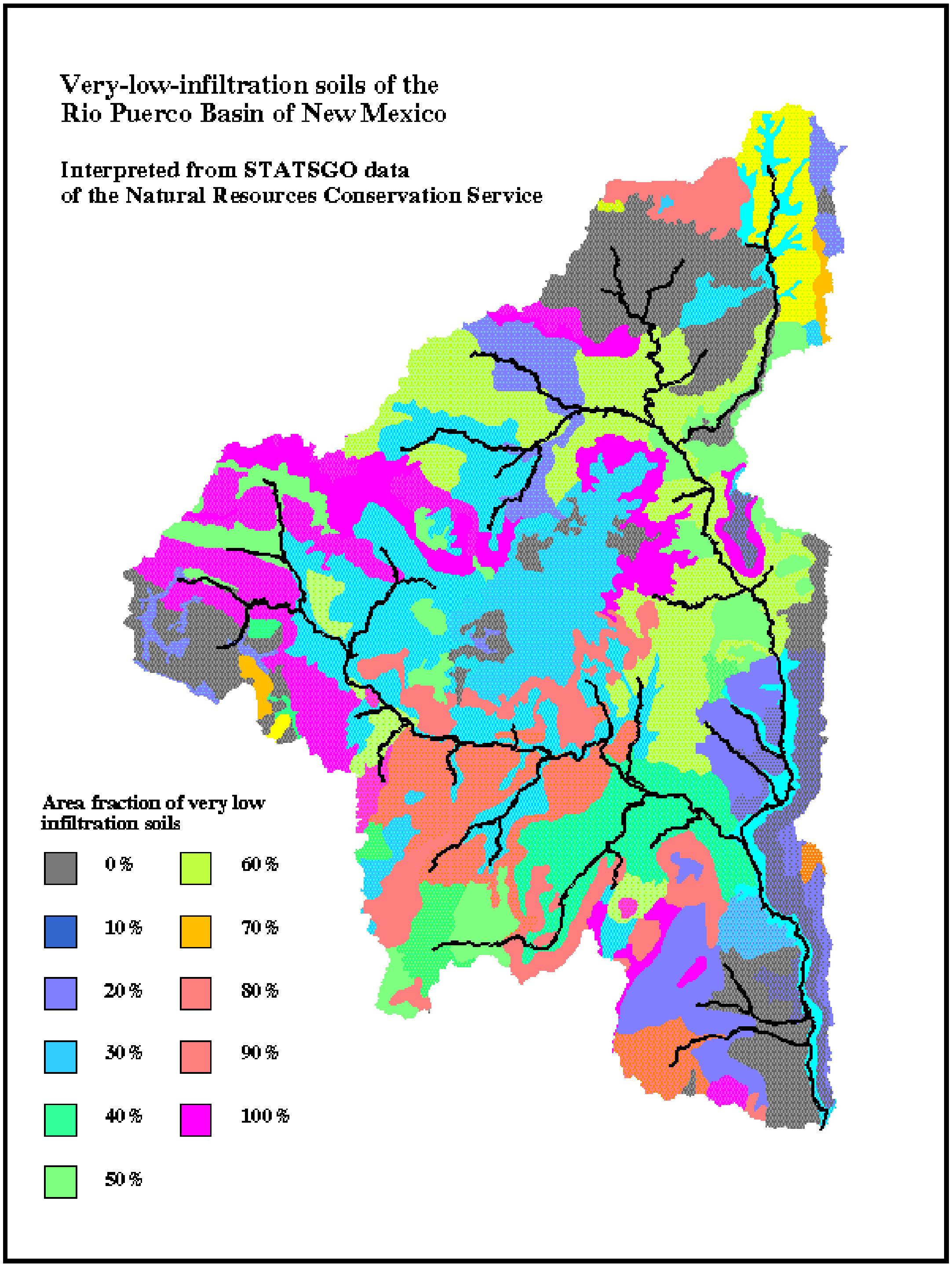
Hydrologic and geomorphic data are being used to calibrate a model of water and sediment discharge in the arroyo. A model overview shows the links from the atmosphere to hillslopes and channel processes. Preliminary hillslope flow model results for Arroyo Chavez are presented in the detailed diagrams. Data from six stream gages will be used to test model outputs of stream discharge. Channelization has produced dramatic effects near La Ventana in the Upper Puerco. Please read Erosion in the Rio Puerco: Geography and Processes for more information, or visit the Water Resources Division's Albuquerque District Office to learn more about hydrology and sediment in New Mexico.

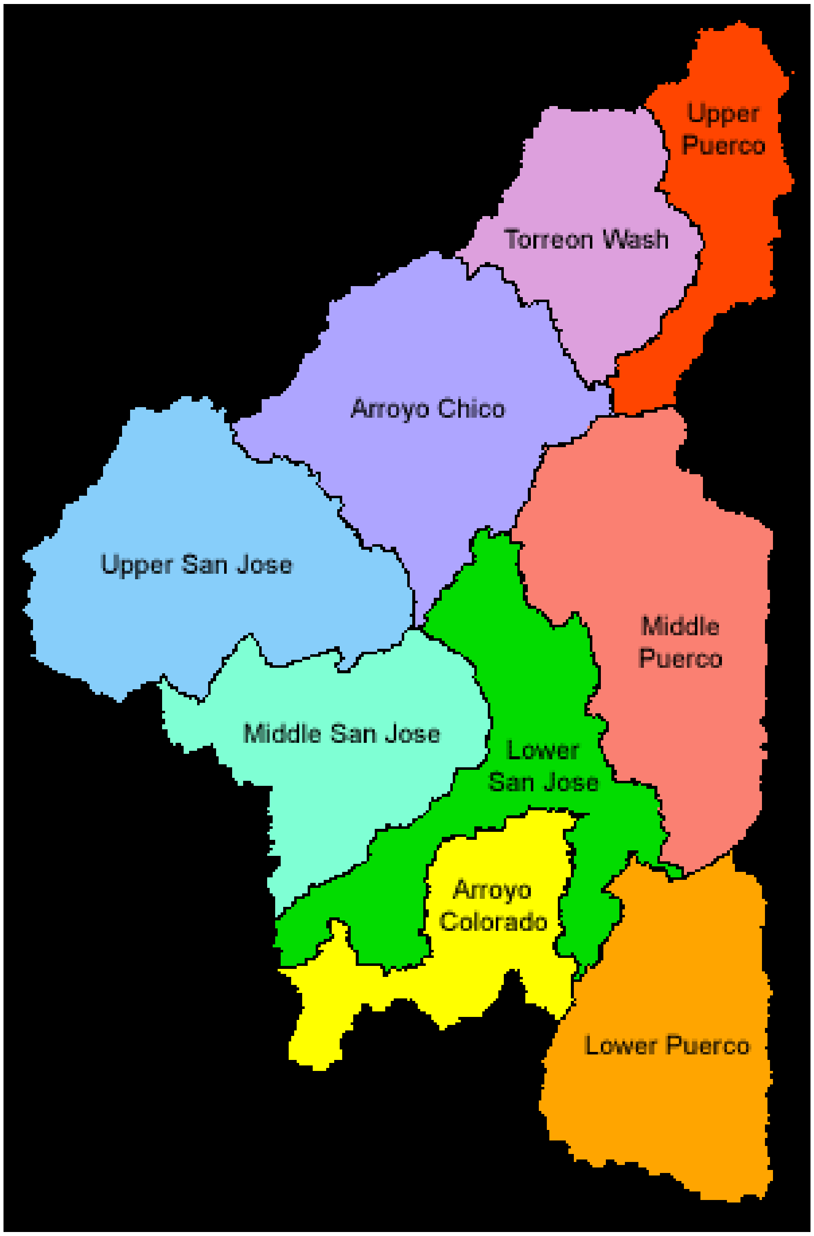
Related Links

Visit the Water, Energy, and Biogeochemical Budget web site to learn more about USGS research activities in a variety of other watersheds.

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/
Maintained by Richard Pelltier
Last modified: 13:50:10 on 26-Dec-2000


Major Streams of the
Rio Puerco Basin
Upper
Rio
Puerco
Torreon
Wash
Arroyo
Chavez
Arroyo
Chico
Middle
Rio Puerco
Rio San José
Arroyo
Colorado
Lower
Rio Puerco


Very-low-infiltration soils of the
Rio Puerco Basin of New Mexico
Interpreted from STATSGO data
of the Natural Resources Conservation Service
Area fraction of very low
infiltration soils
0 %
10 %
20 %
30 %
40 %
50 %
60 %
70 %
80 %
90 %
100 %


Upper
Puerco
Torreon Wash
Arroyo Chico
Upper San Jose
Middle
Puerco
Middle San Jose
Lower
San Jose
Arroyo
Colorado
Lower Puerco

http://climchange.cr.usgs.gov/rio_puerco/intro/overview.html

overview

The Rio Puerco basin occupies roughly 16,000 km2 of northwestern New Mexico. Rio Puerco is one of the main tributaries of the Rio Grande, entering the river near Bernardo. It supplies more than 70% of the suspended sediment entering the Rio Grande above Elephant Butte reservoir.

The topography of the basin reflects the differential resistance of rock units to weathering and erosion. The highest parts of the basin drain Precambrian Granite of the Nacimiento range and basic volcanics of the Mt. Taylor Complex. Intermediate elevation mesas are on Mesozoic sandstones (e.g. Point Lookout Fm.) and the lowest areas are on Mesozoic shales (e.g. Mancos Fm.).

The distribution of soils and vegetation is also influenced strongly by topography and geology. This Normalized Density Vegetation Index (NDVI) image from July 5, 1989, represents a pre-monsoon period in a dry year. The colors going from red-yellow-blue-green indicate increasing chlorophyll content. Areas of little or no chlorophyll are displayed as dark gray or black. We are using such images to compare wet and dry seasons in wet and dry years. The average rainfall in the basin varies annually between about 12 to 20 inches, and is delivered mostly by the summer monsoon. Comparisons of images between very wet and very dry intervals show many parts of the basin are very responsive to seasonal variations in precipitation.

However, large areas, particularly in the Arroyo Chico drainage (to the north of Mt. Taylor), show little vegetation change with annual or seasonal precipitation variation. This information will be used to assess erosion potential. Natural vs. human controls on vegetation distribution are important to assessing impacts of grazing and other landuse practices on erosion and the overall Puerco sediment budget.
,,,,,,,.

Group Name: **The Rio Puerco Management Committee**
Contact: Michael W. Coleman, Watershed Team Leader
Contact Address: NM Environment Dept , P.O. Box 26110
Santa Fe, New Mexico 87502
Contact Phone: 505-827-0505
Contact Email: michael_coleman@nmenv.state.nm.us

Activity:Restoration/Conservation Project

Description:Section 401(c) of Public Law 104-333, the Omnibus Parks and Public Lands Management Act of 1996 established the Rio Puerco Management Committee (RPMC) to carry out a broad-based collaborative effort to restore and manage the Rio Puerco Watershed in northwest New Mexico. This watershed has gained notoriety as a severely degraded basin where soil erosion surpasses that of any other watershed in the country, according to the Corps of Engineers. Beginning in February, 1997, the RPMC has evolved into a cohesive organization focused on the primary goals of sediment reduction, vegetation and habitat improvement, and promotion of interagency and public cooperation,socio-economic benefits, education and participation. The RPMC is presently active implementing several Clean Water Act section 319 projects through the NM Environment Dept. and EPA (stream restoration and subwatershed projects), and are participating in a number of watershed and educational projects throughout the watershed, developed under funding provided via an appropriation through the U.S. Department of the Interior and the Bureau of Land Management.

Address: c/o Bureau of Land Management, 435 Montano NE
Albuquerque, New Mexico 87107

http://climchange.cr.usgs.gov/rio_puerco/erosion/streamflow.html

History of Streamflow and Suspended-Sediment Collection in the Rio Puerco Basin, New Mexico

Allen Gellis, U.S. Geological Survey, Albuquerque, NM 87110

Introduction

The high sediment loads and sediment transport characteristics of the Rio Puerco, central New Mexico, have for decades attracted the attention of geologists, hydrologists, and engineers (Bryan and Post, 1927; Nordin and Curtis, 1962; Nordin, 1963; Heath, 1983; Gellis,1992). Suspended-sediment concentrations in excess of 400,000 ppm were observed by Nordin (1963) for the Rio Puerco near Bernardo and averages of 79,000 mg/L were reported by the Bureau of Reclamation (1994). Simons and others (1991) estimated that 90 percent of the suspended-sediment load in the Rio Puerco is silt and clay (<0.062mm). The problems caused by the transport of this sediment into the Rio Grande has been a concern since the 1920's when Bryan and Post (1927) outlined a detailed plan to control erosion and sediment transport in the Rio Puerco. In response to continuing problems of sedimentation in Elephant Butte Reservoir and the Rio Grande, the Bureau of Reclamation, in 1994, investigated the development of a sediment control project for the Rio Puerco (Bureau of Reclamation, 1994).

The drainage area of the Rio Puerco located in central New Mexico is 7,350 mi2 (19,036 km2) of which 1,130 mi2 (2,927 km2) does not contribute to surface runoff (fig. 1). The Rio Puerco is intermittent through most of its length with higher elevations receiving snowmelt and precipitation runoff events and lower reaches dominated by convective rainfall-runoff events. The large aerial extent of erosive geologic units in the basin provides a large source of available sediment to the channel. Happ (1948) estimated the sources of sediment in the Rio Puerco as: 40% erosion of the existing Rio Puerco channel (bed and banks), 30% erosion in tributary channels, and 30% sheet, rill, and minor gully erosion.

Suspended-Sediment Data

Collection of suspended sediment for computation of daily suspended-sediment discharge began in the Rio Puerco basin by the U.S. Geological Survey (USGS) in 1948 (fig. 1; Table 1). During the period 1948-1956, five stations were operating on the main stem Rio Puerco and its two major tributaries, the Rio San Jose and Arroyo Chico (Table 1). At the time of this paper, only two stations are operating in the basin, the Rio Puerco at Bernardo and the Rio Puerco above Arroyo Chico. Collection of suspended sediment data and computation of sediment loads in the Rio Puerco followed USGS procedures outlined by Porterfield (1972) and Edwards and Glysson (1988). Daily samples were collected by an observer with additional samples collected during runoff events by USGS personnel. In 1995, an automatic suspended-sediment sampler was installed at the Rio Puerco near Bernardo and the Rio Puerco above Arroyo Chico. An additional, higher stage automatic sampler was installed at the Rio Puerco near Bernardo in 1997. The sediment records can be described as good from 1948 to 1972, fair from 1973 to 1992, and good with the installation of an automatic sampler in 1993. Sediment records are labeled as fair from 1973 to 1992 because few runoff events were adequately sampled in that time period.

For the period of suspended-sediment collection at the Rio Puerco near Bernardo, 1948-96, the average annual suspended-sediment load was 4.44 million tons (4.03 metric tons). The sediment yield of the Rio Puerco is moderately high compared to world rivers (fig. 2a). However, by normalizing sediment load by average annual runoff instead of drainage area the Rio Puerco has the third highest sediment concentration (fig. 2b).

Compared to the suspended-sediment loads transported at the Rio Grande near San Marcia, located approximately 52 miles (84 km) downstream of the Rio Puerco, the Rio Puerco transported 83% of the total load of the Rio Grande from 1948 to 1973 and 64% of the total load from 1974 to 1996. For the same periods, 1948-73 and 1974-96, the Rio Puerco transported 5.6 and 2.3%, respectively, of the total runoff measured at the Rio Grande near San Marcia. In 1974, Cochiti Reservoir located approximately 92 miles (148 km) upstream from the mouth of the Rio Puerco, was closed and therefore, 1974 was chosen as a break in the two time periods. The closure of Cochiti Reservoir may have reduced the upstream contributions of sediment and therefore, may have effected downstream sediment transport.

During the period of sediment collection at the five stations (fig. 1) most of the runoff (30 to 50%) occurs in August or September (fig. 3a). Rainfall events during the monsoonal period in New Mexico from July to September are typical of convective-type rainfall events. The station Rio Puerco above Arroyo Chico has peak runoff in May and is a function of snowmelt in the Nacimiento Mountains above Cuba. Thirty-one to 51 percent of the suspended-sediment load at the five stations is transported during the monsoonal period in August or September (fig. 3b).

A sediment budget for the Rio Puerco was developed using suspended-sediment data from these five stations from 1949 to 1955 (fig. 1). Compared to the Rio Puerco near Bernardo, the largest upstream contributor of suspended sediment from 1949 to 1955, is the Arroyo Chico which drains 24 percent of the basin and delivers 34 percent of the suspended-sediment load (fig. 4). The Arroyo Chico also contributed most of the runoff (52%). The highest average annual sediment yield of any station is the Rio Puerco above Arroyo Chico (2,721 tons/mi^2). The highest total sediment concentration of any station, reported as total suspended sediment for the period divided by total runoff, is the Rio Puerco above Arroyo Chico (190 tons sediment/acre-feet runoff). The Rio San Jose at Correo reported the lowest values on sediment transport of any station (fig. 4). This low value of suspended-sediment transported at the Rio San Jose near Correo relative to the main stem Rio Puerco and Arroyo Chico may reflect differences in geology, soils, and channel hydraulics.

Trends in Suspended Sediment

Suspended-sediment loads and average annual suspended-sediment concentrations show a decrease for the period of record at Rio Puerco near Bernardo, Rio Puerco above Arroyo Chico, and Arroyo Chico near Guadalupe (fig. 5). Gellis (1992) reported that this decrease was due to channel changes over time referred to as arroyo evolution. In the arroyo evolution model systematic changes in channel geometry occur following channel entrenchment, from channel deepening to channel widening. Channel widening leads to less erosive flows, increased areas on the floodplain for colonization of vegetation, and channel aggradation. The increase in sediment deposition over time leads to a decrease in suspended-sediment loads. Similar decreases in suspended-sediment loads were observed in the Colorado River basin (Gellis and others, 1991) and in the Rio Grande (Gellis, 1992). Love (1997) concluded that arroyo evolution, which is largely based on a headward erosion model, may not be applicable in the main stem Rio Puerco.

Elliott (1979) distinguished downstream channel reaches from upstream reaches based on multiple discriminant function analyses of selected channel geometric, sedimentologic, and planimetric variables. Upstream channel reaches had large width-to-depth ratios, contained relatively small amounts of silt and clay sized material in the channel perimeter, contained low vegetation density, and a lateral shifting channel that was actively eroding. The channel in the downstream reaches had relatively small width-to-depth ratios, large amounts of silt and clay sized material in the channel perimeter, high vegetation density, and a relatively stable channel position. According to Elliott (1979), the 1930's lower Rio Puerco channel was similar to the 1977 upstream reaches and led Elliott to conclude that channel stabilization was progressing from downstream to upstream reaches. Resurveys of the 1977 cross sections in 1994 to 1997 by Elliott and others (1998), reaffirmed this earlier hypothesis. Channel changes were continuing in the upper reaches of the Rio Puerco where decreasing width-to-depth ratios were observed.

Love (1997) attributed the decrease in suspended-sediment loads at the Rio Puerco to a decrease in annual peak flows since the 1930's (fig. 6). The decrease in peak flows coupled with the planting of tamarisk led to an increase in vegetation on the floodplain. The increased vegetation led to an increase in roughness, increase in sediment deposition, and a decrease in suspended-sediment loads. Further research may indicate whether the decrease in peak flows is due to climate (rainfall and rainfall intensity) or to changes in channel cross-sectional and planform geometry.

Another possible explanation for the decrease in suspended-sediment loads may include successful land-management treatments in reducing erosion implemented by various land-management agencies in the Rio Puerco basin. The Bureau of Land Management, National Resource Conservation Service, Bureau of Indian Affairs, and other agencies have been implementing programs to reduce erosion and improve vegetation cover in the Rio Puerco since the 1930's (Burkham, 1966; Soil Conservation Service, 1977). However, the success of these programs is often not monitored and quantified. The lack of monitoring of erosion-control structures has not been limited to the Rio Puerco but is a problem present throughout the Southwest. For example, a lack of project documentation, monitoring, and evaluation of watershed and riparian treatments was documented for the U.S. Forest Service southwestern region (Ahlborn and others, 1992). Gellis and others (1995) noted a similar lack of project documentation, maintenance, and monitoring for erosion-control structures built on the Zuni Indian Reservation, New Mexico.

Conclusions

Compared to world rivers, the Rio Puerco basin in central New Mexico transports one of the world's highest average annual sediment concentrations. Compared to suspended-sediment loads transported at the Rio Grande near San Marcial, the Rio Puerco transported 83% of the total load from 1948 to 1973 and 64% of the total load from 1974 to 1996. The largest contributor of total suspended-sediment load in the Rio Puerco basin is the Arroyo Chico, which drains 24 percent of the basin and delivers 34 percent of the suspended-sediment load. The highest average annual sediment yield and the highest total sediment concentration, 2,721 tons/mi2 and 190 tons sediment/acre-feet runoff, respectively, was measured at the Rio Puerco above Arroyo Chico.

A decrease in suspended-sediment loads over time is observed at three stations in the Rio Puerco with long periods of record, the Rio Puerco near Bernardo, the Rio Puerco above Arroyo Chico, and the Arroyo Chico near Guadalupe. The decrease in sediment loads may be due to changes in channel and planform geometry of the Rio Puerco or to a decrease in peak flows. Both explanations favor an increase in vegetation, which leads to an increase in channel roughness and an increase in sediment deposition. It is also possible that the decrease in sediment loads is due to successful upland erosion-control strategies implemented over time by various land-management agencies. The success of many of these strategies has not been monitored or quantified.

References

Ahlborn, G., Platts, W., Hanes, T., and Jensen, S., 1992, Evaluation of watershed and riparian treatments, U.S. Forest Service Southwestern Region. Unpublished report to the U.S. Department of Agriculture Forest Service, Biosystems Analysis Inc., 40 p.

Bryan, K.B., and Post, G.M., 1927, Erosion and control of silt on the Rio Puerco, New Mexico: Unpublished report to the Chief Engineer, Middle Rio Grande Conservancy District Albuquerque, N.M., October. 1927, 133 p.

Bureau of Reclamation, 1994, Rio Puerco sedimentation and water quality study: U.S. Bureau of Reclamation Preliminary Findings Report, 47 p.

Burkham, D.E., 1966, Hydrology of Cornfield Wash area and effects of land-treatment practices, Sandoval County New Mexico, 1951-60: U.S. Geological Survey Water-Supply Paper 1831, 87pp.

Edwards, T.K., and Glysson, G.D., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86-531, 118 p.

Elliott, J.G., 1979, Evolution of large arroyos--The Rio Puerco of New Mexico: Unpublished Master's Thesis, Colorado State university, Fort Collins.

Elliott, J.G., Gellis, A.C., and Aby, S.B., 1998, Evolution of Arroyos--Incised Channels of the Southwestern United States: In Thorne, C., ed., Incised Channels, IN PRESS.

Gellis, A.C., Hereford, R., Schumm, S.A., and Hayes, B.R., 1991, Channel evolution and hydrologic variations in the Colorado River basin--Factors influencing sediment and salt loads: Journal of Hydrology, v. 124, p. 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 No. 265, Proceedings of the 36th Annual New Mexico Water Conference, Las Cruces, N.Mex., p. 77-93.

Gellis, A.C., Cheama, A., Laahty, V., and Lalio, S., 1995, Assessment of gully-control structures in the Rio Nutria watershed, Zuni Reservation, New Mexico: Water Resources Bulletin, v. 31, no. 4, p. 633-646.

Happ, S.C., 1948, Sedimentation in the Rio Grande valley, New Mexico: U.S. Department of Agriculture, Soil Conservation Service Report.

Heath, D.L., 1983, Flood and recharge relationships of the lower Rio Puerco, New Mexico: New Mexico Geological Society Guidebook, 34th Field Conference, Socorro Region II, p. 329-337.

Kondolf, G.M., Matthews W.V. G., 1991, Unmeasured Residuals in Sediment Budgets-- A Cautionary Note:Water Resources Research, v. 27, no. 9, p. 2483-2486.

Love, D.W., 1997, Implications for models of arroyo entrenchment and distribution of archaeological sites in the middle Rio Puerco: In Duran, M.S. and Kirkpatrick, D.T., eds., Layers of Time, the Archaeological Society of New Mexico, v. 23, p. 69-84.

Marcus, W.A., Nielson, C.C., and Cornwell, J.C., 1993, Sediment budget-based estimates of trace metal inputs to a Chesapeake estuary: Environmental Geology, v. 22, p. 1-9.

Milliman, J.D. and Meade, R.H. 1983 World-Wide Delivery of River Sediment to the Oceans Journal of Geology, v. 91, no. 1, p. 1-21

Nordin, C.F., and Curtis, W.F., 1962, Formation and deposition of clay balls, Rio Puerco, New Mexico: U.S. Geological Survey Professional Paper 450-B, art. 28, p. 37-40.

Nordin, C.F., 1963, A preliminary study of sediment transport parameters Rio Puerco near Bernardo, New Mexico: U.S. Geological Survey Professional Paper 462-C, p. C1-C21.

Porterfield, G., 1972, Computation of fluvial-sediment discharge: Geological Survey Techniques of Water-Resources Investigations of the United States Geological Survey: Book 3, Chapter C3, 66 pp.

Roberts, R.G., Church, M., 1986, The sediment budget in severely disturbed watersheds, Queen Charlotte Ranges, British Columbia: Canadian Journal Of Forestry Research, v. 16, p. 1092-1106.

Simons, D.B., Li, R., Li, L., and Ballantine, M.J., 1981, Erosion and sedimentation analysis of the Rio Puerco and Rio Salado Watersheds: Simons Li and Associates, Report submitted to the U.S. Army Corps of Engineers, Albuquerque District, 66 p.

Soil Conservation Service, 1977, The small watershed program in New Mexico, 18 p> Sutherland. R.A. and Bryan, R.B., 1991, Sediment budgeting—A case study in the Katiorin drainage basin, Kenya: Earth Surface Processes and Landforms, v. 16, p. 383-398.

Trimble, S.W., 1983, A sediment budget for Coon Creek Basin in the Driftless Area, Wisconsin,1853-1977: American Journal of Science, v. 283, p. 454-474.

Table 1. Summary of sediment and runoff characteristics for USGS gaging stations in the Rio Puerco Basin.

Station	**Period of Record***	**Drainage Area (mi^2)**	**Average Annual Suspended-Sediment Load (tons)**	**Average Annual Runoff (acre-feet)**
Rio Puerco above Arroyo Chico near Guadalupe (formerly referred to as Rio Puerco below Cabezon)	1949-55; 1982-96	420	860,500	10,500
Arroyo Chico near Guadalupe	1949-55; 1979-86	1390	1,931,600	17,300
Rio San Jose near Correo	1949-55	2,670	533,400	10,100
Rio Puerco at Rio Puerco	1949-55	5,160	6,924,000	39,800
Rio Puerco near Bernardo	1949-55	6,220	4,439,300	28,590

* Based on a water year, from October 1 of the previous year to September 30 of the current year.

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/erosion/streamflow.html
Maintained by Richard Pelltier
Last modified: 10:15:54 on 22-Mar-2000

http://climchange.cr.usgs.gov/rio_puerco/erosion/clapp.html

Erosion, Sediment Generation, and Arroyo Cycling in Northwestern New Mexico

Erik Matthew Clapp
University of Vermont

Establishing long-term rates of sediment generation and erosion in drainage basins is critical in understanding the impacts of human and climate induced landscape change on the hydrology, ecology, and geomorphology of a region. Measuring sediment export for short periods of time leads to both over and under estimates of long-term process rates due to susceptibility of monitoring to short-term fluctuations in erosion. Using In Situ-produced, cosmogenic 10Be and 26Al we have estimated long-term, time integrated rates of sediment generation and erosion (2.7 +/- 0.7 x 105 g cm-2 yr-1) in a small arroyo cut basin in northwestern New Mexico. Basin-wide, bedrock equivalent erosion rates (100 +/- 25 m My-1) are in agreement with estimates from the region using several other methods. Comparison of our basin infilling rates (56.5 m3 yr-1) with rates derived from radiocarbon dating of basal sediments (54.7 m3 yr-1) indicate that sufficient sediment mass is being generated within the drainage to fill the basin and allow for a minimum of several arroyo cutting and infilling sequences over the past 5,000 yrs.

Introduction

Accelerated rates of sediment generation and delivery to fluvial systems results in changing channel geometry which can lead to increased flooding, changes in groundwater supply, erosion of valuable land, and increased water turbidity. Extensive debates exist over the long-term rates of sediment generation and denudation for the Colorado Plateau (Dole and Stabler, 1909; Judson and Ritter, 1964; Saunders and Young, 1983), cycles of arroyo incision and infilling in the Southwestern United States (Graf, 1991; Hereford, 1992; Waters, 1985), and climate vs landuse as the controlling force in changes of long-term rates of denudation and deposition (Hereford, 1987; Gellis, 1991). In order to quantify the magnitude of present day sediment generation problems, it is critical to establish long-term baseline rates of denudation by which to compare the current rates.

Estimating long-term process rates by short-term monitoring of suspended sediment loads in rivers (Dole & Stabler, 1909; Judson & Ritter, 1964; Holeman, 1968; Gurnell et al., 1988; and Harbor & Warburton, 1993), soil creep, or surface wash on hillslopes (Leopold et al., 1966; Selby, 1974; Dunne, 1977; Gellis, 1996) is problematic, as these processes are sensitive to the dramatic variations in climate and landuse which are inherent to the natural systems (Selby, 1982). Denudation and deposition rates can be better constrained in depositional basins or alluvial fans where volumetric measurements of total material deposited over time can be made (Reneau & Dietrich, 1991; Hicks et al., 1990; Clague, 1985; Church and Ryder, 1972; Judson, 1968; and Langbein & Schumm, 1958). If the time over which deposition occurred can be estimated through radiocarbon dating or correlation with crosscutting and datable features (i.e. faults), an integrated deposition and basin-wide denudation rate can be calculated. These estimates are also problematic however, in that the removal of material between periods of deposition, by surface processes and dissolution, cannot be detected thus leading to underestimates of denudation. Using in situ-produced cosmogenic 10Be and 26Al (Bierman & Steig, 1996; Bierman, 1995; Bierman et al., 1995; Bishop, 1985; Brook et al., 1993; Brown et al., 1995; Gosse et al., 1995; Granger et al., 1996; Nishiizumi et al. 1991; Phillips & Zreda, 1992), we have determined integrated rates of sediment generation and denudation in Arroyo Chavez; a small, arroyo cut basin in northwestern New Mexico. Our approach is unique in that it provides a long-term integration of all processes within a drainage basin, while also giving insight into the relative rates of individual processes.

Because cosmogenic radionuclides accumulate over the exposure history of a rock or sediment sample, there is a relationship between the rate at which sediment is being derived and transported within a drainage basin (erosion), and the abundance of a cosmogenic radionuclide (Bierman & Steig, 1996; Brown et al., 1995; Granger et al., 1996). More specifically, if a drainage basin is eroding slowly, sediments will reside at Earth's surface for a longer period of time and will thus accumulate relatively high abundances of radionuclides. Alternatively, a rapidly eroding basin, where sediments are generated and transported quickly, will allow less time for radionuclide accumulation. If the assumption is made that the sediments leaving a drainage basin via a stream channel are a completely mixed and representative sample of the sediments within the basin, then the abundance of radionuclides within these sediments will give the minimum average exposure time or the maximum, basin-wide average rate of erosion.

Sediment particles en-route from initial bedrock source areas to basin outlet, will reside for some period of time in geomorphic compartments (figure 16) including: bedrock, hillslope colluvium, fans, terraces, basin fill, and the stream channel. The sediment will be transported through the compartments until exported from a drainage basin. If storage within the geomorphic compartments is greater than a few thousand years, cosmogenic isotope abundances will increase to a detectable level, and will record the relative importance of storage within each compartment. Cosmogenic isotope abundances within compartments can also be used to estimate the relative contribution of multiple source areas to a single compartment through the use of cosmogenic isotope mixing models.

Basin-Wide Sediment Generation, Denudation, and Arroyo Cycling

Our data (figs. 17 & 18) can be used to calculate the basin-wide rate of mass loss (Bierman and Steig, 1996) of 2.7 +/- 0.7 x 105 g cm-2 yr-1. Judson and Ritter (1964), reported dissolved loads from the Colorado River of only 5% allowing us to interpret the mass loss as a rate of sediment generation. The mass loss value can then be converted to a basin-wide "bedrock equivalent" denudation rate of 100 +/- 25 m My-1 by dividing by the density of the basin bedrock (2.4 g cm-3). Our estimate of landscape lowering rates are comparable to calculations based on suspended sediment export in the Colorado River of 165 m My-1 (Judson & Ritter, 1964), 10 to 1000 m My-1 (Saunders & Young, 1983) and evolution of nearby volcanic plugs of 100 m My-1 (Hallet, 1993).

Our sediment generation rate can also be used to estimate a total time of basin infilling. We used a simple triangular, prismatic approximation of the basin volume (2.79 x 105 m3), a basal depth (4.88 m) equivalent to the depth of a previously measured radiocarbon date (Pavich, 1997), and the sediment generation rate (0.27 +/- 0.07 Kg m-2 yr-1) multiplied by the contributing area (0.4 km2), to estimate a basin filling time of 4,900 yrs. A comparison to the 5,100 yr calibrated radiocarbon age from Pavich (1997), indicates that our 4,900 yr filling time allows enough time for the observed basin accumulation and a minimum of two periods of arroyo cutting and infilling over the past 5,100 yrs. Particle size analysis reveals that greater than 50% (by weight) of the basin sediments are of a small enough size (<125μ) to be imported from outside the basin by aeolian transport. Although we cannot distinguish between the internal and external sources of sediment to the basin, we know that internally derived sediment is abundant enough to account for basin filling and some sediment export. The contribution of aeolian sediments make it possible for more frequent arroyo cut and fill cycles to occur as well. Without aeolian contribution, arroyo cycling is possible on only 2000-3000 year cycles.

Our data shows that in situ-produced, cosmogenic 10Be and 26Al can be used to estimate long-term, time integrated rates of sediment generation and erosion in a small arroyo cut basin in northwestern New Mexico. Basin-wide, bedrock equivalent erosion rates (100 +/- 25 m My-1) are in agreement with estimates from other researchers collecting data over long periods of time. Sediment generation calculations indicate that that sufficient sediment mass is being generated within the drainage to fill the basin and allow for a minimum of several arroyo cutting and infilling sequences over the past 5,000 yrs. It is our assertion that the use of cosmogenic isotopes can allow for the rapid establishment of long-term, baseline rates of sediment generation and erosion which can be used to evaluate the impact of climatic, and anthropogenic influences landscape evolution.

References

Bierman, P., and Turner, J. (1995). 10Be and 26Al evidence for exceptionally low rates of Australian bedrock erosion and the likely existence of pre-Pleistocene landscapes. Quaternary Research 44, 378-382.

Bierman, P. R., Gillespie, A., and Caffee, M. (1995). Cosmogenic age-estimates for earthquake recurrence intervals and debris-flow fan deposition, Owens Valley, California. Science 270, 447-450.

Bierman, P. R., and Steig, E. (1996). Estimating rates of denudation using cosmogenic isotope abundances in sediment. Earth Surface Processes and Landforms 21.

Bishop, P. (1985). Southeast Australian late Mesozoic and Cenozoic denudation rates: a test for late Tertiary increases in continental denudation. Geology 13, 479-482.

Brook, E. J., Kurz, M. D., Denton, G. H., and Ackert, R. P. J. (1993). Chronology of Taylor Glacier advances in Arena Valley, Antarctica using in situ cosmogenic 3He and 10Be. Quaternary Research 39, 11-23.

Brown, E., Stallard, R. F., Larsen, M. C., Raisbeck, G. M., and Yiou, F. (1995). Denudation rates determined from the accumulation of in situ-produced 10Be in the Luquillo Experimental Forest, Puerto Rico. Earth and Planetary Science Letters 129, 193-202.

Church, M., and Ryder, J. M. (1972). Paraglacial sedimentation: a consideration of fluvial processes conditioned by glaciation. Geological Society of America Bulletin 83, 3059-3072.

Clague, J. J. (1985). The Quaternary stratigraphic record of British Colubia - evidence for episodic sedimentation and erosion controlled by glaciation. Canadian Journal of Earth Sciences 23, 885-894.

Clark, D., Bierman, P. R., and Larsen, P. (1995). Improving in situ cosmogenic chronometers. Quaternary Research 44, 366-376.

Dole, R. B., and Stabler, H. (1909). Denudation. USGS Water Supply Paper 234, 78-93.

Dunne, T. (1977). Evaluation of Erosion conditions and trends,. In "Guidelines for watershed management, FA0 conservation guide.", pp. 53-83. United Nations Food and Agricultural Organization, Rome.

Gellis, A., Hereford, R., Schumm, S.A., and Hayes, B.R. (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. (1996).

Gosse, J. (1995). Precise cosmogenic 10-Be measurements in western North America: support for a Younger Dryas cooling event. Geology 23, 877-880.

Graf, J., B., Webb, R., H., and Hereford, R. (1991). Relationship of sediment load and flood-plain formation to climatic variability, Paria River drainage basin, Utah and Arizona. Geological Society of America Bulletin 103, 1405-1415.

Granger, D. E., Kirchner, J.W., and Finkel, R.C. (1996). Spatially averaged long-term erosion rates measured from in situ produced cosmogenic nuclides in alluvial sediment. Journal of Geology 104, 249-257.

Granger, D. E., Kirchner, J.W., and Finkel, R.C. (1997). Quaternary downcutting rate of the New River, Virginia, measured from differential decay of cosmogenic 26Al and 10Be in cave-deposited alluvium. Geology 25, 107-110.

Gurnrell, A. M., Warburton, J., and Clark, M.J. (1988). A comparison of the sediment transport and yield characteristics of two adjacent glacier basins, Val d'Herens, Switzerland.,. In "Sediment Budgets: Proceedings of the Port Alegre Symposium, December 1988.", pp. 431-441, Wallingford Institute of Hydrology.

Hallet, B. R. (1994). "Volcanic Geology, Paleomagnetism, Geochronology, and Geochemistry of the Rio Puerco Necks, West-Central, New Mexico." Unpublished Ph.D. Dissertation thesis, New Mexico Institute of Mining and Technology.

Harbor, J., and Warburton, J. (1993). Relative rates of glacial and nonglacial erosion in alpine environments. Arctic and Alpine Research 25, 1-7.

Hereford, R. (1987). Sediment-yield history of a small basinin southern Utah, 1937-1976: Implications for land management and geomorphology. Geology 15, 954-957.

Hereford, R., and Webb, R.H. (1992). Historic Variation of Warm-Season Rainfall, Southern Colorado Plateau, Southwestern U.S.A. Climate Change 22, 239-256.

Hicks, D. M., McSaveny, M.J., and Chinn, T.J.H. (1990). Sedimentation in proglacial Ivory Lake, Southern Alps, New Zealand. Arctic and Alpine Research 22, 26-42.

Holeman, J. N. (1968). The sediment yield of the major rivers of the world. Water Resources Research 4, 737-747.

Judson, S. (1968). Erosion of the land or what's happening to our continents. American Scientist 56, 356-374.

Judson, S., and Ritter, D. (1964). Rates of regional denudation in the United States. Journal of Geophysical Research 69, 3395-3401.

Langbein, W. D., and Schumm, S.A. (1958). Yield of sediment in relation to mean annual precipitation. Transactions of the American Geophysical Union 39, 1076-1084.

Larsen, P. (1995). "In situ production rates of cosmogenic 10Be and 26Al over the past 21.5 ky from the terminal moraine of the Laurentide ice sheet, north-central New Jersey." Unpublished MS thesis, University of Vermont.

Leopold, L. B., Emmett, W.W., and Myrick, R.M. (1966). Channel and hillslope processes in a semi-arid area, New Mexico. U.S. Geological Survey.

Nishiizumi, K., Kohl, C. P., Shoemaker, E. M., Arnold, J. R., Klein, J., Fink, D., and Middleton, R. (1991). In situ 10Be-26Al exposure ages at Meteor Crater, Arizona. Geochimica et Cosmochimica Acta 55, 2699-2703.

Pavich, M.J., Gellis, A.C., Aby, S., Chronostratigraphy of Quaternary Alluvium, Rio Puerco Basin, New Mexico, Geological Society of America Abstracts with Programs, 29 (6), A-372, 1997.

Phillips, F. M., and Zreda, M. G. (1992). Late Quaternary glacial history of the Sierra Nevada from cosmogenic 36Cl dating of moraines at Bishop Creek. EOS 73, 186.

Reneau, S. L., and Dietrich, W. E. (1991). Erosion rates in the southern Oregon Coast Range: evidence for an equilibrium between hillslope erosion and sediment yield. Earth Surface Processes and Landforms 16, 307-322.

Saunders, I., and Young, A. (1983). Rates of surface processes on slopes, slope retreat, and denudation. Earth Surface Processes and Landforms 8, 473-501.

Selby. (1982). "Hillslope Materials and Processes." Oxford University Press, Oxford.

Waters, M.R., Late Qauternary Alluvial Stratigraphy of Whitewater Draw, Arizona: Implications for Regional Correlation of Fluvial Deposits in the American Southwest, Geology, 13, 705-708, 1985.

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/erosion/clapp.html
Maintained by Richard Pelltier
Last modified: 10:15:14 on 22-Mar-2000

http://climchange.cr.usgs.gov/rio_puerco/erosion/yields.html

Erosion Yields in the Arroyo Chavez Basin, Rio Puerco Basin, New Mexico

Allen Gellis, U.S. Geological Survey
Scott Aby, Dixon, NM

Introduction

Three major channels have cut and filled the Rio Puerco valley in the past 3,000 years (Love and Young, 1983; Love, 1986). Dates in two of these paleochannels are 2100 B.P. and 625-500 B.P., respectively. An interesting aspect of these cut-and-fill cycles is that the Rio Puerco channel filled to the same level in the valley it occupied prior to each cutting event. For example, by 1880 A.D., the Rio Puerco occupied the same level in the valley it had before its incision around 600 B.P. (Love, 1986); the Rio Puerco then incised in 1885 (Bryan, 1925). Recent surveys indicate that the Rio Puerco is in a cycle of aggradation (Elliott and others, 1998; Gellis and Elliott, 1998) (fig. 12). This raises interesting questions on what the sediment source(s) are for this filling and how does the system aggrade; presumably without a change in base level of the Rio Grande.

To examine possible sources of sediment in filling the Rio Puerco channel, a study quantifying a sediment budget for two subbasins of the Rio Puerco, the Arroyo Chavez (2.21 km2) and Volcano Hill Wash (9.13 km2), began in 1995. This paper describes the preliminary results of erosion and sediment yields for the Arroyo Chavez basin.

Topographic Setting

The portion of the Arroyo Chavez basin studied is located in the U.S. Geological Survey San Luis 1:24000 quadrangle map (fig.8). Rainfall measured for three years (1985-88) in the basin averaged 340 mm. A longer record of precipitation, 1941 to 1989, measured at Cuba, 40 km from Arroyo Chavez was 337 mm. Therefore, annual rainfall during the period of study were similar to long-term climatic records. Elevations in Arroyo Chavez range from 1,938 m to 2,021 m. Mesas and slopes are developed on interbedded sandstones and shales of the Menafee Fm.

Methods

A sediment budget for a drainage basin is based on the amount of sediment leaving that basin and an accounting of the sources of that sediment (Dietricht and Dunne, 1978; Swanson and others, 1982). An essential feature of a sediment budget is defining transport processes, storage elements, and linkages among the two (Swanson and others, 1982). A sediment budget carried out by Leopold and others (1966) for an ephemeral drainage outside of Santa Fe, NM, indicated that channels in most reaches were aggrading. Sheetwash was the largest source of this sediment accounting for the aggradation. The average rate of aggradation for all channels was 0.015 meters per year. At this rate of aggradation, the channel would completely fill to the level of the highest terrace in 100 to 200 years.

In the Arroyo Chavez basin the transport processes, storage elements, and linkages were defined for four geomorphic surfaces that describe the basin: mesa, side slope, fan, and alluvial valley floor (figs. 13 and 14). There are two alluvial valley floor surfaces: one is adjacent to the main channel, the other is in a tributary valley containing discontinuous channels. To quantify the sediment budget, collection of sediment in each element utilized various techniques (Table 1).

Sediment traps were used to quantify sheetwash and were based on a modified Gerlach Trough (Gerlach, 1967; Gellis, 1998). Sediment traps collected sediment and runoff during rainfall events. The length of the traps were 68 and 85 centimeters (cm) and the depth was 13 cm. To prevent precipitation from entering the trap directly, a lid made of sheet metal was fitted with a hinge to the back of the trap. One to three 1.27cm diameter holes were drilled into the side of the trap, and were connected by tubing to 18.9 liter collection buckets. The traps were installed flush to the ground surface with the opening parallel to the slope contour. The contributing area was bounded with metal edging. At each trap, single-ring infiltration tests were performed.

Sheetwash erosion and deposition was also quantified using nail/washer lines (Leopold and Others, 1966). Fifteen centimeter long nails were driven into the ground with washers placed on the ground surface. Erosion is measured as the increase in distance from the top of the washer to the top of the nail and deposition is measured as the amount of sediment deposited over the washer.

To quantify sediment yields at a larger scale than the sediment traps, straw dams were constructed in 1-2 order channels. At this larger scale, elements quantified in the contributing area to the dams included sheetwash, channel erosion, rilling, piping, gullying, and headcutting. The sediment pool upstream of the dam was dug out and periodically surveyed to quantify sediment volume.

Main channel and tributary erosion were quantified through resurveys of monumented channel cross sections (Emmett, 1965; Gellis, 1998). Bank erosion was measured using bank pins and maximum channel scour was measured using scour chains (Leopold and others, 1966).

To measure flow and suspended sediment, a USGS streamflow gaging station equipped with an automatic suspended-sediment sampler was installed. The automatic sampler was activated by stage and collected samples at set time intervals during a runoff event.

To measure the eolian contribution to the basin, eight collectors were installed. The collectors were 9.5 liter buckets attached to a pole 1.4 meters above the ground. The eolian design followed Reheis and Kihl (1995). A wire mesh was put at the top of the bucket and covered with marbles to mimic the ground surface. The marbles were rinsed during collection and the dust was brought back to the lab for drying.

Results

Preliminary results are only available from the sediment traps, straw dams, sediment discharge at the streamflow station, and eolian collectors. The sediment traps and straw dams operated over different time periods. To normalize for this difference, sediment yields from the sediment traps and straw dams were calculated by taking the total volume of sediment, in kilograms, and dividing by the number of days in operation. This value was divided by the contributing area and multiplied by 365 days, to obtain sediment yield, in kilograms, per square meter, per 365 days.

Results indicate that the alluvial valley floor immediately adjacent to the main channel has the highest sediment yields, measured at straw dam 5 (5.48 kg/m2/365 days) and sediment traps 5a (3.03 kg/m2/365 days) and trap 5b (1.33 kg/m2/365 days)(Table 2). The alluvial valley floor is a gullied, piped surface with many headcuts working upgradient. Alluviation of the alluvial valley floor dates to about 5100 ybp (calibrated 14C age, Pavich, 1997). A major source of sediment in the Arroyo Chavez basin is this older sediment and as the Arroyo Chavez channel fills it is in a sense cannibalizing itself. The mesa and side slopes surfaces showed the lowest sediment yields ranging from 0.15 to 0.97 g/m2/365 days. The lowest sediment yield recorded for the traps was in trap 6 (0.12 kg/m 2/365 days) located in the tributary alluvial valley floor, a well grassed area.

Sediment yields from the sediment traps and straw dams show an increase in sediment yield with drainage area to around 300 m2 (fig. 15). Typically, sediment yield decreases with an increase in area as more sites in the basin are available for sediment storage (Schumm, 1977; Walling, 1983). Compared to a river basin scale, the drainage areas of sediment yields quantified in the sediment traps and straw dams are relatively small and therefore, sediment storage sites are minimal.

Suspended-sediment discharge measured at the mouth of the basin from October 1, 1996 to September 30, 1997, indicated that 2,350 metric tons of suspended sediment were transported. This amount of transported sediment is analogous to 1.06 kg/m2/yr. Using a value of 1442 kg/m3 for the density of soil, the average values of surface erosion measured from the straw dams and sediment traps range from 0.023 to 2.1 mm per 365 days (Table 2). These values of surface erosion are within values of surface erosion and denudation rates reported for the Southwest, which range from 0.005 mm to 7.3 mm (Table 3). The erosion rates from this study are within denudation rates reported at geologic time scales(>1Ma)(Table 3).

The eolian collectors were sampled three times between July 20, 1996, to March 25, 1998. The total mass sampled for this time period ranged from 1.47 to 3.84 grams (Table 3). The mass of eolian dust was divided by the number of days between collection and multiplying by 365 to obtain an annual rate (g/m2/365 days). This annual rate applied to the area of Arroyo Chavez basin indicates the total eolian contribution would range from 11 to 26.6 metric tons. This value of eolian deposition is 4.7 to 11.3 percent of the total suspended-sediment transported out of the Arroyo Chavez basin from 10/1/1996 to 9/30/97 (2,350 metric tons), and is therefore an important component of the sediment budget.

Summary

The Rio Puerco has cut and filled its channel three times in the last 3,000 years. An important question is what is the sediment source for this channel fill? To address this question, a sediment budget study was initiated in the Arroyo Chavez basin in 1995. The objective of the sediment budget was to quantify rates of erosion and deposition on the main geomorphic surfaces in the basin: mesa, side slope, fan, and alluvial valley floor. Results are available for erosion yields measured at straw dams and sediment traps, eolian flux, and suspended-sediment discharge measured at the mouth of the basin.

A major source of sediment in the Arroyo Chavez basin is the alluvial valley floor adjacent to the main channel which has sediment yields of 1.33 to 5.48 kg/m2/365 days. The alluvial valley floor is an area of gullying, piping, and headcutting. The lowest sediment yield of 0.12 kg/m2/365 days was measured in a tributary alluvial valley containing discontinuous channels. The tributary valley floor is a well grassed area.

Surface lowering rates estimated from the straw dams and sediment traps indicate rates from 0.023 to 2.1 mm/365 days. These values are within rates reported for the Southwest, which range from 0.005 to 7.3 mm. The eolian contribution of sediment to the Arroyo Chavez basin was measured at 7 sites. The eolian flux to the basin ranged from 4.99 to 12.0 g/m2/365 days. This value of eolian deposition is 4.7

to 11.3 percent of the total sediment discharge transported out of the Arroyo Chavez basin and is therefore an important component of the sediment budget.

References

Albrecht, A., Herzog., G.F., Klein, J., Dezfouly-Arjomandy, B., and Goff, F., 1993, Quaternary erosion and cosmic-ray-exposure history derived from 10Be and 26Al produced in situ-An Example from Pajarito Plateau, Valles caldera region: Geology, v.21, p.551-554.

Bryan, K., 1925, Date of channel trenching in the arid Southwest: Science, v. 62, p.338-344.

Dethier, D.P., Harrington, C.D., and Aldrich, M.J., 1988, Late Cenozoic rates of erosion in the western Espanola basin, New Mexico--Evidence from geologic dating of erosion surfaces: Geological Society of America Bulletin, v.100, p.928-937.

Dietrich, W.E., and Dunne, T., 1978, Sediment budget for a small catchment in mountainous terrain: Zeitschrift fur Geomorphologie, v. 29, p. 191-206.

Elliott, J.G., Gellis, A.C., and Aby, S.B., 1998, Evolution of Arroyos--Incised Channels of the Southwestern United States: In Thorne, C., ed., Incised Channels, IN PRESS.

Emmett, W.W., 1965, The Vigil Network--Methods of measurement and a sampling of data collected: In, Symposium of Budapest, IAHS Publication no. 66, p. 89-106.

Gellis, A.C., and Elliott, J.G., 1998, Arroyo changes in elected watersheds of New Mexico, United States: In Harvey, M., and Anthony, D., eds., Applying Geomorphology to Environmental Management, A Special Publication Honoring Stanley A. Schumm, Water Resources Publications, LLC, IN PRESS.

Gellis, A.C., 1998, Characterization and evaluation of channel and hillslope erosion on the Zuni Reservation, 1992-95: U.S. Geological Survey Water-Resources Investigation 97-4292, 12 p.

Gerlach, T., 1967, Hillslope troughs for measuring sediment movement: Revue Geomorphologie Dynamique, v. 4, p. 1

Gustavson, T.C., Finley, R.J., and Baumgardner, R.W.Jr., 1981, Retreat of the Caprock Escarpment and denudation of the Rolling Plains in the Texas Panhandle: Bulletin of the Association of Engineering Geologists, v.18, no.4., p.413-422.

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 :352G.

Love, D.W., and Young, J.D., 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, p. 277-284.

Love, D.W., 1986, A geological perspective of sediment storage and delivery along the Rio Puerco: In, drainage basin sediment delivery, Hadley, R.F., ed., IAHS Publication 159, p. 305-322.

Reheis, M.C. and Kihl, R., 1995, Dust deposition in southern Nevada and California, 1984-1989: relations to climate, source area and source lithology, Jour. Geophys. Res., 100, 8893-8918.

Schumm, S.A., 1977, The fluvial system: John Wiley and sons, 338 pp.

Swanson, F.J., Janda, R.J., Dunne, T., and Swanston, D.N., 1982, Sediment budgets and routing in forested drainage basins: U.S. Department of Agriculture, Forest Service General Technical Report PNW-141, 23pp.

Walling, D.E., 1983, The sediment delivery problem: Journal of Hydrology, v.65, p.209-237.

White, W.D., and Wells, S.G., 1979, Forest-fire devegetation and drainage basin adjustments in mountainous terrain: In Rhodes, D.D., and Williams, G.P., eds., Adjustments of the Fluvial System, Proceedings of the Tenth Annual Geomorphology Symposia Series, Binghamton, N.Y., p.199-223.

Table 1. Instrumentation used to quantify the geomorphic elements in figures 13 and 14.

GEOMORPHIC SURFACE	ELEMENT IN FIGURE	INSTRUMENTATION
Mesa	Sheetwash	Sediment Traps Nail/Washer Lines
Mesa	Mass Movement	Painted Rocks Rock Nets
Mesa & Side Slope	Sheetwash; Channel Erosion	Straw Dams
Side Slope	Channel Erosion and Deposition	Nail/Washer Lines
Side Slope	Sheetwash	Sediment Traps Nail/Washer Lines
Fan	Channel Erosion and Deposition	Benchmarked Channel Cross Sections
Fan	Bank Erosion	Bank Pins
Fan	Sheetwash	Sediment Traps Nail/Washer Lines
Terrace	Rilling, Gullying, Piping, Sheetwash	Straw Dams
Terrace	Sheetwash	Sediment Traps Nail/Washer Lines
Terrace	Tributary and Main Channel Erosion and Deposition	Benchmarked Channel Cross Sections; Scour Chain
Terrace	Bank Erosion	Bank Pins
Entire Basin	Eolian Flux	Eolian Traps
Entire Basin	Precipitation	Manual Raingage; Tipping Bucket

		Raingages
Main Channel	Sediment Discharge	Streamflow Measurement and Suspended-Sediment Sampling

Table 2. Values of erosion reported in this study.
A - Sediment Yields

GEOMORPHIC SURFACE	STRUCTURE NUMBER	DATES	DRAINAGE AREA (m^2)	SAMPLED SEDIMENT (kg)	SEDIMENT YIELD (kg/365 days)	DENUDATION RATE (mm/365 days)
Mesa and Side Slope	Straw Dam 1	8/1/95 to 8/3/98	2,276	3,101	0.45	0.029
Mesa	Straw Dam 2	8/1/95 to 11/5/97	1,354	1,718	0.56	0.036
Mesa and Side Slope	Straw Dam 3	8/1/95 to 9/17/97	541	1,120	0.97	0.063
Alluvial Valley Floor	Straw Dam 5	4/17/96 to 9/17/97	245	4,029	11.59	0.75
Mesa	Trap 1	6/27/96 to 3/18/98	36.7	12.9	0.20	0.14
Side Slope	Trap 2	6/27/96 to 3/18/98	7.93	2.98	0.22	0.15
Mesa	Trap 3	6/27/96 to 3/18/98	35.3	17.0	0.28	0.20
Fan Surface	Trap 4	6/27/96 to 3/18/98	27.4	32.4	0.68	0.48
Alluvial Valley Floor	Trap 5a	6/27/96 to 3/18/98	27.3	143	3.03	2.10
Alluvial Valley Floor	Trap 5b	12/3/96 to 11/12/97	0.84	1.05	1.33	0.92
Discontinuous Valley Floor	Trap 6	7/2/96 to 3/18/98	6.38	1.28	0.12	0.084
Discontinuous Valley Side Slope	Trap 7	7/2/96 to 3/18/98	27.6	9.10	0.19	0.13

Side Slope	Trap 8	6/27/96 to 3/18/98	21.8	5.70	0.15	0.11
Arroyo Chavez Basin	Sediment Station	10/1/96 to 9/30/97	2.21×10^6	2.35×10^6	1.06	
Rio Puerco at Bernardo	Sediment Station	10/1/47 to 9/30/96	16.1×10^9		0.25	

B - Eolian Yields

COLLECTOR ID	DATES	MASS SAMPLED (g)	EOLIAN FLUX (g/m^2/365 days
ET-1	7/20/96-3/25/98	2.78	7.91
ET-3	7/20/96-3/25/98	2.70	7.70
ET-4	7/20/96-4/16/97 10/9/97-3/25/98	1.47	4.99
ET-5	7/20/96-3/25/98	3.23	9.19
ET-6	7/20/96-3/25/98	3.29	9.36
ET-7	7/20/96-3/25/98	3.84	10.9
ET-8	7/20/96-3/25/98	3.13	12.0

Table 3. Surface erosion rates and denudation rates from studies conducted in the Southwest

LOCATION	TIME PERIOD ANALYZED	EROSION/DENUDATION RATE (mm/yr)	GEOLOGY	METHOD OF ANALYSIS	REFERENCE
Jemez Mountains, New Mexico	1.14 Ma	0.005 to 0.011	Rhyolitic volcanic rocks	Cosmogenic Nuclides	Albrecht and others, 1993
Jemez Mountains, New Mexico	10/1977 to 11/1978	0.8 to 7.3	Rhyolitic volcanic rocks	Erosion Pins	White and Wells, 1979
Western Espanola Basin, New Mexico	1.1 Ma	0.1	Weakly lithified Sandstone	Hypsometric	Dethier and others, 1988
Western Espanola Basin, New Mexico	1.1 Ma	0.07	Indurated tuff/boulder gravel	Hypsometric	Dethier and others, 1988

Western Espanola Basin, New Mexico	1.1 Ma	0.04	Indurated tuff/basalt	Hypsometric	Dethier and others, 1988
Red River Basin, Texas	3 Ma	0.47	Poorly consolidated shales, siltstones, and sandstones	Hypsometric	Gustavson and others, 1981
Red River Basin, Texas	10/1978-9/1979	0.13 to 2.97	Poorly consolidated shales, siltstones, and sandstones	Suspended-Sediment Analysis and Reservoir Sedimentation Rates	Gustavson and others, 1981
Rio Puerco Basin, New Mexico	1 Ma	0.1	Sandstone	Cosmogenic Nuclides	Clapp, Pavich and Bierman, Unpublished Data
Arroyo de los Frijoles Basin, Santa Fe, New Mexico	1961 to 1993	0.19 to 0.96	Unconsolidated gravel, sand, and silt	Erosion Pins	Gellis, Emmett, and Leopold, Unpublished Data
Arroyo Chavez, Rio Puerco basin	1995-1998	0.03 to 2.1 (*)	Sandstone and Shale	Straw Dams and Sediment Traps	This Study (*rate mm/ 365 days)

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/erosion/yields.html
Maintained by Richard Pelltier
Last modified: 10:16:14 on 22-Mar-2000

The Rio Puerco Arroyo Cycle and the History of Landscape Changes

Scott Aby
U.S. Geological Survey, Albuquerque, New Mexico
Allen Gellis
U.S. Geological Survey, Albuquerque, New Mexico
and
Milan Pavich
U.S. Geological Survey, Reston, Virginia

Climate change impacts society by altering the hydrologic, geomorphic and geochemical processes controlling landscapes. The complex response of landscapes to climate change often has a profound impact on societies, particularly those living in or near river valleys. Landscape responses to rapid climate fluctuations in fluvial systems can often be dramatically greater than anticipated, as shown by recent floods in the Mississippi and Red River valleys, seemingly out of proportion to the climatic variation.

How long-term climate changes affect fluvial systems is an important reserach question. In the late 1800's, the semi-arid southwest underwent dramatic landscape changes due to the incision of arroyos (Cooke and Reeves, 1976). Arroyos are incised channel systems **(fig. 1)**, such as the Chaco Arroyo studied by Love (1983), that carry large volumes of sediment during ephemeral or intermittent flows. Arroyos are geomorphically complex and among the most dynamic parts of the southwestern landscape. The Rio Puerco **(fig. 2)** carries exceptionally high sediment loads, and is the major source of suspended sediment entering the Rio Grande; on average, the Rio Puerco delivers 78% of the total suspended sediment load of the Rio Grande although it drains only 26% of the Rio Grande Basin and provides only 4% of the runoff.

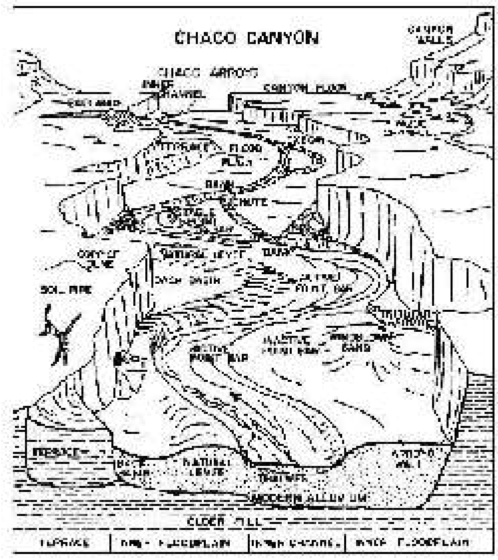


Figure 1. Arroyo morphology as seen in Chaco Arroyo, New Mexico. The arroyo comprises an incised channel and erosional and depositional geomorphic forms. From Love (1983).

The most striking process in arroyos is their alternation between periods of incision and aggradation. Following cutting, which is the present state of Chaco Arroyo seen in fig. 1, arroyos slowly fill or aggrade with sediment. This "arroyo cycle" as portrayed by Gellis (1992) in **fig. 3** is a common phenomenon throughout the southwest (see "The Arroyo Problem in the Southwestern United States"). The relation of the arroyo cycle to climate change is not clear at this time. Despite our uncertainty about the future direction or rate of climate change, history does provide lessons about the magnitudes of landscape change within arroyos. This paper presents a short introduction to the history of the Rio Puerco, New Mexico, and the effects of it's instability on past populations. Future effects are under study through a combination of sediment monitoring and modeling of arroyo processes.

Figure 2. Location of the Rio Puerco drainage basin, New Mexico

Figure 3. Arroyo evolution: stages A through G can represent changes at a cross-section through time or changes from the lower reaches to the upper reaches of the watershed at any point in time. From Gellis (1992).

1. The Natural Arroyo Cycle in the Rio Puerco

Several cycles of arroyo incision and filling have occured during the cycles of Pleistocene and Holocene climate change. Despite the distance from glaciated areas, wetter pluvial climates during glacial periods have had a major impact on the production and distribution of sediment on the southwestern landscape (Bull, 1992). To appreciate the time-scales of change, we have summarized some important processes in **Table 1.** Note that the observed, and measurable, changes in arroyos are significant on the time scale of human activity.

Despite the potential for rapid changes in arroyos, the arroyo cycle and its relation to climate is still not adequately understood for the most recent geologic period, the Holocene. In the last 10,000 years, there have been repeated cycles of arroyo cutting and filling (Cooke and Reeves, 1976; Gellis and Elliott, in press; Dean,1994). **Figure 3** (from Gellis, 1992) shows the stages in the arroyo cycle for a typical southwestern drainage basin. In the southwest, Gellis and Elliott (in press) have documented that cutting was most prevalent between 400-800 years before present (ybp), 1900-2700 ybp, 4400-5400, and 6500-7400 ybp. The non-random distribution of cutting episodes with time over large areas suggests that some regional forcing mechanism is responsible for the crude synchroneity. However, if climate change is the forcing mechanism, the state of the arroyo system before a climate change ensues may also be critical.

Dean (1994) argued that the aggradation/degradation cycles on the Colorado Plateau have averaged about 550 yrs. Pavich (unpublished data) has evidence from ^{14}C dating of alluvium that 500-year and longer gaps exist in the record of alluvial fills in the Rio Puerco. These gaps also correlate with gaps in the ages of pack-rat middens in New Mexico (Betancourt et al., 1993). Although the data-base is small, these gaps in arroyo sediment ages, interpreted to be periods of enhanced cutting or incision, show that the Rio Puerco ^{14}C-dated alluvial stratigraphy may correlate with other climatically related records.

Table 1. Summary of processes on different time scales

In a period of this number of years:	We can observe these changes:
10	Increases in thickness of aggraded alluvium, piping, gullying, bank collapse, density of riparian vegetation, all resulting in changes in channel geometry, El Nino cycles
100	Rapid arroyo incision and head cutting, development of incised, entrenched arroyo
1000	Arroyo aggradation, climate variations such as the Little Ice Age, Medieval Warm Period, major droughts in the west and southwest
10,000	Major climate changes such as the transition from a more humid to the semi-arid climate of the Holocene over the entire southwest.Beginning of semi- arid climate in the southwest
100,000	Major glacially-driven wet/dry cycle, cycle of rock weathering and sediment production

2. The Most Recent Incision Cycle

Love and Young (1983) argued for fill cycles in the Rio Puerco from 900 to 1250 A.D. and 1325 to 1450 A.D., based on archeological data, and an incision between these two fills. Between 1450 A.D. and 1880 A.D., filling appears to have been the dominant process (Gellis and Elliott, in press). The incision that began about 1880 followed a period of about 500 years of aggradation, close to the average fill cycle period suggested by Dean (1994). Unfortunately ^{14}C is of little help in resolving the details of transition from filling to cutting because of lack of preservation and lack of dating precision in that time period. The record of the most recent incision has been assembled from historical observations.

Many people believe that the Rio Puerco underwent a transition from a well vegetated, unincised stream to a barren, arid wasteland since the latter part of last century. This transition is usually attributed to incision of the main channel below the valley floor and subsequent lowering of the water table and loss of vegetation. Incision is attributed to either overgrazing or a climatic shift (Bryan, 1928; Bailey, 1935). Nearly a century of scientific debate has focused on the precise cause of that incision. Incision and subsequent changes in the landscape have also led to legal action, including a recent act of congress calling for a restoration of the Rio Puerco to its "original state". However, it is not clear what the Puerco's "original state" may have been and it is equally unclear what natural changes would have taken place in the river without the influence of man. In order to provide information relevant to these issues, an attempt is underway to compile historical data on vegetation, land use, and channel conditions within the Rio Puerco basin during the recorded history of the region. What follows is an outline of information gathered on the state of the Puerco's main channel so far.

The picture that early Spanish explorers paint of the Rio Puerco in the 17th and early 18th centuries is one of a relatively well-vegetated area. In the few descriptions of this river that have survived, the Cottonwoods along its banks are invariably mentioned, and they were numerous enough that a legal dispute arose as to who owned the rights to their timber (Lopez, 1980). Today cottonwood trees are entirely absent from most reaches of the river. De Vargas, in 1692, named the Rio Puerco "La Torriente de los Alamos". This name again suggests that Cottonwood trees ("Alamos") were a prominent feature along the river's banks and also indicates that the Rio Puerco has flowed fast and muddy (Como un Torriente) for centuries. Indeed, the Puerco was dry when De Vargas first crossed it, but upon returning his men had to hurry to ferry supplies as the river was quickly rising, presumably in response to local rainfall. Such "flashy" flows are still common in the arid Southwest and often promote stream incision. Residents of Los Quelites (settled in 1765 near the confluence of the Rio Puerco and Rio San Jose) discovered this erosive power when a gully developed in their fields shortly after settlement. The formation of a gully in the fields of Los Quelites indicates that the main channel was incised below the surrounding valley floor at this time. Unfortunaltely, no Spanish reports have been found that provide quantitative descriptions of the shape, width, or depth of the channel of the Puerco.

The Rio Puerco has had reaches that flowed within deep, vertical-walled channels (arroyos by definition) at least 30 feet deep since at least 1846. During this year Lieutenant James W. Abert twice crossed the river on a military reconnaissance. He found the channel to be 10-12 feet deep at a location west of Albuquerque and 30 feet deep upstream near the abandoned settlement of "Poblazon" (Bryan, 1928). In 1849 Lieutenant J.H. Simpson described banks up to 30 feet high between La Ventana and Cabezon. However, residents of the area near Cabezon remember the channel in some places between Guadalupe and Cuba as "insignificant" and small bridges (<8 feet long) were used to cross the Rio Puerco and Arroyo Chico (a major tributary that enters the Puerco near Cabezon) as late as approximately 1890. Irrigation was practiced in several locations along the entire length of the Puerco in the second half of the nineteenth century, and residents recall that one man could divert the stream into the community irrigation ditch by dropping a single cottonwood tree across the river. The existence of this type of irrigation system alone is conclusive evidence that the main channel was not everywhere deeply incised during the 1870's and early 1880's. A photograph of the Rio Puerco in flood by R.H. Chapman in 1905 shows the main channel to be unincised and flood flow is spread over at least a hundred meters of broad valley floor. It is unclear exactly where this photo was taken, but such a situation is impossible at all locations on the Rio Puerco today as flood discharge would not overtop the banks of the present arroyo. Portions of the Rio Puerco were "not deeply incised" even as late as 1935 and major tributaries were unincised at this time (Gorbach et al, 1996). Photos taken in 1916 and 1983 **(Figures 4a and 4b)** show the contrast of unincised and incised channels south of the AT & SF bridge (Hawley, Love, and Wells, 1983). **Figures 5a and 5b** contrast the incised channels near Cabezon in 1885 and 1977 (Schumm, et. al., 1984).

Figure 4a. The Rio Puerco south of the AT & SF railroad bridge; the highway bridge in 1916 (from New Mexico State Engineer's Office).

Figure 4b. The Rio Puerco south of the AT & SF railroad bridge; the same reach illustrated in Figure 4a, only taken in July, 1983 (photography from Doug Heath).

Figure 5a. The Rio Puerco near Cabezon in 1885 (photography by E.A. Bass).

Figure 5b. The Rio Puerco near Cabezon; the same reach illustrated in Figure 5a, only taken in 1977 (photography by H.E. Malde).

The only way to reconcile these conflicting accounts is to conclude that the Rio Puerco was not completely incised until some time in this century when a continuous arroyo system obtained. The successive abandonment of agricultural land and villages along the Puerco during the late 1880's and 1890's (Bryan, 1928) suggests that the bulk of main-stem arroyo integration/incision took place during this time.

As early as 1902 scientists were beginning to notice arroyos as prominent features of the Southwestern landscape and to speculate as to what caused their formation (Tuan, 1962). By 1927 the Rio Puerco was recognized as the largest sediment- producing tributary of the Rio Grande and was seen as a serious threat to the long-term usefullness of Elephant Butte Reservoir (Bryan and Post, 1927). If it is accepted that the Rio Puerco entrenched its valley floor during the late 1880's through the early 1900's then one would expect a large increase in sediment production during the first decades of this century as thousands of tributaries to the Puerco incised their channels in an effort to "catch up" with the main stem. Erosion within the Puerco valley has been a constant concern of land-management agencies ever since. Thousands of earthen erosion control structures have been built in tributary basins of the Puerco and tamarisk (or Salt Cedar) were introduced to the valley in 1926 for their bank- stabilizing ability, but no large-scale effort has ever been undertaken to "rehabilitate" the main channel. Despite the lack of direct remediation measures on the main stem, sediment loads and peak discharge near the mouth of the Puerco have consistently declined since the late 1940's (Gellis, 1991). It is not possible to say with certainty what has caused this decline. Reduction in the amount of grazing, bank stabilization by Tamarisk and subsequent sediment storage, successful erosion control structures, and natural evolution of the arroyo system may all have contributed. Despite this decline in total sediment production, the Rio Puerco still supplies approximately 78% of the sediment entering Elephant Butte Reservoir. Headward erosion of tributary arroyos is very active and huge amounts of sediment are derived from caving of arroyo walls both along the main channel and on tributaries.

The continuing effort to compile historic information on the Rio Puerco will help to answer questions of interest to scientists, ranchers, land-managers, and residents of the Puerco Basin. In the long term, it may be possible to separate the effects of climate change from those of human activities on the evolution of the Rio Puerco and other arroyos in the Southwest.

3. Holocene Context of Human and Climate Impacts and LINKS

Human impacts, including those on climate, must be viewed in the context of the background natural variability. The Holocene, the last 10 kyr, has been a period of minimal climatic variability (Broecker, 1997) compared with the previous 90 kyr. Thus, recent human activities which increase variability of climate and/or land-cover can be measured against a relatively constant background. Despite the relatively small Holocene climatic variations such as the Little Ice Age, and the Medieval Warm Period, measured against the much larger magnitude variations during the Pleistocene, the arroyo systems show very large magnitude changes in morphology and sediment storage.

Through field studies and modeling we are addressing questions such as:

- What is the annual and peak discharge response to El Nino extremes?
- What is the sediment load response to El Nino cycles?
- If the arroyo is unstable under a "constant" climate, how will it respond to a more variable climate?

In addition to climate-related questions, there are practical questions about the relation of arroyo processes to land-use. Two useful links for more information in the Rio Puerco region are:

- The importance of arroyos to urban land-use can be found in Albuquerque's Environmental Story.
- The relation of land cover and hydrologic processes to El Nino cycles is under study at the Sevilleta LTER.

References Cited

Bailey, R.W., 1935, Epicycles of erosion in the valleys of the Colorado Plateau Province: Journal of Geology, v. 63, p. 337-355.

Betancourt, J L., Pierson, E.A., Rylander, K.A., Fairchild-Parks, J.A. and Dean, J.S., 1993, Influence of history and climate on New Mexico Pinon-Juniper woodlands, in: Managing Pinon-Juniper Ecosystems for Sustainability and Social Needs, E.F. Aldon and D.W. Shaw, eds., USDA Forest Service General Technical Report RM-236, p. 42-62.

Broecker, W.S., 1997, Will our ride into the greenhouse future be a smooth one?: GSA Today, v. 7, no. 5, p. 1-7.

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

Bryan, K, and Post, G.M., Erosion and control of silt on the Rio Puerco, New Mexico: (unpublished) Report to the Chief Engineer State of New Mexico Middle Rio Grande Conservancy District, Albuquerque, New Mexico, 173 p.

Bull, W.B., 1991, Geomorphic Responses to Climate Change, Oxford University Press, New York.

Cooke, R.U. and Reeves, R.W., 1976, Arroyos and Environmental Change in the American South-West, Clarendon Press, Oxford, 213 p.

Dean, J. S., 1994, The Medieval Warm Period on the Southern Colorado Plateau, in: Hughes and Diaz, eds., The Medieval Warm Period, Climatic Change, v.26, p. 225-242.

Gellis, A.C., 1992, Decreasing trends of suspended sediment concentrations of selected streamflow stations in New Mexico, in: Proceedings of the 36th annual New Mexico water conference- agencies and science working for the future, p.77-93, New Mexico Water Resources Research Institute Report 265.

Gellis, A.C. and Elliott, J.G., in press, Arroyo Changes in Selected Watersheds of the Southwestern United States, in: Gorbach,C., Love, D., Piper,S., Davis, R., and Cross, A., (unpublished) Rio Puerco sedimentatin and water quality study: Preliminary findings report: U.S. Department of the Interior Bureau of Reclamation, Albuquerque Area Office, 40 p.

Hawley, J.W., Love, D.W., and Wells, S.G., 1983, Summary of the Hydrology, Sedimentology and Stratigraphy of the Rio Puerco Valley, in: Chaco Canyon Country: a field guide to the geomorphology, Quaternary geology, paleoecology and environmental geology of northwestern New Mexico, S.G. Wells, D.W. Love and T.W. Gardner, eds.

Lopez, L., 1980, The founding of San Francisco on the Rio Puerco: A Document: New Mexico Historical Review, v. 55, p. 71-78.

Love, D.W., 1983, Quaternary facies in Chaco Canyon and their implications for geomorphic-sedimentologic models, in: Chaco Canyon Country: a field guide to the geomorphology, Quaternary geology, paleoecology and environmental geology of northwestern New Mexico, S.G. Wells, D.W. Love and T.W. Gardner, eds., p. 195-206.

Love, D.W. and Young, J.D., 1983, Progress report in the late Cenozoic geologic evolution of the lower Rio Puerco, New Mexico Geological Society Guidebook, 34th Field Conference, p. 277-284.

Schumm, S.A., Harvey, M.D. and Watson, C.C., 1984, Incised Channels: morphology, dynamics and control, Water Resources Publications, Littleton, CO, 200 p.

Tuan, Y., 1966, New Mexican gullies: A critical review and some recent observations: Annals of the Association of American Geographers, v. 56, p. 573-597.

This page is <URL:http://geochange.er.usgs.gov/sw/impacts/geology/puerco1/>
Maintained by Peter Schweitzer and Randy Schumann
Last updated 10 Jul 1997

http://climchange.cr.usgs.gov/rio_puerco/archeo

Archeological Site Locations within the Rio Puerco Drainage Basin

Curt Larsen and Martha Herzog
U.S. Geological Survey
Reston, VA 20192

Archeological site locations can aid in the understanding of population dynamics, settlement pattern analyses, as well as provide clues to landscape and environmental changes. In New Mexico, a composite record of site locations is maintained by the Laboratory of Anthropology in Santa Fe. In the Rio Puerco drainage basin, a total of 10,905 known sites are recorded. These sites range in age from paleoindian (9,500 to 9,000 BC) to 19th and 20th century historic settlements. The types of sites in the database range from lithic scatters to masonry and adobe structures. Collecting bias notwithstanding, clear concentrations of sites are present within the upper and middle Rio San Jose sub basin, and the upper and middle Rio Puerco valley. The greatest numbers of sites are less than 2000 years old and fall within a puebloan cultural grouping commonly referred to as Anasazi. Using the Pecos chronological framework for discussion, there is a gradual increase in site number throughout the Archaic phase (5500-200 BC). Subsequently, site numbers increase at an apparent exponential rate from the introduction of early agriculture in the Late Archaic and Basketmaker II phases (1800 BC - 500 AD) and reach a peak during the Pueblo II phase (900-1100 AD), which corresponds with the maximum expansion and development at Chaco Canyon to the west. Site numbers fall off rapidly after this peak such that by the Pueblo IV phase (1300-1600 AD) the number of sites recalls the site density of the prior Basketmaker II phase (0-500 AD). Navajo sites make their first appearance in the basin with an apparent depopulation of the area during Pueblo IV. These sites tend to cluster in the northern portion of the Puerco basin in the Torreon sub drainage basin. By the time of Spanish contact in the 16th and 17th centuries, site density increased, but had shifted concentration to the upper Rio San Jose sub basin in the area of the present Acoma and Laguna Pueblos as well as the Jemez Pueblo area of the upper Rio Puerco valley. Although there are few sites in the data base for this period, 18th and early 19th century settlement continued in approximately the same areas as did subsequent Anglo-american and Hispanic occupation during the U.S. Territorial period and the first half of the 20th century.

In terms of landscape and water, Archaic sites are noted in the upper reaches of tributaries in the sub basins as well as the main Rio Puerco valley. Throughout the Archaic there is an apparent eastward shift resulting in site clusters in the middle Rio Puerco valley in the area of Guadalupe. Concentrated occupation continues in the Guadalupe area from Basketmaker II (0-500 AD) through Pueblo III (1100-1300 AD) with peak site density along the alluvial valley of the Rio Puerco immediately downstream from the confluence of the Arroyo Chico with the Rio Puerco and southward to Canons Tapia and Salado near Guadalupe during Pueblo II. Pueblo I and Pueblo II phases also show site concentrations west of Mount Taylor in the upper Rio San Jose valley suggesting physical continuity with the cultural center at Chaco Canyon.

It is significant to note that specific sub basins consistently lack archeological evidence. Most notable is the Arroyo Chico sub basin which is underlain by Mancos Shale and is the chief source of sediment carried by the present Rio Puerco. This suggests long term unsuitability for or desire for permanent settlement in this area. In contrast is the adjacent Torrejon sub basin to the north which shows little occupation until Navajo enter the area in the 16th and 17th centuries. This portion of the drainage basin consists of interbedded sandstones and subordinate shale. The Anasazi sites of the middle Rio Puerco valley are well sited for dependable water resources. The Pueblo I through III settlement downstream of the Arroyo Chico are sited to receive water throughout the growing season. Runoff supplied by the Arroyo Chico possibly delivered suitable sediment and water to alluvial floodplains while the upper Rio Puerco, with its headwaters in the Nacimiento Mountains to the north, could be depended upon for sustained water furnished by precipitation in higher elevations and possible snowmelt. Similar conditions exist further downstream in the Guadalupe area where runoff from Mount Taylor supplied water to the western flank of the valley to augment flow from either the Arroyo Chico or the upper Rio Puerco. The latter area also contains abundant springs along the slopes of the Mount Taylor complex.

When viewed through a paleoclimate filter, in this case Grissino-Mayer's tree ring reconstructions from El Malpais National Monument for the past 2000 years, the first concentrated spread of occupation to the middle Rio Puerco valley took place during a suggested higher rainfall period centered about 600 AD. The greatest number of sites, Pueblo II, correspond with a subsequent moist phase between 1000 and 1100 AD and represent the height of development at Chaco Canyon. The subsequent collapse at Chaco Canyon corresponds with drier period centered about 1150 AD. The general abandonment of the area during Pueblo IV (1300 - 1600 AD) also seems synchronous with a two-century shift to drier conditions as well as the entrance of Navajo and the Spanish to the area. The Spanish colonial period, which continued until Mexican independence in the early 19th century, appears to have corresponded with dominantly drier conditions. Rainfall apparently increased during the 19th and 20th centuries during the U.S. Territorial era, with clearly more arid conditions in the mid 1900's and greater moisture frequency over the past half century.

Note:
The uniqueness and sophistication of the New Mexico Laboratory of Anthropology makes it one of a kind. Its important data bases provide insights into the patterns of past human/environment interactions and can be effectively used to view dynamic changes in the ecological setting. Its ARMS database is digitized and available for use by qualified researchers. Although the sites contained in the files are not random (they result from both academic and private industry sources), they show distinctive clustering with regard to landforms, river systems, and in some cases, underlying geological conditions. Conversely, since archeological site survey is required for Federally initiated or funded construction projects, site patterns can also follow pipelines, transmission lines, and highways, hence linear arrangements of sites are not necessarily "roads to Chaco Canyon".

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/archeo/index.html
Maintained by Richard Pelltier
Last modified: 15:16:43 on 26-Oct-2000

Hydrography of the Rio Puerco Basin

Sub Basins of the Rio Puerco Basin

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/archeo/hydro.html
Maintained by Richard Pelltier
Last modified: 12:25:06 on 24-Jul-2000

http://climchange.cr.usgs.gov/rio_puerco/puerco2/

Erosion in the Rio Puerco: Geography and Processes

by
Raymond D. Watts
U.S. Geological Survey, Denver, Colorado
Richard Pelltier
U.S. Geological Survey, Denver, Colorado
and
Peter Molnar
Colorado State University, Ft. Collins, Colorado

"The Rio Puerco, a tributary of the Rio Grande in New Mexico, has deepened and widened its channel, or arroyo, since the settlement of the region. This process of accelerated erosion still continues. Historical evidence, largely the notes and maps of government land surveyors, [shows] that the cutting began between 1885 and 1890. The deepening of the arroyos has decreased the agricultural and grazing value of the country, resulting in the abandonment of six small towns and numerous ranches. The coincidence between the introduction of large numbers of stock and the cutting of arroyos indicates that overgrazing precipitated this form of destructive erosion. The ultimate cause ... appears to lie in cyclic fluctuations in climate."
--Kirk Bryan, Journal of Geology, 1928.

Topics in this paper include:

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/puerco2/puerco.html
Maintained by Richard Pelltier
Last modified: 10:38:00 on 22-Mar-2000

This curve depicts the general rate of sediment delivery by streams according to their drainage basins' mean annual precipitation. For low precipitation there is little water to move sediment; for high precipitation vegetation holds sediment in place. The maximum of sediment production occurs in semi-arid basins.
Adapted from Figure 3-7 of Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964,
Fluvial processes in geomorphology, 522 p., Freeman, San Francisco.

Peak flows at two stream gages (on the Rio San José below Grants, NM, and on the Arroyo Chico just above its confluence with the Rio Puerco) exhibit a difference of flood amplitudes of about a factor of 10. The basins are nearly of the same size and mean elevation.
Peak flow data for these stations are available from USGS at URLs:
http://water.usgs.gov/swr/NM/data.modules/peak.cgi?statnum=08340500 and
http://water.usgs.gov/swr/NM/data.modules/peak.cgi?statnum=08343500.

The drainage network of the Rio Puerco basin has two major branches: the main stem, which drains areas on the north and east sides of Mount Taylor, and the Rio San José, which drains areas to the south and west of Mount Taylor.

A high-erosion basin: the Rio Puerco of New Mexico

The Rio Puerco basin of New Mexico lies due West of Albuquerque. The Rio Puerco is a tributary of the Rio Grande; at the confluence the Rio Puerco contributes about 4% of the annual water flow and about 78% of the sediment.

Rio Puerco Location Map

Why is the Rio Puerco a particularly high generator of sediment? First, it is in the range of annual precipitation that produces maximum sediment (see sediment yield curve and erosion vulnerability map). Second, a large fraction of the Rio Puerco Basin is composed of shales and siltstones that erode readily, creating areas of high sediment yield that contribute to a large store of fine-grained, easily-eroded, valley-fill materials. Third, the Rio Puerco basin has substantial topographic relief; high terrain helps to generate precipitation and steep slopes provide sediment-moving power to the resulting runoff. Fourth, the Rio Puerco basin is prone to large thunderstorms during the summer monsoon season; annual precipitation is concentrated in a few events that are capable of moving large quantities of sediment.

The geologic and topographic factors that predispose the Rio Puerco to high erosion have existed for many thousands of years. Variations in sediment production and periodic occurrence of basin-wide episodes of arroyo incision have puzzled scientists since the Rio Puerco was first studied in the 1920's. Scientists have speculated on the relative importance of varying climate, grazing, and cycles of sediment movement self-induced by the basin and its channels. Current research is aimed at improving quantitative knowledge of these factors.

What problems are caused by Rio Puerco's sediment? These fall into two categories: local effects and downstream effects.

Previous: Conditions that cause erosion Next: Local effects of erosion.

Generalized Geologic Map of the Rio Puerco Basin. Areas with generally high sediment yield are darkly shaded. Geologic units from oldest to youngest are: Precambrian (PC), Paleozoic and Mesozoic sediments (Mpz), Cretaceous sediments (K), Tertiary (Paleogene) sediments (Tp), Tertiary basin fill of the Albuquerque basin structural basin (Tbf, TQbf), Tertiary basalt flows (Tb), Tertiary intrusions (Ti), Quarternary basalt flows (Qb), Quarternary terraces (Qt), and Quarternary sediments (Qs).

Local effects

When a valley is filled with fine sediments, as is the valley of the Rio Puerco, erosion causes steep-walled gullies called arroyos. These channels create significant barriers to transportation, access of livestock to water, and diversion of water for crop irrigation. The process of cutting arroyos into valley bottoms is called incision.

The Rio Puerco has not always had continuous arroyos. Prior to the 1880's, the area around the nearly abandoned town of San Luis was a broad flood plain. Annual renewal of soils by flood-borne silt encouraged vigorous grass cover. Historical accounts state that this was prime grazing land, and that residents of San Luis irrigated crops by diverting river waters into their fields.

Incision of the arroyo caused drastic changes. The river now flows entirely within the arroyo; without floods, the valley bottom supports desert shrubs rather than grass. Diversion of river water to fields near San Luis would have to originate far upstream, and it is impractical to maintain the needed diversion and transport structures.

As streams in the basin entrenched into the valley floor the water-dependent riparian habitat shrank laterally and entrenched. Cottonwood trees, once prevalent in the valley bottoms, are now scarce. Reduction in wooded habitat has provoked an inevitable reduction in population of birds, grazing animals, rodents, and other species that depend on shade, food, and concealment provided by the riparian forest environment. Despite the reduction in riparian area, the arroyos and their terraces still support populations of mule deer, raccoons, coyotes, and other animals. In the many parts of the basin where arroyos are now refilling with sediment, terraces that store the accumulating sediment widen over time as a result of meandering of the channel within the arroyo. Much of the vegetation on these new terraces, however, is exotic: Russian olives and tamarisk (salt cedar) trees displace native cottonwoods. Thus, the current cycle of incision has caused significant changes in habitat and ecological resources of the basin.

Arroyos have little respect for human structures. The soft materials of the valley bottom are readily removed by flowing water. Meandering streams inevitably impinge on the bases of structures like this bridge, eventually removing the bridge approach. Engineering solutions require extensive armoring of channel walls using materials brought in from quarries at some distance, which makes these solutions expensive. It is often better (as in the case of this illustration) to abandon threatened structures and to choose stream crossings at locations that have some form of natural protection, rather than provide artificial protection.

For more information on historical changes of arroyos, please see The Rio Puerco Arroyo Cycle & the History of Landscape Changes.

Previous: A high-erosion location - the Rio Puerco basin of New Mexico Next: Downstream effects

The Arroyo Chico just above its confluence with Rio Puerco is incised through 6 m of valley fill material and 2 m into bedrock. A vegetated terrace remnant is seen at left; it is likely that the terrace was substantially wider in the past, but its edges have been eroded during periods of high flow.

This ditch heading, suspended approximately 30 feet above the the bed of the river, was functional until 1951. Residents periodically built larger dams to keep up with the deepening channel, but maintenance of the diversion structures often became impossible, resulting in abandoned structures like this one.

Lower reach of the Rio Puerco, looking downstream from US 85 in 1996. The floodplain of the channel has aggraded and colonized with salt cedar (tamarisk). Floodplain aggradation and vegetation have caused the main channel to narrow and develop a single thread channel. (Photo by Jerry Wall, Courtesy of C. Gorbach)

Figure representing the concentration of soils of very low infiltration within the Rio Puerco basin. Each map unit is color coded according to the area percentage of soils that are classified as "very low infiltration." The Natural Resources Conservation Service recognizes four infiltration classes: very low, low, high, and very high.
Source: http://www.ftw.nrcs.usda.gov/kim/stat_data.html

Downstream effects

Sand and silt from the Rio Puerco and from the Rio Grande itself naturally build up (aggrade) the channel of the Rio Grande and form levees along the river margins. Spring floods occur when the snowpack melts in the southern Rocky Mountains; in natural conditions these floods breach natural levees and disperse water across the desert, where it evaporates and filters into the soil. Elephant Butte Reservoir, 100 km downstream on the Rio Grande near Truth or Consequences, NM, was built to catch Spring runoff water for later delivery to the lower Rio Grande basin in New Mexico, Texas, and Mexico.

The Corps of Engineers and the Bureau of Reclamation have built and maintained a conveyance channel, at substantial public expense, to ensure the maximum delivery of water into Elephant Butte Reservoir.

With or without a conveyance channel, sediment moves downstream with water. For several decades after Elephant Butte Dam was completed, in 1916, large quantities of sediment were carried into the reservoir, reducing its storage volume. Much of this sediment originated in the Rio Puerco. The diminishing output of sediment from the Rio Puerco is evident in slower filling of Elephant Butte Reservoir since the 1930's.

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/puerco2/downseff.html
Maintained by Richard Pelltier
Last modified: 10:37:56 on 22-Mar-2000

Photograph of a collapsing wall of the Rio Puerco arroyo. The wall is approximately 6m high. Thousands of similar collapses along all sections of the arroyo place loose sediment directly in the stream channel. With such a constant supply, streams are fully saturated with sediment. The muddy flows that result gave the Rio Puerco its name, which means "pig river" or "dirty river" in Spanish.

The Rio Puerco at the Interstate 40 crossing exhibits arroyo walls with slumps, vegetated terraces, and natural levees along the margin of the inner channel. The slumping arroyo wall is approximately 6m high.

Local precipitation has flowed through the valley-fill materials, creating voids through the process of *piping*. The void in this arroyo bank is more than 6 m high.

Detail view of a wall of the current arroyo. Here the river previously cut an arroyo into the sandstone (the blocks just below the man's hand) in a different path from the current one, depositing fist- to head-sized cobbles. That arroyo was then filled with fine-grained sediments prior to incision of the current arroyo.

The wall of this arroyo displays a small channel that was refilled prior to incision of the current arroyo (the old channel is where the layers of sediment appear to "sag" on the arroyo wall). Scientists can often find pieces of charcoal in these earlier channels (charcoal is the result of lighting-ignited wildfires) and use carbon-14 age determinations to gauge the history of incision and refilling at each site. The horizontal structure at the top of the channel fill indicates episodic deposition of fine-grained water-borne sediments. Episodic deposition was provided either by a series of low peak flows in this channel or by overflow from another channel. In either case, this channel was eventually abandoned in favor of another; such shifts occur frequently in sediment-laden streams.

Four levels of terraces are seen here close to the inner channel. Deposition forms a smooth upper surface, then flow in the stream removes material from the terrace edge, typically leaving a small scarp. The cohesive, fine-grained sediments of the Rio Puerco cause scarps at all scales to be nearly vertical. During periods of low stream levels, the vertical walls degenerate into smoother slopes.

View of the Rio Puerco main stem just above the confluence of one of its major tributaries, the Arroyo Chico. The river is incised 3 m into the broad valley, and vegetated terraces have formed inside the arroyo. Terraces are sites of slow flows and sediment deposition when floods exceed the capacity of the unvegetated inner channel.

The junctions of the trunks and roots of trees on this terrace lie about 50 cm below the current terrace surface. These junctions were at the terrace surface when the trees began to grow, so 50 cm of sediment has been deposited on the terrace during the trees' lifetime; the ages of the trees have not been determined. During the same period, the margin of the terrace has retreated an unknown distance

http://climchange.cr.usgs.gov/rio_puerco/puerco2/upland.html

Upland Erosion

Arroyos are dramatic features of the landscape, but their formation depends on the supply of sediment that comes into the valley from the less dramatic hill slopes, which cover more than 90% of the landscape. Scientists have installed simple instruments that catch water and sediment on hill slopes during precipitation events. After each event, scientists weigh the sediment and water produced by each small test area. They also monitor precipitation, streamflow, and sediment transport in nearby streams in order to better understand the magnitude of each event. These studies provide quantitative data on the supply of sediment from uplands into stream channels, and relationships between precipitation rates and rates of sediment movement.

Preliminary results indicate that the amount of sediment moved by rainstorms of similar magnitude varies over a wide range. Random processes or unmeasured variables (raindrop size, for example) cause these variations. Measurements of numerous events will be required in order to develop reliable quantitative models of sediment movement.

Upland studies have been designed to compare sediment production between areas that have been managed with differing levels of grazing. One study site has won awards for its protective range management practices, while another has numerous erosion features that are the result, in part, of sparse vegetation.

Previous: How do arroyos work?

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/puerco2/upland.html
Maintained by Richard Pelltier
Last modified: 10:38:01 on 22-Mar-2000

Scientists have constructed a small artificial wall to collect runoff and sediment moving on a hillside during precipitation events. The board at the bottom of the photo covers a collection trough; tubes connect the trough to collection buckets that provide capacity for large events (see next illustration).

Tubes from the collection trough (see prior illustration) carry excess water and sediment to collection buckets, which are weighed after each storm event in order to measure water and sediment production.

Sediment Volume Changes in Elephant Butte Reservoir
Source: Chris Gorbach, 1995, personal communication, U.S. Bureau of Reclamation, Albuquerque, NM.

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/puerco2/elephant.html
Maintained by Richard Pelltier
Last modified: 10:37:57 on 22-Mar-2000

Water: The Driver of Erosion

Weather - the summer monsoon of the Southwest

The Rio Puerco, like many parts of New Mexico and Arizona, is affected by summer monsoons. These are moist flows of air that originate primarily in the Gulf of Mexico; the local manifestation is thunderstorms - exactly the sort of intense rain that can readily move materials and cut channels.

For more information on this topic, please read:
Precipitation Trends and Water Consumption in the Southwestern United States, by Henry Diaz and Craig Anderson.

Water flow - the driver of sediment

Water flow in channels is a prerequisite to the formation of arroyos. When precipitation falls on sand, gravel, or highly fractured rock (such as volcanic rocks that are abundant in the Rio Puerco basin), then the water percolates into the ground and does not create runoff. On the other hand, if rain falls on clay-rich soils that do not readily absorb water, then abundant runoff is produced. Thus, soil infiltration rates are key determinants of the amount of water that flows in channels during and after storms.

Some catchments in the Rio Puerco basin produce 10 times more water than others of the same size and elevation. Some of this discrepancy may be due to differences in precipitation, but runoff generation and channel infiltration are also likely contributing factors.

Tributaries and scaling

The geographic extent of thunderstorms may be a subtle climatic influence over the arroyo cycle in the Rio Puerco. When rain falls simultaneously in the catchments of multiple tributaries, then the downstream convergence of flow may sustain sediment transport for distances greater than would be possible for precipitation in a single catchment. Satellite observations of clouds and Doppler radar precipitation data both provide information about the extent of storms over the Rio Puerco basin, which has few weather stations.

Previous: Downstream Effects

Next: How do Arroyos Work?

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/puerco2/hydrology.html
Maintained by Richard Pelltier
Last modified: 10:37:59 on 22-Mar-2000

Information

For more information on the Rio Puerco Basin, please contact:

Contact	Specialty	Affiliation
Milan Pavich	Rio Puerco project coordinator; Soils geology; Sediment geochronolgy	U.S. Geological Survey
Jim Yount jyount@usgs.gov	Geologic and geomorphic mapping	U.S. Geological Survey
Allen Gellis agellis@usgs.gov	Erosion history; Hillslope processes	U.S. Geological Survey
Ray Watts rwatts@usgs.gov	Geographic analysis; Numerical modeling	U.S. Geological Survey
Mel Podwysocki mpodwyso@usgs.gov	Remote sensing	U.S. Geological Survey
Richard Pelltier rtpelltier@usgs.gov	Data; Rio Puerco WWW site	U.S. Geological Survey
Peter Molnar molnarp@lamar.colostate.edu	Hydrologic modeling	Colorado State University
Chris Gorbach cgorbach@uc.usbr.gov	Civil engineering on the Rio Grande	U.S. Bureau of Reclamation

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/puerco2/contacts.html
Maintained by Richard Pelltier
Last modified: 10:52:23 on 22-Mar-2000

http://geochange.er.usgs.gov/sw/changes/anthropogenic/population/

Population Growth of the Southwest United States, 1900-1990

by

Martin Chourre and Stewart Wright

U.S. Geological Survey

Introduction

The accompanying maps show the population changes that occurred from 1900 to 1990 in the southwestern United States (Arizona, California, Colorado, Nevada, New Mexico and Utah). The maps represent population and population density by county at decennial intervals. Making generalizations about population trends for the entire region is difficult because local factors affect population change. The small scale of these maps shows the data for the entire region, but not in enough detail to display significant local differences, some of which can be inferred by comparing the total population and population density maps. To be able to compare maps throughout the century, the classification scheme used remains the same for each of the map types.

Geographic Analysis

The Southwest population maps are based upon US Census data and to show population change over time. By arranging the numbers into groups or classes, a visual portrayal of the population values can be created. Several methods are used to show population trends. Growth factors, such as economy or climate, cannot be derived from these models. This type of information needs to be collected on a local basis, taking into account all of the local factors that influence population growth for a specific area.

A small-scale map (1:2,000,000) will show more area in less detail and a large-scale map (1:24,000) will show less area in greater detail. This relationship is important when analyzing data of different scales. Small-scale maps can be used to locate areas of interest requiring more detailed study, and to support local or large-scale modeling and analysis. The value of small-scale mapping is to show the population trends throughout the region.

Because of the small scale and the cartographic generalization of some of the pre-1990 boundary locations, these data sets may not be suitable for large-scale modeling or comprehensive analysis. These boundary locations are not based on legal land descriptions, which could affect the size of a county and render the population density figures inaccurate for local analysis. The scale of the maps also affects accuracy. Exact boundary positions cannot be mapped in detail at this small scale.

Some geographic principles apply when comparing total population with population density. The size of a county will affect how population density is shown when compared to total population. The County of San Francisco is quite small (less than 50 square miles) though its population is fairly high. Given this situation, the population density remains in the high category through the decades, while total population remains in the middle category. When looking at the population density maps, the impression is that San Francisco is a highly populated place, but when looking at the total population it is not in the high category. The same is true for Denver County in Colorado. Its population density is in the high category, but its total population is in the middle category.

Click to view **animated maps** of TOTAL POPULATION and POPULATION DENSITY by county for the southwestern United States, by decade for the period 1900-1990.

Click any map to view a larger image

In the 1980 and 1990 population density maps, the counties where Las Vegas (Clark) and Albuquerque (Bernalillo) are located tell a similar story. The total population of Las Vegas is larger than that of Albuquerque, yet the population density is higher for Bernalillo County than Clark County. In the 1980 population density map, Maricopa County, Arizona, has a medium population density even though the population of Phoenix is quite high. These examples show how the size of a county affects the population density.

Click any map to view a larger image

Total population or population density by themselves do not give any indication as to where population is concentrated in the county. But, when viewed together, some assumptions can be made. San Bernardino County, California is the largest county in the southwestern United States. The population density maps show the county in the low to medium ranges throughout the decades. The total population maps show the population growing into the high category by 1990. Taking into consideration the population growth of the surrounding counties, an assumption can be made that most of the people in San Bernardino County are concentrated in the Los Angeles metropolitan area.

Click any map to view a larger image

Changing county boundaries can be used to deduce certain characteristics about an area other than the total population and population density. Looking at Colorado in 1900, Arapahoe County has a high population and a lower population density because of its size. In 1910, when Denver County first appears, both the population and the population density classifications increase inside the new county. The assumption can be made that in 1900, before Denver County was formed, most people were concentrated in the western part of Arapahoe County. In 1900, the population density for San Diego County, California was fairly low. In 1910, when Imperial County was formed, the population density increased in San Diego County. This points to the fact that in 1900, before Imperial County was formed, most people were concentrated in the western part of the county near the city of San Diego.

Click any map to view a larger image

The class values show a trend as well. The number of counties in the lower classification ranges decreases and the number in the higher ranges increases with time. Between 1910 and 1920, the numbers stayed the same and growth was slow enough that the classification scheme was unable to pick out any growth for that time period. Between 1930 and 1940, the large increases in the numbers from lower to higher classes suggest a surge in growth.

Click any map to view a larger image

Population Trends

Different economies and climates affect population trends throughout the region. Mining and agriculture have both played a significant role on population growth and decline in the Southwest, but other factors such as availability of water are significant. When viewing the population trends for the entire region, the local factors controlling these trends must be considered individually.

Federal Government policies have played an important role in the development of the Southwest. The Mining Act of 1879 provided initial impetus for the mining industry, and the various Homestead Acts made inexpensive land available for farmers. Public works such as irrigation, electric power generation, road building and water diversion and retention projects helped foster urban and rural growth. For example, the construction of Hoover Dam in the 1930s played a huge role in the development of the Las Vegas area. In the time period immediately preceding and during WWII, the expansion of military bases and ship and aircraft building industries brought many workers to the Southwest. People stayed after the war or moved to the Southwest upon completion of military service. More recently, the use of government lands for resource utilization, such as oil and gas drilling and grazing permits for livestock, has played an important part in the growth of the Southwest. Many local and state governments offer incentives such as low taxes, cheap utilities, and inexpensive land to businesses that relocate from other states.

As mining and agriculture became less labor-intensive and more mechanized, people started moving to urban areas throughout the country, especially in the Southwest, providing the labor pool for manufacturing and industry. Modern transportation, such as better highways, increased rail service and commercial airlines have increased mobility, allowing people to travel and do business over greater distances. Since the end of WWII, tourism and recreation-oriented businesses have become increasingly important in the Southwest. Many people are moving West for better quality of life, more open space, less congestion and increased recreational opportunities. The growing elderly population has been drawn to the warm and sunny climate of the region. Large retirement settlements have been a significant factor in the growth of some regions in the Southwest.

There are many reasons for the huge population growth of the southwestern United States in the 20th century. The Front Range of Colorado, the Wasatch Front in Utah, the Las Vegas, Los Angeles and other metropolitan areas, all exhibit unique population trends. Trends for the future may be based upon different factors yet to exist.

Conclusion

The visual impact of these maps, especially when viewed as an animation, can be a useful tool in understanding population growth and decline. As each decade passes, a pattern emerges that can be seen easily. These patterns can be examined more closely to determine the causes of the population trend for a local area.

The population of the Southwestern United States has increased by approximately 1,500% over the last 90 years, while the population of the United States as a whole has grown by just 225%. In the Southwest, Arizona and Nevada have led the way with increases of 2,880% and 2,840%, respectively. The metropolitan area in Nevada that is responsible for this growth is Las Vegas (Clark County). Clark County had a 90-year growth rate of 22,480%, growing from 3,284 people in 1900 to 741,459 people in 1990. Maricopa County (Phoenix), Arizona, had a 100-year growth rate of 10,275%, with most of that growth occurring between 1960 and 1990.

Considering both the local factors and the general population increase that the southwestern United States has seen over the last 90 years, and assuming that growth will continue, it is easy to see why plans for the future are necessary. Water and natural resources need to be managed to accommodate the future growth and economies need to be examined to ensure a healthy environment.

A brief description of the Geographic Data is available.

Read discussion || Add a comment || Subscribe || Register ||

Click to view **animated maps** of TOTAL POPULATION and POPULATION DENSITY by county for the southwestern United States, by decade for the period 1900-1990.
http://geochange.er.usgs.gov/sw/changes/anthropogenic/population/denanim.gif
http://geochange.er.usgs.gov/sw/changes/anthropogenic/population/popanim.gif

ACC NO: 5001204 PROJ NO: 609.02

Effects of exotic species invasion and flow alteration on western riparian ecosystems: effects of stream hydrology and geomorphology on managing riparian vegetation dynamics on DOI lands

PRIMARY PROGRAM ELEMENT: Ecosystems
SECONDARY PROGRAM ELEMENT: Application of Science Information to Management

DURATION: Start Date: 10/1/1995 End Date: 9/30/2000

INVESTIGATORS: Gregor T Auble; Lee S Ischinger; Jonathan M Friedman; Michael L Scott; Patrick B Shafroth

PROJECT CONTACT:
Gregor Auble
CO
Phone: 970-226-9448
Fax: 970-226-9230
E-mail: greg_auble@usgs.gov

PROJECT DESCRIPTION:

Riparian ecosystems in the semi-arid regions of the western US have important habitat and aesthetic values because they are structurally distinct from the surrounding drier landscape. These systems are especially sensitive to impacts from land and water management actions. This study comprises a series of case studies done in collaboration with Department of Interior agencies having site-specific management questions concerning riparian vegetation. Base resources are used to investigate and evaluate potential studies to identify if both site-specific questions and a broader research agenda can be effectively addressed, and to leverage management agency resources so as to produce scientifically robust results. This study, in combination with a complementary study focused on more basic research questions concerning exotic trees, describe activities of an interdisciplinary team whose overall goal is to better inform riparian management decisions based on predictions of plant response to altered flow an

PROGRESS: 10/23/2000
Have completed sampling and analysis on cottonwood mortality caused by in-channel sand mining at Coal Creek, CO, and by channel incision at Mojave River, CA. Completed field sampling of vegetation distribution at Park Service sites along Little Colorado and Fremont rivers, at Fish and Wildlife Service sites on upper Green River. We continue long-term monitoring of seedling establishment and grazing effects along upper Missouri River, MT. Open literature papers have been published on Coal Creek, Gunnison River, and Missouri River work: a project completion report was provided to BLM on the San Miguel River analysis.

DESCRIPTORS:
Base Funds; aquatic; desert and arid lands; ecosystem science; forests; human impacts; lakes/reservoirs; National Wildlife Refuges; National Parks; plants; populations; public lands; riparian; river systems; terrestrial; wetlands

http://water.usgs.gov/osw/sediment/index.html

Summary of U.S. Geological Survey On-Line Instantaneous Fluvial Sediment and Ancillary Data

by Lisa M. Turcios, John R. Gray, and Annette L. Ledford

Instantaneous fluvial sediment data, in addition to other instantaneous water-quality and ancillary data collected by the U.S. Geological Survey (USGS), are available on-line through the National Water Information System World Wide Web (NWISWeb) water-quality data base at http://waterdata.usgs.gov/nwis/qwdata. The NWISWeb water-quality data base was populated and is periodically refreshed from electronic files maintained by individual USGS District offices across the United States and Puerto Rico. It represents the single largest repository of USGS electronic instantaneous-value suspended-sediment, bedload, and bed-material data. These Web pages provide a summary of fluvial-sediment data by State, and by USGS station number retrieved from the then-under-construction NWISWeb data base on January 13, 2000.

The meta data can be accessed by following the links at the bottom of this Web page.

More than 2.6-million values of instantaneous-value sediment and ancillary data were retrieved for 15,415 sites in all 50 States, Puerto Rico, and other locations, including Canada, the Federated States of Micronesia, Guam, and Southern Ryukyu Islands, from the NWISWeb data base on January 13, 2000. The NWISWeb data base is described, along with the criteria used to retrieve sediment and ancillary data, and selected characteristics of those data in a report to be published in the Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nevada, March 25-29, 2001. A copy of the report is available in pdf format and will require the use of Adobe Acrobat software to view.

Additional Helpful Information:

Appendix A contains a complete list of selected parameter codes used in the retrieval.
Appendix B summarizes retrieval results for selected instantaneous fluvial sediment and ancillary data.
Appendix C contains some helpful explanations about remark codes associated with selected sediment and ancillary data parameter codes.

Maps showing locations of sites in the United States and Puerto Rico with sediment and ancillary data retrieved from the NWISWeb data base on January 13, 2000:

Figure 1 shows a map of sites that have at least 30 paired values of instantaneous-value suspended-sediment concentration and associated water discharge.
Figure 2 shows a map of sites that have at least 30 values of particle-size distribution of suspended sediment.
Figure 3 shows a map of sites that have at least 1 value of bedload discharge.

Figure 4 shows a map of sites that have at least 10 values of bed material particle-size distributions.

The results of the January 13, 2000, retrieval from then-under-construction NWISWeb water-quality data base, which are summarized in these Web pages, do not include all instantaneous-value sediment and ancillary data collected by the USGS. Only those data that were present in USGS District Office NWIS data bases in the spring of 1999 were used to populate the NWISWeb data base that was the source of the January 13, 2000, retrieval. There is evidence that a considerable amount of USGS suspended-sediment concentration data and some bedload-transport data were not available on the NWISWeb on January 13, 2000. In many cases, these data can be obtained through USGS District offices for a fraction of the cost of collecting a comparable amount of sediment and ancillary data. For more information, we recommend contacting the local USGS office for Water Resources by following the links available at http://water.usgs.gov/local_offices.html.

Daily-value suspended-sediment data collected by the USGS from 1930 through September 30, 1994, are available to the public on-line at http://webserver.cr.usgs.gov/sediment/. These and subsequent daily-value USGS suspended-sediment data are entered into the NWISWeb data base as the data become available.

For more information about the data collected, you may follow this link to Chapter 2. Water-Quality System of the User's Manual for the National Water Information System of the U.S. Geological Survey.

Sediment Data Summary by State
Chose state to view summary pages.
Station data for each state may take minutes to load.
Suggestions for printing.

Alabama Alaska Arizona Arkansas California Colorado Connecticut Delaware District of Columbia Florida Georgia Hawaii Idaho Illinois Indiana Iowa Kansas Kentucky Louisiana Maine Maryland Massachusetts Michigan Minnesota Mississippi Missouri Montana Nebraska New Hampshire New Jersey New Mexico New York Nevada North Carolina North Dakota Ohio Oklahoma Oregon Pennsylvania Puerto Rico Rhode Island South Carolina South Dakota Tennessee Texas Utah Vermont Virginia Washington West Virginia Wisconsin Wyoming also including Canada Federated States of Micronesia Guam Ryukyu Islands, Southern To Be Determined

We want your feedback!
U.S. Department of the Interior, U.S. Geological Survey
Maintainer: Office of Surface Water
Last update: 15:09:24 Wed 05 Jun 2002
Privacy Statement || Disclaimer || Accessibility
URL: http://water.usgs.gov/osw/sediment/

Station Information

Blank cells in the following tables signify that no data was retrieved for the field from the NWISWeb on January 13, 2000.

Station Identification Number	Station Name	Drainage area (square miles)	Hydrologic unit code	Latitude (decimal degrees)	Longitude (decimal degrees)	Agency Code	County Code
08332700	(N) SAN PABLO CR NR CUBA, NM	12.80	13020204	35.95	-106.95	USGS	043
08333450	(N) ARROYO CHAVEZ NR SAN LUIS, NM		13020204	35.69	-107.10	USGS	043
08334000	(N) RIO PUERCO ABV ARROYO CHICO NR GUADALUPE, NM	420.00	13020204	35.60	-107.17	USGS	043
08334300	(N) PAPERS WASH NR STARLAKE TRADING POST, NM		13020205	35.89	-107.42	USGS	031
08340500	(C) ARROYO CHICO NR GUADALUPE, NM	1390.00	13020204	35.59	-107.19	USGS	043
08342000	(C) BLUEWATER C NR BLUEWATER, NM	209.00	13020207	35.29	-108.03	USGS	006
08343000	(C) RIO SAN JOSE AT GRANTS, NM	1020.00	13020207	35.15	-107.87	USGS	006
08343500	(N) RIO SAN JOSE NEAR GRANTS, NM	2300.00	13020207	35.07	-107.75	USGS	006
08351225	(N) VOLCANO HILL WASH NR CORREO, NM		13020207	34.84	-107.36	USGS	006
08351500	(C) RIO SAN JOSE AT CORREO, NM	3660.00	13020207	34.97	-107.19	USGS	006
08352500	(C) RIO PUERCO AT RIO PUERCO, NM	6590.00	13020204	34.79	-106.99	USGS	061
08353000	(C) RIO PUERCO NEAR BERNARDO, NM	7350.00	13020204	34.41	-106.85	USGS	053
08323000	(N) RIO GUADALUPE AT BOX CANYON NEAR JEMEZ, NM	235.00	13020202	35.73	-106.76	USGS	043
08324000	(N) JEMEZ RIVER NEAR JEMEZ, NM	470.00	13020202	35.66	-	USGS	043

					106.74		
08329000	(C) JEMEZ RIVER BELOW JEMEZ CANYON DAM, NM	1038.00	13020202	35.39	-106.53	USGS	043

introduction
Glossary of Terms

Appendix A--Parameter Codes
Appendix B--Selected Retrieval Results
Appendix C--Remark and Value Codes

Figure 1--Locations of Sites with Suspended-Sediment Data
Figure 2--Locations of Sites with Particle-Size Distributions of Suspended-Sediment Data
Figure 3--Locations of Sites with Bedload Discharge Data
Figure 4--Locations of Sites with Particle-size Distribution of Bed Material Data

We want your feedback!
U.S. Department of the Interior, U.S. Geological Survey
Maintainer: Office of Surface Water
Last update: 17:21:58 Mon 09 Jul 2001

URL: http://water.usgs.gov/osw/sediment/nm_nv_stations.html

Summary of U.S. Geological Survey On-Line Instantaneous Fluvial Sediment Data

Glossary of Terms

Agency Code
The agency that is reporting the data. Agency codes are fixed values assigned by the National Water Information System (NWIS).

County
The Federal Information Processing Standards (FIPS) code of the county or county equivalent (parish, borough, etc.) in which the site is located.

District
The U.S. Geological Survey District office that operates the site.

Drainage area
The area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above that point.

Hydrologic Unit Code (HUC)

Hydrologic units are geographic areas representing part or all of a surface drainage basin or distinct hydrologic feature

and are delineated on the State Hydrologic Unit Maps. Each hydrologic unit is identified by a unique number (HUC), and a name.

Parameter

Data for water-quality samples, including suspended sediment, bedload, and bed material, are stored under parameter codes. Each parameter code defines a specific type of data. The USGS and USEPA typically use similar parameter-code definitions, although there are exceptions to this rule. Parameter codes fall into three classes:

1.Site and sampling-event data, such as site name, site ID, sample data, etc.

2.Fixed-value codes, which are used to define a certain part of the process of sample collection, processing, or quality assurance.

3.Chemical, physical, and biological data. The following illustrates how codes are defined, and how for one type of measurement, several parameter codes may exist.

Parameter Code	Parameter Definition
70331	Sediment, suspended, sieve diameter, percent finer than 0.062 mm
70342	Sediment, suspended, fall diameter, distilled water, percent finer than 0.062 mm
80154	Sediment, suspended concentration (mg/L)

Station Identification Number

Each site in the data base has a unique 8- to 15-digit identification number.

Station Name

The name of the site in the database.

Chose a State
Printing Suggestions
Introduction
Glossary of Terms

Appendix A--Parameter Codes
Appendix B--Selected Retrieval Results
Appendix C--Remark and Value Codes

Figure 1--Locations of Sites with Suspended-Sediment Data
Figure 2--Locations of Sites with Particle-Size Distributions of Suspended-Sediment Data
Figure 3--Locations of Sites with Bedload Discharge Data
Figure 4--Locations of Sites with Particle-size Distribution of Bed Material Data

http://geochange.er.usgs.gov/sw/changes/natural/diaz/

Precipitation Trends and Water Consumption in the Southwestern United States

by

Henry F. Diaz

National Oceanic and Atmospheric Administration

Environmental Research Laboratory/Climate Diagnostics Center

and

Craig A. Anderson

Cooperative Institute for Research in the Environmental Sciences

University of Colorado, Boulder

This presentation is abstracted from ***Diaz, H.F., and Anderson, C. A.,*** *1995, "Precipitation trends and water consumption related to population in the southwestern United States: A reassessment":* ***Water Resources Research****, v. 31, p. 713-720, March 1995.* The reader is urged to refer to the full paper and(or) contact the authors for more information.

Introduction

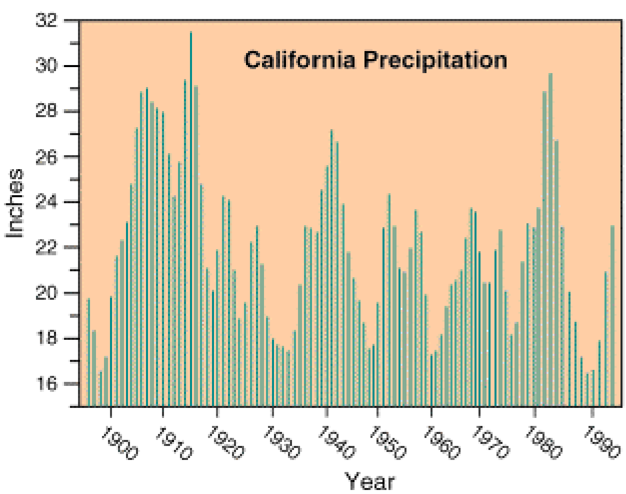


FIGURE 1.

This study compares trends in water consumption, regional precipitation, and population growth in the southwestern states representing the major users of Colorado River Basin water (Arizona, California, Colorado, Nevada, New Mexico, and Utah). Although much of the western United States was characterized by wet weather during the early 1980s, the years since then have been predominantly dry. A decline in water use has also taken place in many of the western states since the mid-1980s, notably in California, which accounts for the majority of water depletions from the Colorado River Basin. However, population in the six-state area has increased at approximately the same rate as in previous decades. A continuation of these trends may result in heightened competition for available water supplies, exert increased pressure on water pricing policies, and force users to increase water conservation efforts.

Climate Variability

The Southwest receives precipitation from several different sources. In California, most of the precipitation results from Pacific storms originating in the Gulf of Alaska during the winter. In contrast, Arizona and New Mexico receive the bulk of their precipitation from the "summer monsoons", whereas Nevada, Utah, and Colorado receive their moisture from a variety of sources.

One of the most important characteristics of precipitation in the Southwest is the high degree of seasonal, interannual, and decadal variability. **FIGURE 1** shows the precipitation record for California since 1895; the data have been smoothed slightly to suppress the high interannual variability. As can be seen, the high rainfalls of the early 1980’s (due to a strong El Niño event) and the subsequent severe drought of the late 1980's were not unique events. Similar very wet and very dry conditions have occurred in the Southwest throughout this century. The level of Great Salt Lake (Utah) and the streamflow of the Colorado River show similar decadal-scale variations **(FIGURE 2)**.

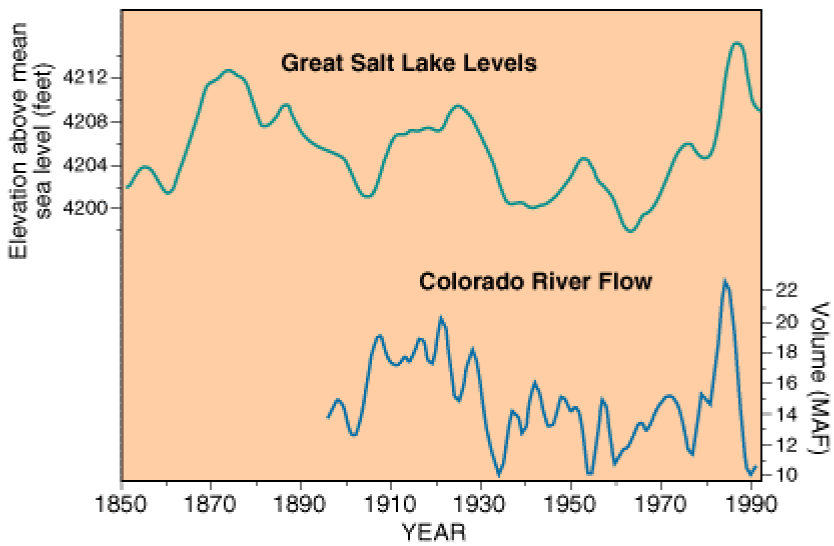


FIGURE 2.

The recurrence of low precipitation and reduced streamflow is a fundamental characteristic of the Southwest. When severe droughts or severe wet conditions occur, they can affect large portions (up to 50%) of the western U.S. (Southwest + Northwest). **FIGURE 3** shows the fraction of the West affected by moderate-to-severe drought or moderate-to-severe wet conditions since 1895. Again, the decadal-scale variability is clearly visible.

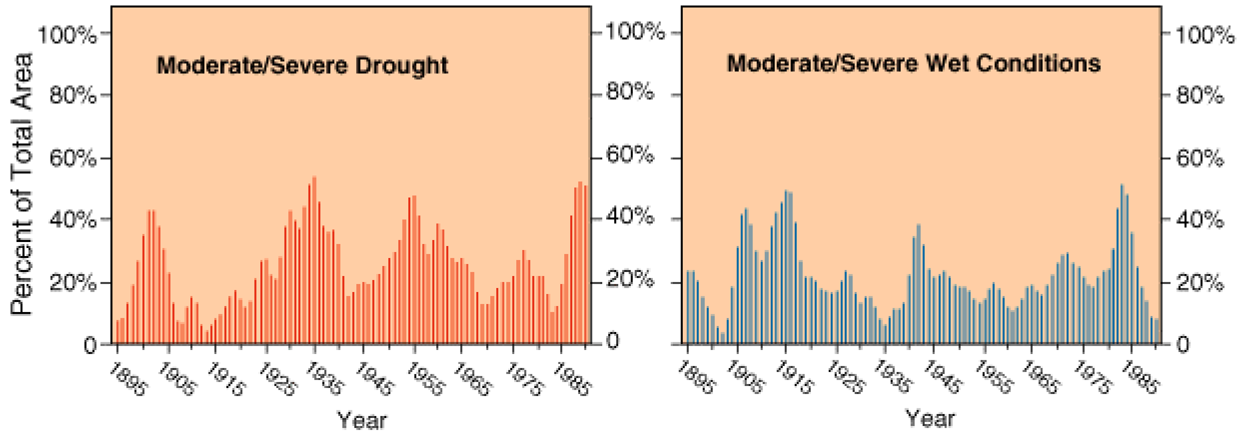


FIGURE 3.

Water Supply

Most of the water supply for the Southwest comes from melting snow during the spring and early summer. However, changes in storm tracks, in the proportion of precipitation that falls as snow, and in seasonality, can result in earlier snow melt, diminished snowpack, increased evaporative losses, and lower runoff. This translates to less water being available for storage in the network of western reservoirs. The largest watershed in the Southwest is the Colorado River Basin **(FIGURE 4)**. When filled to capacity, the reservoirs of this watershed can store 60 million acre feet of water. This amounts to about a 4-year supply at current consumption rates.

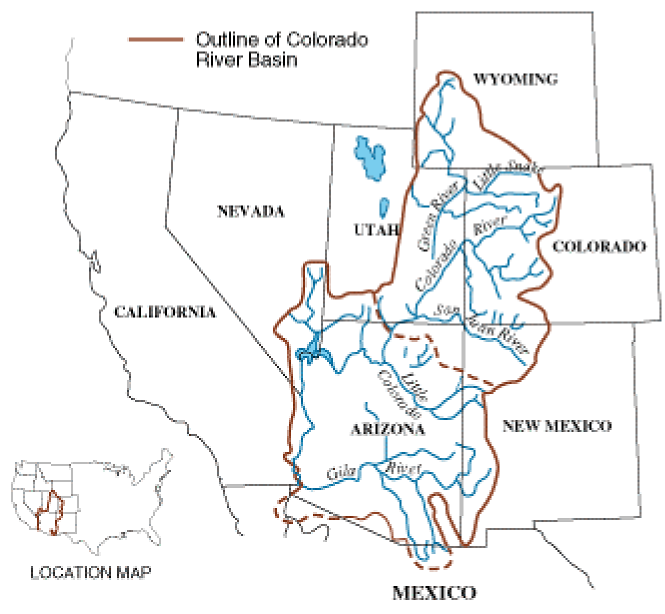


FIGURE 4.

Water Use

FIGURE 5 shows the water-use rates in the six southwestern states since 1950. The usage is divided into four components: 1) civil use, 2) irrigation, 3) consumptive and irrigation conveyance losses, and 4) hydroelectric power generation. Category 3 refers to water lost to the system through various processes (e.g. evapotranspiration and irrigation conveyance losses) and hence is unavailable for further use. Between 1950 and 1990, the population in the Southwest tripled **(FIGURE 6)** and the overall demand for water has increased accordingly. This is particularly true of civil use, which is the smallest of the four categories. The next largest category, irrigation use, increased between 1950 and 1980 and then showed a small decrease. The consumptive use and hydroelectric categories display similar trends. At this time, it is unclear whether the observed decline in the total water use figures between 1980 and 1990 represent a systematic change (due to increased efficiency) or a temporary slowdown that will reverse itself in the next decade. Ultimately, the demand for water is expected to increase as the population of the Southwest continues to grow.

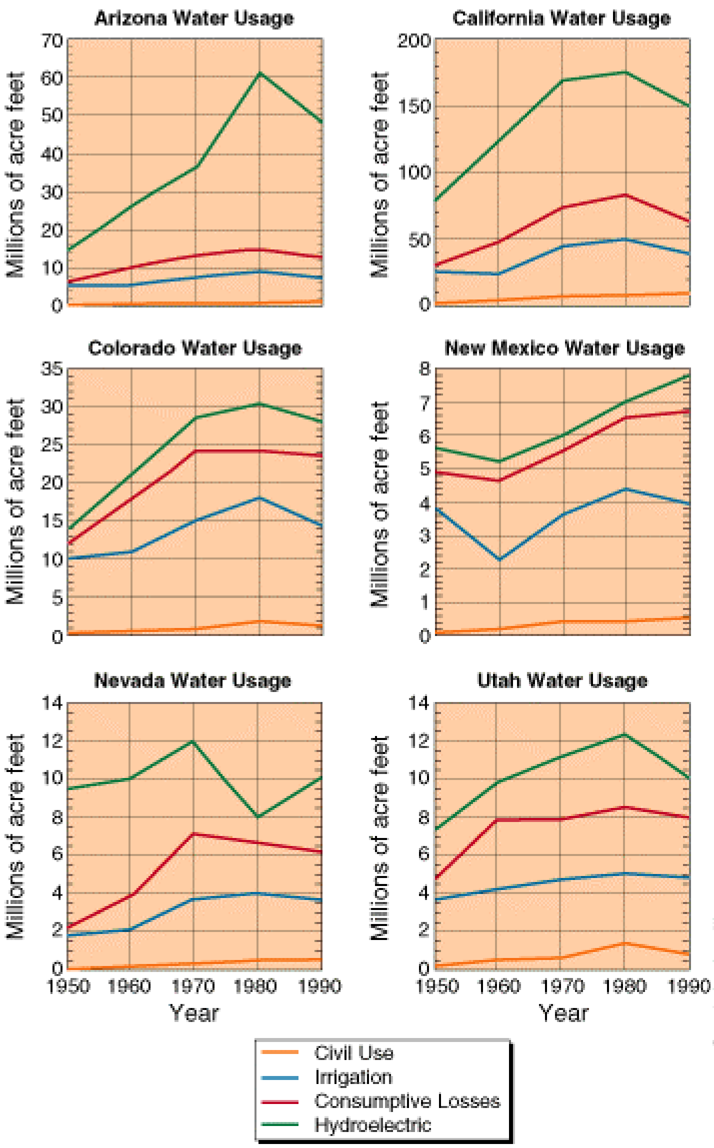


FIGURE 5.

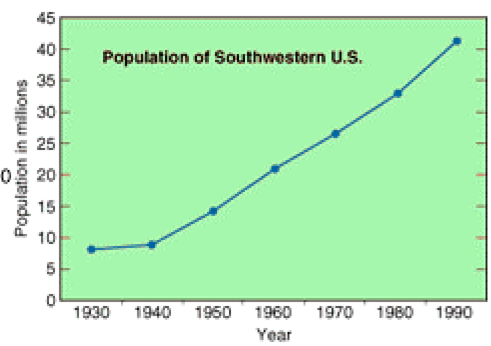


FIGURE 6.

Summary

The climate record clearly shows the occurrence of significant precipitation and streamflow fluctuations on interannual to decadal time scales. These fluctuations can change the amount of water available in Southwestern watersheds by 50% or more for several years. A severe drought lasting more than 5 years will have a major impact on water deliveries and hydroelectric production in the

Southwest. Given the rapidly growing population of the Southwest, water scarcities may become increasingly evident, even in the absence of major dry episodes.

See also

- NOAA-CIRES Climate Diagnostics Center
- Water Use in California
- California's Water Resource
- USGS Water-Use Information

This page is <URL:http://geochange.er.usgs.gov/sw/changes/natural/diaz/>

Maintained by Peter Schweitzer and Randy Schumann

Last updated Thursday, 10-Jul-1997 11:55:10 EDT http://climchange.cr.usgs.gov/rio_puerco/erosion/streamflow.html

History of Streamflow and Suspended-Sediment Collection in the Rio Puerco Basin, New Mexico

Allen Gellis, U.S. Geological Survey, Albuquerque, NM 87110

Introduction

The high sediment loads and sediment transport characteristics of the Rio Puerco, central New Mexico, have for decades attracted the attention of geologists, hydrologists, and engineers (Bryan and Post, 1927; Nordin and Curtis, 1962; Nordin, 1963; Heath, 1983; Gellis,1992). Suspended-sediment concentrations in excess of 400,000 ppm were observed by Nordin (1963) for the Rio Puerco near Bernardo and averages of 79,000 mg/L were reported by the Bureau of Reclamation (1994). Simons and others (1991) estimated that 90 percent of the suspended-sediment load in the Rio Puerco is silt and clay (<0.062mm). The problems caused by the transport of this sediment into the Rio Grande has been a concern since the 1920's when Bryan and Post (1927) outlined a detailed plan to control erosion and sediment transport in the Rio Puerco. In response to continuing problems of sedimentation in Elephant Butte Reservoir and the Rio Grande, the Bureau of Reclamation, in 1994, investigated the development of a sediment control project for the Rio Puerco (Bureau of Reclamation, 1994).

The drainage area of the Rio Puerco located in central New Mexico is 7,350 mi2 (19,036 km2) of which 1,130 mi2 (2,927 km2) does not contribute to surface runoff (fig. 1). The Rio Puerco is intermittent through most of its length with higher elevations receiving snowmelt and precipitation runoff events and lower reaches dominated by convective rainfall-runoff events. The large aerial extent of erosive geologic units in the basin provides a large source of available sediment to the channel. Happ (1948) estimated the sources of sediment in the Rio Puerco as: 40% erosion of the existing Rio Puerco channel (bed and banks), 30% erosion in tributary channels, and 30% sheet, rill, and minor gully erosion.

Suspended-Sediment Data

Collection of suspended sediment for computation of daily suspended-sediment discharge began in the Rio Puerco basin by the U.S. Geological Survey (USGS) in 1948 (fig. 1; Table 1). During the period 1948-1956, five stations were operating on the main stem Rio Puerco and its two major tributaries, the Rio San Jose and Arroyo Chico (Table 1). At the time of this paper, only two stations are operating in the basin, the Rio Puerco at Bernardo and the Rio Puerco above Arroyo Chico. Collection of suspended sediment data and computation of sediment loads in the Rio Puerco followed USGS procedures outlined by Porterfield (1972) and Edwards and Glysson (1988). Daily samples were collected by an observer with additional samples collected during runoff events by USGS personnel. In 1995, an automatic suspended-sediment sampler was installed at the Rio Puerco near Bernardo and the Rio Puerco above Arroyo Chico. An additional, higher stage automatic sampler was installed at the Rio Puerco near Bernardo in 1997. The sediment records can be described as good from 1948 to 1972, fair from 1973 to 1992, and good with the installation of an automatic sampler in 1993. Sediment records are labeled as fair from 1973 to 1992 because few runoff events were adequately sampled in that time period.

For the period of suspended-sediment collection at the Rio Puerco near Bernardo, 1948-96, the average annual suspended-sediment load was 4.44 million tons (4.03 metric tons). The sediment yield of the Rio Puerco is moderately high compared to world rivers (fig. 2a). However, by normalizing sediment load by average annual runoff instead of drainage area the Rio Puerco has the third highest sediment concentration (fig. 2b).

Compared to the suspended-sediment loads transported at the Rio Grande near San Marcia, located approximately 52 miles (84 km) downstream of the Rio Puerco, the Rio Puerco transported 83% of the total load of the Rio Grande from 1948 to 1973 and 64% of the total load from 1974 to 1996. For the same periods, 1948-73 and 1974-96, the Rio Puerco transported 5.6 and 2.3%, respectively, of the total runoff measured at the Rio Grande near San Marcia. In 1974, Cochiti Reservoir located approximately 92 miles (148 km) upstream from the mouth of the Rio Puerco, was closed and therefore, 1974 was chosen as a break in the two time periods. The closure of Cochiti Reservoir may have reduced the upstream contributions of sediment and therefore, may have effected downstream sediment transport.

During the period of sediment collection at the five stations (fig. 1) most of the runoff (30 to 50%) occurs in August or September (fig. 3a). Rainfall events during the monsoonal period in New Mexico from July to September are typical of convective-type rainfall events. The station Rio Puerco above Arroyo Chico has peak runoff in May and is a function of snowmelt in the Nacimiento Mountains above Cuba. Thirty-one to 51 percent of the suspended-sediment load at the five stations is transported during the monsoonal period in August or September (fig. 3b).

A sediment budget for the Rio Puerco was developed using suspended-sediment data from these five stations from 1949 to 1955 (fig. 1). Compared to the Rio Puerco near Bernardo, the largest upstream contributor of suspended sediment from 1949 to 1955, is the Arroyo Chico which drains 24 percent of the basin and delivers 34 percent of the suspended-sediment load (fig. 4). The Arroyo Chico also contributed most of the runoff (52%). The highest average annual sediment yield of any station is the Rio Puerco above Arroyo Chico (2,721 tons/mi^2). The highest total sediment concentration of any station, reported as total suspended sediment for the period divided by total runoff, is the Rio Puerco above Arroyo Chico (190 tons sediment/acre-feet runoff). The Rio San Jose at Correo reported the lowest values on sediment transport of any station (fig. 4). This low value of suspended-sediment transported at the Rio San Jose near Correo relative to the main stem Rio Puerco and Arroyo Chico may reflect differences in geology, soils, and channel hydraulics.

Trends in Suspended Sediment

Suspended-sediment loads and average annual suspended-sediment concentrations show a decrease for the period of record at Rio Puerco near Bernardo, Rio Puerco above Arroyo Chico, and Arroyo Chico near Guadalupe (fig. 5). Gellis (1992) reported that this decrease was due to channel changes over time referred to as arroyo evolution. In the arroyo evolution model systematic changes in channel geometry occur following channel entrenchment, from channel deepening to channel widening. Channel widening leads to less erosive flows, increased areas on the floodplain for colonization of vegetation, and channel aggradation. The increase in sediment deposition over time leads to a decrease in suspended-sediment loads. Similar decreases in suspended-sediment loads were observed in the Colorado River basin (Gellis and others, 1991) and in the Rio Grande (Gellis, 1992). Love (1997) concluded that arroyo evolution, which is largely based on a headward erosion model, may not be applicable in the main stem Rio Puerco.

Elliott (1979) distinguished downstream channel reaches from upstream reaches based on multiple discriminant function analyses of selected channel geometric, sedimentologic, and planimetric variables. Upstream channel reaches had large width-to-depth ratios, contained relatively small amounts of silt and clay sized material in the channel perimeter, contained low vegetation density, and a lateral shifting channel that was actively eroding. The channel in the downstream reaches had relatively small width-to-depth ratios, large amounts of silt and clay sized material in the channel perimeter, high vegetation density, and a relatively stable channel position. According to Elliott (1979), the 1930's lower Rio Puerco channel was similar to the 1977 upstream reaches and led Elliott to conclude that channel stabilization was progressing from downstream to upstream reaches. Resurveys of the 1977 cross sections in 1994 to 1997 by Elliott and others (1998), reaffirmed this earlier hypothesis. Channel changes were continuing in the upper reaches of the Rio Puerco where decreasing width-to-depth ratios were observed.

Love (1997) attributed the decrease in suspended-sediment loads at the Rio Puerco to a decrease in annual peak flows since the 1930's (fig. 6). The decrease in peak flows coupled with the planting of tamarisk led to an increase in vegetation on the floodplain. The increased vegetation led to an increase in roughness, increase in sediment deposition, and a decrease in suspended-sediment loads. Further research may indicate whether the decrease in peak flows is due to climate (rainfall and rainfall intensity) or to changes in channel cross-sectional and planform geometry.

Another possible explanation for the decrease in suspended-sediment loads may include successful land-management treatments in reducing erosion implemented by various land-management agencies in the Rio Puerco basin. The Bureau of Land Management, National Resource Conservation Service, Bureau of Indian Affairs, and other agencies have been implementing programs to reduce erosion and improve vegetation cover in the Rio Puerco since the 1930's (Burkham, 1966; Soil Conservation Service, 1977). However, the success of these programs is often not monitored and quantified. The lack of monitoring of erosion-control structures has not been limited to the Rio Puerco but is a problem present throughout the Southwest. For example, a lack of project documentation, monitoring, and evaluation of watershed and riparian treatments was documented for the U.S. Forest Service southwestern region (Ahlborn and others, 1992). Gellis and others (1995) noted a similar lack of project documentation, maintenance, and monitoring for erosion-control structures built on the Zuni Indian Reservation, New Mexico.

Conclusions

Compared to world rivers, the Rio Puerco basin in central New Mexico transports one of the world's highest average annual sediment concentrations. Compared to suspended-sediment loads transported at the Rio Grande near San Marcial, the Rio Puerco transported 83% of the total load from 1948 to 1973 and 64% of the total load from 1974 to 1996. The largest contributor of total suspended-sediment load in the Rio Puerco basin is the Arroyo Chico, which drains 24 percent of the basin and delivers 34 percent of the suspended-sediment load. The highest average annual sediment yield and the highest total sediment concentration, 2,721 tons/mi2 and 190 tons sediment/acre-feet runoff, respectively, was measured at the Rio Puerco above Arroyo Chico.

A decrease in suspended-sediment loads over time is observed at three stations in the Rio Puerco with long periods of record, the Rio Puerco near Bernardo, the Rio Puerco above Arroyo Chico, and the Arroyo Chico near Guadalupe. The decrease in sediment loads may be due to changes in channel and planform geometry of the Rio Puerco or to a decrease in peak flows. Both explanations favor an increase in vegetation, which leads to an increase in channel roughness and an increase in sediment deposition. It is also possible that the decrease in sediment loads is due to successful upland erosion-control strategies implemented over time by various land-management agencies. The success of many of these strategies has not been monitored or quantified.

References

Ahlborn, G., Platts, W., Hanes, T., and Jensen, S., 1992, Evaluation of watershed and riparian treatments, U.S. Forest Service Southwestern Region. Unpublished report to the U.S. Department of Agriculture Forest Service, Biosystems Analysis Inc., 40 p.

Bryan, K.B., and Post, G.M., 1927, Erosion and control of silt on the Rio Puerco, New Mexico: Unpublished report to the Chief Engineer, Middle Rio Grande Conservancy District Albuquerque, N.M., October. 1927, 133 p.

Bureau of Reclamation, 1994, Rio Puerco sedimentation and water quality study: U.S. Bureau of Reclamation Preliminary Findings Report, 47 p.

Burkham, D.E., 1966, Hydrology of Cornfield Wash area and effects of land-treatment practices, Sandoval County New Mexico, 1951-60: U.S. Geological Survey Water-Supply Paper 1831, 87pp.

Edwards, T.K., and Glysson, G.D., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86-531, 118 p.

Elliott, J.G., 1979, Evolution of large arroyos--The Rio Puerco of New Mexico: Unpublished Master's Thesis, Colorado State university, Fort Collins.

Elliott, J.G., Gellis, A.C., and Aby, S.B., 1998, Evolution of Arroyos--Incised Channels of the Southwestern United States: In Thorne, C., ed., Incised Channels, IN PRESS.

Gellis, A.C., Hereford, R., Schumm, S.A., and Hayes, B.R., 1991, Channel evolution and hydrologic variations in the Colorado River basin--Factors influencing sediment and salt loads: Journal of Hydrology, v. 124, p. 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 No. 265, Proceedings of the 36th Annual New Mexico Water Conference, Las Cruces, N.Mex., p. 77-93.

Gellis, A.C., Cheama, A., Laahty, V., and Lalio, S., 1995, Assessment of gully-control structures in the Rio Nutria watershed, Zuni Reservation, New Mexico: Water Resources Bulletin, v. 31, no. 4, p. 633-646.

Happ, S.C., 1948, Sedimentation in the Rio Grande valley, New Mexico: U.S. Department of Agriculture, Soil Conservation Service Report.

Heath, D.L., 1983, Flood and recharge relationships of the lower Rio Puerco, New Mexico: New Mexico Geological Society Guidebook, 34th Field Conference, Socorro Region II, p. 329-337.

Kondolf, G.M., Matthews W.V. G., 1991, Unmeasured Residuals in Sediment Budgets-- A Cautionary Note:Water Resources Research, v. 27, no. 9, p. 2483-2486.

Love, D.W., 1997, Implications for models of arroyo entrenchment and distribution of archaeological sites in the middle Rio Puerco: In Duran, M.S. and Kirkpatrick, D.T., eds., Layers of Time, the Archaeological Society of New Mexico, v. 23, p. 69-84.

Marcus, W.A., Nielson, C.C., and Cornwell, J.C., 1993, Sediment budget-based estimates of trace metal inputs to a Chesapeake estuary: Environmental Geology, v. 22, p. 1-9.

Milliman, J.D. and Meade, R.H. 1983 World-Wide Delivery of River Sediment to the Oceans Journal of Geology, v. 91, no. 1, p. 1-21

Nordin, C.F., and Curtis, W.F., 1962, Formation and deposition of clay balls, Rio Puerco, New Mexico: U.S. Geological Survey Professional Paper 450-B, art. 28, p. 37-40.

Nordin, C.F., 1963, A preliminary study of sediment transport parameters Rio Puerco near Bernardo, New Mexico: U.S. Geological Survey Professional Paper 462-C, p. C1-C21.

Porterfield, G., 1972, Computation of fluvial-sediment discharge: Geological Survey Techniques of Water-Resources Investigations of the United States Geological Survey: Book 3, Chapter C3, 66 pp.

Roberts, R.G., Church, M., 1986, The sediment budget in severely disturbed watersheds, Queen Charlotte Ranges, British Columbia: Canadian Journal Of Forestry Research, v. 16, p. 1092-1106.

Simons, D.B., Li, R., Li, L., and Ballantine, M.J., 1981, Erosion and sedimentation analysis of the Rio Puerco and Rio Salado Watersheds: Simons Li and Associates, Report submitted to the U.S. Army Corps of Engineers, Albuquerque District, 66 p.

Soil Conservation Service, 1977, The small watershed program in New Mexico, 18 p> Sutherland. R.A. and Bryan, R.B., 1991, Sediment budgeting—A case study in the Katiorin drainage basin, Kenya: Earth Surface Processes and Landforms, v. 16, p. 383-398.

Trimble, S.W., 1983, A sediment budget for Coon Creek Basin in the Driftless Area, Wisconsin,1853-1977: American Journal of Science, v. 283, p. 454-474.

Table 1. Summary of sediment and runoff characteristics for USGS gaging stations in the Rio Puerco Basin.

Station	**Period of Record***	**Drainage Area (mi^2)**	**Average Annual Suspended-Sediment Load (tons)**	**Average Annual Runoff (acre-feet)**
Rio Puerco above Arroyo Chico near Guadalupe (formerly referred to as Rio Puerco below Cabezon)	1949-55; 1982-96	420	860,500	10,500
Arroyo Chico near Guadalupe	1949-55; 1979-86	1390	1,931,600	17,300
Rio San Jose near Correo	1949-55	2,670	533,400	10,100
Rio Puerco at Rio Puerco	1949-55	5,160	6,924,000	39,800
Rio Puerco near Bernardo	1949-55	6,220	4,439,300	28,590

* Based on a water year, from October 1 of the previous year to September 30 of the current year.

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/erosion/streamflow.html
Maintained by Richard Pelltier
Last modified: 10:15:54 on 22-Mar-2000

RIO PUERCO Online

Channelization Effects on the Rio Puerco Above La Ventana, New Mexico

Michael Coleman, New Mexico Environment Department
Allen Gellis, U.S. Geological Survey
Dave Love, New Mexico Bureau of Mines
Richard Hadley, U.S. Geological Survey (Retired)

Abstract

In the mid-1960's the New Mexico State Highway Department established a new route for NM Highway 44 in the valley of the Rio Puerco adjacent to the incised river channel between La Ventana and Cuba, New Mexico. The new route avoided a number of hills and created a flatter, wider and safer highway along the valley floor. The new highway alignment crossed sinuous meanders of the Rio Puerco twice and skirted the outer margin of a third meander loop. Rerouting the main channel and eliminating the naturally sinuous meanders by channelizing a straight reach was seen as the best way to avoid considerable additional construction costs of at least two bridges.

A 1.1-mile reach of the Rio Puerco upstream from La Ventana was channelized between 1965 and 1966. The channelization nearly doubled the channel slope from 0.004 to 0.0074 feet/feet and decreased the incised width and sinuosity. During the next 30 years the channel responded to channelization by eroding both vertically and laterally, decreasing the gradient through exposed alluvium and along bedrock shelves, widening the channel, and increasing the sinuosity. The lower channelized reach is incised more than 50 ft deep in alluvium and widened from 20 to more than 300 ft. As much as 130 ft of lateral erosion has taken place since 1973. Power lines have had to be relocated twice and the largest meander now threatens the highway alignment. The upper channelized reach is incised 25-35 ft into sandstone and shale bedrock, but has only widened where alluvium rather than bedrock forms the walls. A waterfall and set of smaller cascades over sandstone ledges form headcuts within the bedrock reach. Based on a series of aerial photographs taken between 1973 and 1994, the headcut waterfall is advancing northward at an estimated rate of 4 ft/yr. Approximately 14.1 million cubic feet of sediment were eroded during the past 30 years or about 470,000 ft3/yr. This quantity is approximately 20 percent of the river's annual suspended sediment load near its mouth.

Following initial channelization, the Rio Puerco proceeded through stages of channel adjustment as it tried to establish a new equilibrium. The river widened and increased sinuosity, which caused bank failure and mass wasting as the channel expanded against its vertical walls. At the lower end of the bedrock reach, the channel was deflected to the east by a bedrock knob, causing an initial meander cutting into alluvium. Downstream, bank failure enhanced meander development with progressive meander wavelengths decreasing to a straight channel prior to reentering the natural channel. Meanders now have developed point bars and have begun to store sediment as well as continue to

erode the outer banks to continue furnishing sediment for transport and storage.

Based on evolution of the channel during the past 30 years, the channel will continue to migrate laterally and pose a threat to the road and to other human-made structures.

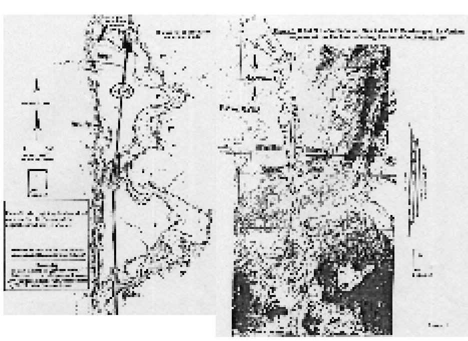
Introduction

The Rio Puerco of the East in central New Mexico is one of the most sediment-laden streams on earth. Suspended sediment concentrations of more than 600,000 parts per million (60 percent) have been recorded at the river's lower end and pose a threat to agriculture and to reservoir storage downstream (Gorbach and others, 1996). The stream drains more than 7,295 square miles east of the Continental Divide to the Rio Grande from the Zuni-Acoma sub-section of the Colorado Plateau and the Nacimiento Mountains of the Southern Rocky Mountains. The stream is ephemeral over much of its length, flowing only in response to precipitation. It also loses water along its path, flowing 53 percent of the year near Guadalupe, midway along its course, but only 20 percent of the year near its mouth. The main channel and many of its tributaries are deeply incised in the landscape, being eroded from 20 to 60 feet below the level of the former valley floors.

In the 1960's an uncontrolled engineering experiment began along an incised, meandering reach of the Rio Puerco near La Ventana, New Mexico. As a result of highway construction, a 1.1-mile reach of the river was channelized into a nearly straight, incised artificial course that has continued to erode and cause problems during the next 30 years. The purpose of this article is to describe the evolution of this artificial reach and some of the consequences to the stream and to human-made structures.

Methods

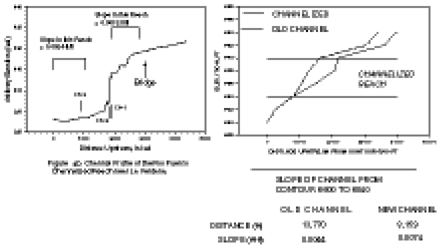
Many of the changes documented for the artificial reach of the Rio Puerco near La Ventana are taken from topographic maps and aerial photographs produced by the U. S. Geological Survey, U. S. Bureau of Land Management, U. S. Forest Service, and New Mexico State Highway Department (NMSHD). Copies of the aerial photographs were obtained from the Earth Data Analysis Center at the University of New Mexico, from the New Mexico Bureau of Mines and Mineral Resources, and from the NMSHD. Engineering plans for the channelized segment were examined at the NMSHD. Photo sets pre- and post-dating the straight channel (1935, 1954, 1973, 1975, 1986, 1989, and 1994) were examined to document the sequence of impacts on the river. Co-author Richard Hadley had the foresight to take ground-based photographs of the artificial reach in 1967, 1968, and 1969. Later, he and co-author Dave Love photographed the reach in 1986. Allen Gellis and Scott Aby surveyed the affected reaches (both new and old) using a Total Station during the late fall of 1997.



Channelization History

The main access road between La Ventana and Cuba formerly traversed a series of drainage valleys to the east-northeast of the present alignment. Prior to the new highway construction and channelization activity above La Ventana, the Rio Puerco occupied a sinuous, lower gradient river channel in a relatively confined (topographically) river valley segment.

As shown in figures 1, 2 and 3, a straight, mostly north to south diversion channel segment ("ditch") was dug to bypass the natural meandering channel between 1965 and 1966. Copies of the original engineering plans, provided for our examination, show the original artificial channel was designed to



incorporate a 10 foot to 20 foot bottom to the channel, defined by sloped banks having a 60 foot slope length. It is apparent that the original channel cut was not completed as designed, perhaps because it cut into resistant bedrock lithologies and a smaller, shallower channel was deemed adequate. To the north the natural channel dimensions are over 150' wide. The channel was forced to enter a 60-foot wide artificial channel mouth, which funneled down to the 20 foot wide channel after only 100 feet. A large earth-fill dam structure isolated the flow and diverted all the Rio Puerco flow into the new north-south "ditch". Within the old meander zone another earth fill berm cut off a recumbent meander loop to provide road base for the new highway. A bulldozer cut into bedrock was designed to keep any remnant stream flow away from the east side of the road embankment. At the southern end of the meander set a third earthen dam was constructed over a box culvert to enable a minor amount of local drainage to continue to access the Rio Puerco. The 5,500 foot long straight channelized segment was reintroduced to the original Rio Puerco channel at the south end of the blocked-off meandering segment.

Geomorphic Response

Geomorphic changes in the Rio Puerco channelized reach through time and space were quantified from examination of the aerial photographs and interpretations from 1997 surveys of the channelized portion.

Change in Slope

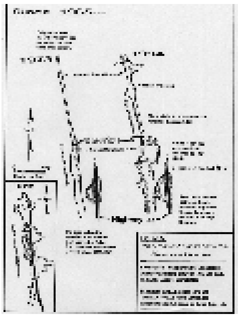
Cutting of the new straight channel and forced abandonment of the meander zone significantly steepened the local stream gradient by shortening the river's local channel length, from 13,770 feet to 8,159 feet (a difference of 5,611 feet), within the area where elevation decreases from 6600 feet a.s.l. to 6540 feet (figs. 1, 4a). The slope of the original Rio Puerco channel (as measured off existing topographic map coverage) was 0.004 vertical feet per longitudinal foot (60 feet elevation drop over a distance of 13,770 feet). The slope of the constructed channel nearly doubled to 0.0074 feet/foot (60 feet /8159 feet). Surveys of the channel in November, 1997 indicate the present slope of the upper portion of the channelized segment exceeds 0.008 ft/ft (figure 4b).

Channel width, depth and slope tends to approach an equilibrium state to transport the available discharge and sediment load. The concept can be expressed as an equation (Bull, 1991):

Stream Power (driving factors) / Resisting Power (resisting factors) = 1.0

Where driving factors are stream discharge and channel slope and resisting factors are sediment size, hydraulic roughness, and bed load. A change in any of these variables will cause an adjustment in the channel. In the case of the Rio Puerco the approximate doubling of the channel slope increased the driving factors and led to significantly accelerated stream bed incision into unconsolidated, highly erosive, river valley fill, and downward into easily eroded Cretaceous Mesa Verde Group bedrock. Mass removal of fill and bedrock is actively underway, as evidenced by headcutting, downcutting and widening of the original "ditch" into a deep and wide vertical walled canyon. All of this eroded sediment is transported downstream and exacerbates sediment loading impacts on downstream reaches, perhaps as far as the lower river where the Rio Puerco system empties into the Rio Grande.

Headcut Movement



The evolution of the channelized segment of the Rio Puerco has been documented from aerial photographs and provides a model for predicting future channel changes. The immediate response of the channel to straight channelization and increased slope was downcutting. The initial incision of the artificial channel reached layers of interbedded resistant and erodible bedrock of the Cretaceous Mesa Verde Group sediments (a sandstone of the La Ventana Tongue of the Cliff House Sandstone) and a series of small stair steps and waterfalls have been produced (figures 2, 3e, and 5). One especially impressive sandstone ledge exposed within the channelized segment has developed into a 15 foot high waterfall. Field surveys indicate that the channel has incised to a depth of 30-35 feet above this ledge, expanding to over 50 feet deep in reaches below the sandstone waterfall.

The waterfall marks the present position of the most active headcut feature in the channelized segment. Studies of air photos taken 1973-1994 provide an estimation of the rate of erosion, indicating a 70 foot+ march upstream over 21 years and a widening of the channel below the headcut (figure 5). The rate of upstream headcut advancement, measured by the position of the bedrock waterfall, is just slightly less than 4 feet per year. Below the falls the lateral erosion of the vertical channel walls is observed at approximately 12.4 feet per year (260 feet/21 years), indicated by the widening of the 30-35 foot wide channel (above the falls) to a current width of >300 feet downstream, during the period 1973-1994. It is quite plausible to predict that the falls will continue to migrate upstream, exposing underlying nonresistant shale to erosion, deepening and widening the channel, promoting downstream widening. Incision of the bed of the Rio Puerco will create a lower base level for the tributary streams.

Sinuosity

Natural river channels exhibit a tendency to develop meander forms which are proportional to the regional slope, the channel size, the range of flow stages which the channel is capable of containing, and the size of sediment materials in the bed and banks. The original Rio Puerco meanders are part of a characteristically sinuous pattern with appropriate belt width development (fig.2), which exists over the vast majority of the watershed. The straight segment is anomalous and artificial, thereby throwing unnatural effects into the process.

Following artificial entrenchment, a narrow deep channel was formed that began to meander and widen by mass wasting and in-channel flow removal of sediments (fig. 3c). The southern two-thirds of the channelized reach has widened from the original 10-20 feet to the present 40 to >300 feet. The meander length of the natural channel is considerably greater than the present reach and is a solid indication that this stream reach will continue to widen as it approaches a new equilibrium (fig. 2).

Based on changes observed in the channelized reach, the river evolves first by incision followed by channel widening, especially in the valley fill portion. These changes will follow the advancement of the headcut waterfall as it advances upstream. Similar changes in channelized streams have been observed elsewhere (Schumm and others, 1984; Simon, 1989).

Estimation of Sediment Removal: MassWasting Rate

Examination of the original Highway Department / Burnett Engineering plans for this highway and river segment indicates the designed channel change was to be a diversion ditch with a 20 feet bottom width, supporting slopes occupying a 60 foot slope width. This would have resulted in a channel cut 53 feet deep, 72 feet wide with the 20 foot bottom zone designed to transmit the flow. It is apparent that hard bedrock ground conditions prevented the construction crews from achieving the original design. The channelized reach was vertical-walled, approximately 20 feet deep and perhaps originally designed at 20 feet wide. The channel just above the waterfall has expanded to a current depth of 30-35 feet and a width of 42 feet. This is the relatively inactive upper segment of the channelized reach (afforded some protection by the bedrock waterfall), but it has deepened 10-15 feet (50-75% increase) and widened approximately 20 feet (100%). The channel dimensions below the major headcut presently range to over 300 feet wide (a lateral increase of >260 feet of bank materials has been removed, resulting in a 1,500% increase in width) and the floor depth has dropped another 15 feet below the falls. Based on these assumptions, the volume of materials eroded (to date) from this channelized reach, and the amount of projected erosion can be conservatively estimated (upper/lower segment division drawn at the waterfall: average measurements used):

(Past:) 1). Current void volume:
(upper segment:) **40'w X 32'd X 1800' lg = 2.304M ft^3** *plus:*
(lower segment:) **150'w X 40'd X 3400' lg = 20.4M ft^3**

Subtotal 22.704M ft^3 *minus:*

2). "original" channelized volume (data from NMSHTD plans): **8.6M ft^3** (319,426 yd^3)

***Resulting estimate of erosion:* ~14.1 million cubic feet of sediment were removed over the past 30 years = >470,000 ft^3/yr** (X 90lb/ft3 /2000lb/ton =21,150T/yr).

(Future:) Bank and streambed removal can be estimated in a similar manner. Consider an upstream advancement of similar channel dimensions as the ones developed since 1973: one mile in length, 15 feet in additional depth, 260 feet wider channel; multiplied by an estimated average density of 90 lb/ft^3 (for the combined alluvial and bedrock materials):

(Projected:) 1). **15' X 260' X 5280' X 90 lb/ft^3 / 2000lb/ton = 926,640 T.**

Converted to cubic yardage: 2). **15' X 260' X 5280' = 20,592,000 ft^3 / 27 ft^3/yd^3 = 762,666 yd^3**

Using these calculations, as the headcut advances and the upstream channel portion comes to resemble the widened and deepened portion below the falls, this river reach is capable of removing over *920,000 tons of sediment per mile of channel*, as the channelized segment advances northward. This estimation represents over 20% of the 4.44 million tons average suspended sediment load the Rio Puerco delivers to the Rio Grande on an annual basis, based on data collection records from 1948 through 1996 (Gellis).

Summary

Channelization in a segment of the Rio Puerco near La Ventana in 1965-67 led to geomorphic changes in the river. Channel slope before the channelization was 0.004 feet/ft. In 1997 upper portions of the channelized reach exceeded 0.008 feet/ft. The increase in slope led to dramatic vertical and lateral changes in the river. The channel has incised to depths over 50 feet. A 15 foot high knickpoint developed in bedrock of the Mesa Verde group. The rate of knickpoint migration measured with air photos indicates movement of 4 feet per year. Below the knickpoint the lateral erosion of he channel wall is 12.4 feet per year to a current width over 300 feet.

Based on changes in width and depth of the Rio Puerco channel it is estimated that over 21,150 tons per year have been removed. As the knickpoint migrates upstream it is estimated that over 920,000 tons of sediment are produced per mile of channel. This represents 20 percent of the 4.44 million tons of suspended sediment transported annually by the Rio Puerco to the Rio Grande.

References

Bull, W.B., 1991,Geomorphic responses to climatic change: Oxford University Press, 326 pp.

Gorbach, C., Love, D., Piper, S., Davis, R., and Cross, A., 1996, Rio Puerco sedimentation and water quality study: Preliminary Findings Report: U. S. Bureau of Reclamation, Albuquerque Area Office, 101 p.

Schumm, S.A., Harvey, M.D., Watson, C.C., 1984: Incised channels: Littleton Press, Littleton, CO, 200pp.

Simon, A., 1989: A model of channel response in disturbed alluvial channels; in Earth Surface Processes 14: p11-26.

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/papers/channel.html
Maintained by Richard Pelltier
Last modified: 10:23:22 on 22-Mar-2000

Paleo Climate

from Grissino-Mayer, 1995

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/archeo/paleocli.html
Maintained by Richard Pelltier
Last modified: 12:25:08 on 24-Jul-2000

http://climchange.cr.usgs.gov/rio_puerco/archeo/numsites.html

Number of Archeological Site Locations

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/archeo/numsites.html
Maintained by Richard Pelltier
Last modified: 12:25:07 on 24-Jul-2000

http://climchange.cr.usgs.gov/rio_puerco/archeo/nmstww2.html

NM Statehood to WWII Site Locations
88-55 BP (1912-1945 AD)

Essentially modern--leading up to Rt. 66
Settlement clusters in the Upper Rio San Jose and Upper Rio Puerco

U.S. Department of the Interior
U.S. Geological Survey
This page is http://climchange.cr.usgs.gov/rio_puerco/archeo/nmstww2.html
Maintained by Richard Pelltier
Last modified: 12:25:07 on 24-Jul-2000

http://climchange.cr.usgs.gov/rio_puerco/pics/strmnet.gif

http://geology.uvm.edu/geowww/morphwww/cosmo/riopuerco/puerco.html

http://geochange.er.usgs.gov/sw/impacts/geology/arroyos/