TECHNICAL SERVICE CENTER
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UPPER GILA RIVER FLUVIAL GEOMORPHOLOGY STUDY

BACKGROUND INFORMATION AND SUMMARY

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Upper Gila River Fluvial Geomorphology Study Background Information and Summary

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BACKGROUND INFORMATION AND SUMMARY

SUMMARY

This document reviews existing studies that contain information that may be useful in the present study of the upper Gila River. The references include, but are not limited to, hydrologic and geologic data, accounts of floods and precipitation events, studies of channel change and erosion, sedimentation in San Carlos Reservoir, water resources documents, scour studies of bridges on the Gila River, links between flood records and climate, floods and vegetation, land use planning, water quality, and ground water. The document is in two parts: (1) an annotated bibliography that summarizes references that may be pertinent to the present study, and (2) a bibliography of related references that include water quality data, hydrogeologic data, fisheries studies, vegetation studies, soils data, and other miscellaneous information that is helpful for background information. This document is subject to amendment as other references become available during the course of the study.

ANNOTATED BIBLIOGRAPHPY

Aldridge, B.N., 1970, Floods of November 1965 to January 1966 in the Gila River Basin, Arizona and New Mexico, and Adjacent Basins in Arizona: U.S. Geological Survey Water-Supply Paper 1850-C, p. C1-C176.

Describes the meteorological conditions during 1965 and 1966 and the precipitation and runoff which resulted from those conditions. The upper Gila River was affected by the storm of December 22-23, 1965 and December 29-30, 1965. Prior to the storm of December 22-23, 1965, snow accumulated for 10 days. On December 22, precipitation in the form of snow at higher elevations added to the snowpack while snow changed to rain at lower elevations as warm winds from the south increased the air temperature and accelerated snowmelt. Peak discharges were not as large as floods near turn of century; two peaks in the upstream reaches coalesced into one peak by the time the floodwaters reached the gage at Calva.

Snow continued to melt following this storm. Precipitation on December 29 increasing in intensity on December 30 along with warm temperatures accelerated the rate of snowmelt below 7,000 feet. Eagle Creek recorded its highest discharge since at least 1916, while flood peaks were lower on the mainstem Gila River relative to previously recorded peak values. In Arizona, damage occurred mainly to farms, roads and irrigation systems, with the exception of Little Hollywood, which was flooded. Clifton also had some flooding in the northern part of town. Areas with dense saltcedar growth on the margins of farm fields near the Gila River channel confined flow to a low conveyance channel, which could not contain the floodwaters.

Aldridge, B.N., and Eychaner, J.H., 1984, Floods of October 1977 in Southern Arizona and March 1978 in Central Arizona: U.S. Geological Survey Water Supply Paper 2223, 143 pp.

Major floods occurred during 1978 in the Verde River Basin, Salt River Basin, Agua Fria River Basin, Santa Cruz River Basin, and San Pedro River Basin. The Gila River did not experience flooding in its upper reaches, and was only impacted by these events downstream of the San Pedro River and the Salt River.

Aldridge, B.N., and Hales, T.A., 1983, Floods of November 1978 to March 1979 in Arizona and West-Central New Mexico: U.S. Geological Survey Open-File Report 83-201.

Same as USGS Water Supply Paper 2241. See Aldridge and Hales (1984).

Aldridge, B.N., and Hales, T.A., 1984, Floods of November 1978 to March 1979 in Arizona and West-Central New Mexico: U.S. Geological Survey Water-Supply Paper 2241, 149 pp.

This report describes the major floods in Arizona in November 1978 and March 1979 on the Gila River upstream from Coolidge Dam. Floods occurred on November 24-25, 1978 and on December 18-20, 1978. The November 24-25 flood had a calculated recurrence interval of 10-25 years upstream of Coolidge Dam, and was a larger magnitude event in both the headwaters of the Gila and San Francisco Rivers.

The December 18-20, 1978 flood on the Gila River upstream of the San Francisco River had its source area in the wilderness area in New Mexico and in mountainous areas between Wilderness and Cliff, New Mexico. The calculated recurrence interval for this flood was greater than 100 years. Near Gila Hot Springs, the flood crested after 2300 hrs on December 19th, inundating the bathhouse (2 ft deep). No other recorded flood had inundated the bathhouse; the closest being the 1941 flood whose high water line was lower than the bathhouse floor. West Fork and Middle Fork Gila Rivers generated extreme runoff and experienced erosion along their banks. S.R. Anderson, USGS, estimated peak flows to be 15-20,000 cfs in West Fork and 8-10,000 cfs from Middle Fork. The East Fork Gila River only had moderate runoff. Tributaries which contributed to the flood on the mainstem Gila River include: Mogollon, Duck, Mangas, and Bear Creeks between Gila and Redrock, New Mexico. Between Redrock and the confluence with the San Francisco River, no significant flow from tributaries was identified. Eagle Creek had its highest discharge since the installation of the gage in 1944, and possibly the largest since 1916. Bonita Creek had evidence for flooding, but no discharge estimate was made.

The San Francisco River had a peak stage lower than October 1972 at Clifton by about 1 foot. Other than a few tenths of a foot of scour in the channel bottom, no channel changes occurred in the San Francisco River in this reach. The peak discharge estimate was the seventh highest since 1870.

DATA:

Table 2. Precipitation and departures above normal at climatological stations in Arizona, November 1978 to March 1979

Table 3. Precipitation at climatological stations in central Arizona reporting at least 3 inches, December 17-20, 1978

Table 4. Time and discharge of selected flood peaks—Gila River near Gila, New Mexico, to Gila River near Calva, Arizona, 1941-79

Table 5. Time and discharge of selected flood peaks—San Francisco River near Alma, New Mexico, to Gila River near Calva, Arizona, 1941-79

Figure 5. Discharge of the Gila River at gaging stations upstream from the San Francisco River in Arizona and New Mexico, December 18-21, 1978

Figure 6. Discharge of the San Francisco River at Clifton and the Gila River at gaging stations between the San Francisco River and San Carlos Reservoir, December 18-22, 1978

Figure 7. Relation between peak discharge at the Gila River near Redrock, New Mexico, and travel time to Duncan, Arizona

Anderson, L., 1990, Seismotectonic Study for Coolidge Dam: U.S. Bureau of Reclamation Seismotectonic Report 90-9, Seismotectonics and Geophysics Group.

Summarizes geology, seismicity, and earthquake hazards for Gila-Safford Basin.

Arizona Daily Star, December 23, 1965, "Ariz. Sites Menaced By Floods", Phoenix, Arizona.

Describes the flooding which occurred from the heavy rain of December 21 and the threat for further flooding from upstream flood peaks. Mentions closed highways and roads, heavy snow warnings for the Mogollon Rim country, flooding on the Gila River, San Francisco River, and San Carlos River, forcing 10 families to flee their homes.

Arizona Department of Health Services, Division of Environmental Health Services, Bureau of Water Quality Control, 1976, Water Quality Standards Study and Recommendations for the Upper Gila and San Pedro River Basins – A Report Prepared for the Arizona Water Quality Control Council: URS Company, Denver, Colorado, variously paginated.

This report in part identifies areas of high sediment yield in the upper Gila River Basin. Sedimentation is a problem because it reduces sunlight penetration into bodies of water, which hinders sight-feeding fish and decreases recreational use. Sedimentation also reduces fish habitat and fish food habitat and increases water treatment costs for agricultural, industrial and municipal use.

Sediment yield classes are divided into three estimated sedimentation rates in the watershed: 0.5-1.0, 0.2-0.5, and < 0.2 acre-feet per sq. mile per year. Areas with high sedimentation rates in the upper Gila River basin include the Safford-San Simon area and the San Pedro River area.

The report also includes other general information, such as geology, climate, and water chemistry.

DATA:
Table VIII-5. Existing Flood Control Storage (1965)
Figure VIII-3. Sediment Yield, Upper Gila and San Pedro River Basins, Arizona 1974

Arizona Department of Water Resources, 1994, Arizona Water Resources Assessment, Hydrologic Summary Vol. II.

Discusses general water resource information for the upper Gila River watershed. The upper Gila River watershed comprises 12,890 square miles, which is 1/5 of the entire Gila River watershed. Primary ground water basins include Morenci, Duncan Valley, Bonita Creek, and the Safford Valley. A 35-mile stretch of the river with perennial flow starts approximately 20 miles downstream from Arizona-New Mexico border.

DATA:
Table 26. Perennial stream reaches in the Upper Gila River Watershed
Table 27. Annual flows for Selected USGS Streamgaging Stations in the upper Gila River Watershed

Arizona Republic, December 23, 1965, "Flood Threat Along Gila: Graham, Greenlee Warned": Phoenix, Arizona.

The article describes the flooding upstream in the Gila River basin that may affect Safford later in the evening of December 23rd. At the time of the article, the Gila River at Cliff, N.M. was 2 feet over flood stage and the San Francisco River through Clifton was near flood stage. Floodwaters resulted from rain on snow, in which an inch or more rain fell on melting snow. The sewage disposal plant at Safford is in a position vulnerable to large floods. Water works and the sewage plant had already been damaged by floodwaters at an estimated cost of $25,000.

Arizona Republic, December 24, 1965, “Poetic Hope in Safford: ‘Flow Not, Gentle Gila’”, Phoenix, Arizona.

The article recounts some of the plights of people living along the Gila River during the flood of December 24, 1965. Discusses flooding in Hollywood, where Graham County tried to keep flood waters out by constructing earthen dikes.

“Old timers in the area began to see in the swollen waterway a repetition of a long-ago flood that left scores homeless.”

Arizona Republic, December 25, 1965, “50 Families Isolated by Floodwaters”, Phoenix, Arizona, p.1.

The article describes how 50 families in Kelvin and Riverside Terrace were isolated by Gila River flooding on December 24, 1965. During the night of December 23, the river stage rose 10 to 12 feet, flooding roads and bridges.

“Bittick, who has six small children, watched as water destroyed all the children’s Christmas gifts which were packed away in his parked car.” “Residents in the area said the river reached heights not seen since 1926”.

Arizona Republic, December 29, 1965, “New Dams Prevent Damage”, Phoenix, Arizona.

Article states that the dam built on Stockton Wash prevented more that $125,000 in damage in Safford, AZ. Frye Creek Dam built upstream of Thatcher, AZ was credited with preventing $200,000 worth in damages during a flood in September 1962.

Arizona Republic, January 6, 1966, “Graham County Eyes Flood Damage”, Phoenix, Arizona.

At the time the article was written Solomonville crossing was still flooded and the author was not sure if the bridge had been washed out. The road north of Pima Bridge closed Saturday and Sunday with normal traffic resuming by Monday. Flood waters also cut more land out of Graham County farms already eaten away by floods and resulting soil erosion. The Irwin Golding farm land, directly north of the Gila River, was described as being ‘practically another river bed,’ by the Civil Defense director. The flood also deposited debris and silt in the channel in Safford vicinity and caused a “trash jam” in the channel.

Harold Gietz, Graham County Civil Defense director, stated, “One good thing the last rise did was cut a deep, wide channel in the Gila River and this produced twice the amount of flow”.

Arizona Republic, January 25, 1972, “Delegations Discuss Help for Graham Flood Victims”, Phoenix, Arizona, pp. 23,24.

The article discusses actions taken by Graham county to aid flood victims in the community of Little Hollywood, which was devastated by the flood of October, 1972.

Arizona Republic, September 3, 1972, “Rain-swollen Gila River poses flood threat to Safford Valley”.

The article states that the flood stage upstream in New Mexico may pose a threat to Safford area; at the time of the article, the Gila River was running high at Duncan, but was still within its banks.

Arizona State Land Department, 1997, Arizona Stream Navigability Study for the Upper Gila River and San Francisco River, Final Report: SFC Engineering Company in association with George V. Sabol Consulting Engineers, Inc., JE Fuller/Hydrology & Geomorphology, Inc., and SWCA, Inc. Environmental Consultants, variously paginated.

Comprehensive report which provides an overview of the archaeology, historical information, geomorphology and hydrology of the upper Gila River basin. The report also provides a history of boating and GIS for the upper Gila River titled: “Navigable Rivers Land Use GIS. The Geomorphology and Hydrology sections are described in detail under their respective contributing authors.

Arizona Water Commission, 1975, Phase 1, Arizona State Water Plan, Inventory of Resources and Uses.

Overview of the water budget for Arizona; includes a section on the study area. The report provides information on inflow and outflow for the study area, maximum, minimum and median flows for 1914-1973, annual flow values (in acre-feet) for Safford Valley near Solomon, AZ, location, aerial extent, and estimated annual water use by phreatophytes and hydrophytes as of 1967, Average annual unit runoff, and averages and extremes in sediment loads and TDS concentrations.

Arizona Water Quality Control Council, 1967, Water Quality Control Policy- Gila River System in Arizona.

Provides background information for the Gila River System for making policy decisions on water quality. Some of the background information includes a flow chart of inflow and outflow volumes/yr (based on 1965 water year), location and identification of stream gages, a general description of major tributaries, a brief history of the Gila River basin, and major diversions from the Gila River system.

DATA:
Exhibit 1. Total volume at gaging stations for Water Years 1961-1965 for stream gages and diversions.

Boucher, Paul F., and Ronald D. Moody, 1998, The Historical Role of Fire and Ecosystem Management of Fires: Gila National Forest, New Mexico, *in* Pruden, T.L., and Brennnan, L.A. (eds). Fire in Ecosystem Management: Shifting the Paradigm from Suppression to Prescription. Tall Timbers Fire Ecology Conference Proceedings, No. 20: Tall Timbers Research Station, Tallahassee, FL, p. 374-379.

Documents the role that fire plays in the ecosystem in the Gila National Forest. The author describes changes brought about by fire suppression beginning in 1975. Species such as oak, mesquite, and pinyon pine, replaced grasses; loss of grasses caused a loss of topsoil in the forest. Grazing also reduced understory. This loss of fuels reduced spreading of fires in the forest. The author hypothesizes that a coupling of grazing and fire suppression facilitated a change in fire regime from understory burning to stand replacement fires. Stand replacement fires are more intense and devastating to the existing stand of trees. As the era of grazing has waned, fuels have begun to increase, and fires continue to grow in size

and intensity. To return the forest to its natural fire regime, Boucher and Moody recommend prescribed natural burns with careful monitoring to ensure that fires do not become unmanageable.

Brown, C.B., 1945, Rates of Sediment Production in Southwestern United States: U.S. Soil Conservation Service, Washington, D.C.

Provides estimates for long-term silting rate of San Carlos Reservoir (5,000 to 10,800 acre-feet/year), which are based on annual runoff volumes and sediment concentration. Includes records for San Carlos, Arizona, San Carlos Reservoir, Silt Barrier, and Duncan, Arizona.

DATA:
Table 1. Sediment records in the southwestern United States
Table 4. Estimated sediment production in the Upper Gila River Watershed

Burkham, D.E., 1970, Precipitation, Streamflow, and Major Floods at Selected Sites in the Gila River above Coolidge Dam, Arizona - Gila River Phreatophyte Project: U.S. Geological Survey Professional Paper 655-B, 33 pp.

Studied hydrologic records for the period 1875-1962, and discovered the following trends: (1) a fluctuating decline in annual precipitation through the 20th century, occurring mainly during the winter months; (2) a nearly continual decline in annual runoff since 1920; and (3) a decrease in number of large floods following 1916. The report includes some pictures of the San Francisco River and Gila River floodplains and floods from the early 1900's and 1965.

Describes the following major historic floods in the basin:

Febuary 22, 1891
September 27-Oct. 4, 1895
October 9-16, 1896
January 10-11, 1905
November 28, 1905
December 3, 1906
December 20, 1914
January 30, 1915
January 18-20; 29, 1916
October 14-15, 1916
September 29-October 1, 1941
December 21-24, 1965
December 30-31, 1965

DATA:
Table 1. Precipitation data for six U.S. Weather Bureau stations in or near the Gila River basin above Coolidge Dam
Table 2. Winter Precipitation and runoff, in inches, during water years 1921-30 and 1951-60
Table 3. Mean summer stream flow at gaging stations in or near the Gila River basin, 1938-61
Table 4. Estimated surface-water loss from the Gila River in the Safford Valley
Figure 1. Map showing location of precipitation gages and stream-gaging stations
Figure 2. Graphs showing progressive 10-year average of seasonal precipitation
Figure 3. Typical hydrograph of winter flow
Figure 4. Typical hydrograph of summer flow
Figure 5. Duration curves of summer flow
Figure 6. Duration curves of winter flow
Figure 7. Progressive 10-year average annual flow
Figure 8. Relation of winter runoff and average winter precipitation
Figure 12. Progressive 10-year average reduction in annual streamflow
Figure 13. Relation of annual streamflow at head of Safford Valley and that at San Carlos
Figure 15. Relation of summer streamflow to size of basin
Figure 16. Annual floods of record in the Gila River basin
Figure 22. Hydrographs showing floodflows

Figure 23. Graph showing peak-discharge frequency curves

Burkham, D.E., 1972. Channel changes of the Gila River in Safford Valley, Arizona, 1846-1970: U.S. Geological Survey Professional Paper 655-G, 24 pp.

Documents channel changes occurring in Safford Valley from 1846 to 1970 using surveyor's maps for the early periods and aerial photos. A stable, narrow, meandering channel existed with an average width of less than 150 ft in 1875 and expanded to less than 300 ft in 1903. From 1905-17, large floods caused erosion of the floodplain, with most of the widening occurring during 1905-6 and 1915-16. The average width increased to 2,000 ft. From 1918-70, the floodplain underwent rebuilding such that the average width of the channel decreased to less than 200 feet (by 1964). This was accompanied by an increase in sinuosity. Salt cedar became dominant during 1920-30 and reached its maximum extent during 1945-55. In 1965 and 1967, floods caused minor widening of channel. In 1968, the average width measured 400 feet. Burkham concludes that major widening events are coincident with major floods in 1891, 1905-17, and 1965-67, and that grazing was not a big impact in sediment production, as the majority of livestock were below major flood producing source areas; however, grazing may have accelerated erosion of floodplain in the lowlands.

Burkham also documents changes in channel patterns caused by alluvial fan deposition. He discusses in detail a tributary near Calva (Plate 4), Salt Creek at Bylas, and the Gila River near Ft. Thomas. Generally, the erosion of fan toes during floods of early 1900's caused an increase in fan gradient, and new deposition of fan sediment into the main channel. This directed the main channel toward the opposite bank and caused erosion of that bank.

In response to major erosion occurring in the 1920;s through the 1940's, the Soil Conservation Service began an erosion control program in the 1930's to stabilize banks. They used black willow to revegetate banks with "mechanical reinforcements" such as brush and cable revetments, cable and log jetties, rail tetrahedron lines. The program was implemented during a period of few floods. This program may have had some local effects, but was overshadowed by the intrusion of salt cedar.

DATA:

Table 1. Characteristics of subreaches A,B, and D of the Gila River, Safford Valley
Table 2. Average change in the altitude of the bottom land at cross sections along the Gila River, Safford Valley
Table 3. Estimated volume of sediment accretion for subreaches in Safford Valley, 1935-70
Figure 5. Diagrams showing historical changes in the bottom land in subreaches A, B, and D
Figure 7. Graph showing net average change in the altitude of the bottom land, 1935-70, at cross sections in subreaches A and B of the Gila River
Figure 9. Graphs showing sinuosity of the stream channel of the Gila River in Safford Valley, 1875-1970
Plate 1. Map showing extent of study reach and location of cross sections, alluvial fans, and photograph sites
Plate 2. Maps and aerial photographs showing channel changes of the Gila River near Pima
Plate 3. Graphs showing annual streamflow volumes, annual floods, and average stream channel width, Gila River in Safford Valley
Plate 4. Photographs showing development of the alluvial fan at the mouth of a tributary to the Gila River near Calva, Arizona
Plate 5. Photographs and profiles showing horizontal and vertical changes in the Gila River near Fort Thomas

Burkham, D.E., 1976. Flow from Small Watersheds Adjacent to the Study Reach of the Gila River Phreatophyte Project, Arizona: U.S. Geological Survey Professional Paper 655-I, 19 pp.

The purpose of this study was to collect data from storm runoff during 1963-1971 from tributaries to the Gila River and characterize flow in tributary streams. These tributaries are generally long and narrow and have a drainage area of 1-20 square miles. Their gradient varies from 2% near Gila River to >40% on Mt. Turnbull. Floodplain alluvium along the tributaries is 50 to ~300 ft wide. Most floods in the tributaries resulted from localized summer thunderstorms. The authors also wanted to compare the average annual discharge data for these watersheds to discharge relations developed for other watersheds in the region in order to determine whether the runoff-producing characteristics were similar. To compare the watersheds they used runoff relations derived from Moosburner (1970) and Burkham (1966, 1970).

The study encountered a number of problems and limitations. They could not directly measure peak flow or other discharge values due to lack of a control section, high flow velocities, and other problems. Data were adequate for study only because tributaries had no flow more than 96% of the time and were well documented. Peak discharge values and storm totals were within 100% of true values; seasonal runoff values were within 50% of true values. Prediction errors runoff relations of similar basins from Moosburner (1970) and other discharge equations (Burkham 1966, 1970) were 100-250%. High error is most likely caused by significant differences in basin size and shape and improper definition of region for the relation.

DATA:

Tables 1. Storm runoff from tributaries, Gila River Phreatophyte Project, 1963-71
Figure 1. Index Map of project area
Figure 4. Relation of peak discharge to storm volume for single-peak storms
Figure 5. Hypothetical hydrograph for a single-peak flow event
Figure 8. Relation of mean annual runoff to size of basin
Plate 1. Map showing watershed boundaries and instrument locations
Plate 2. Photographs and graphs showing development of the alluvial fan at the mouth of a tributary to the Gila River

Burkham, D.E., 1976, Hydraulic Effects of Changes in Bottom-Land Vegetation on Three Major Floods, Gila River in Southeastern Arizona - Gila River Phreatophyte Project: U.S. Geological Survey Professional Paper 655-J, 14 pp.

Report describes the channel changes associated with changes in riparian vegetation during large floods in December 1965, August 1967, and October 1972. These floods were the largest in the study reach since 1917. For each flood, mean velocity, mean depth, channel roughness coefficient, changes in the altitude of the bottom land, and changes resulting from vegetation alteration were analyzed. Two reaches were analyzed: Reach one extends from the U.S. Highway 70 bridge near Bylas to the Railroad bridge two miles downstream from Calva; Reach two extends downstream from the Railroad bridge to San Carlos Reservoir.

The analysis focused on cross sections 3-7 in reach one and cross sections 11-15 in Reach two. The study concluded that channel changes could not be linked to vegetation changes; (for example, “The effects of vegetation alteration between the 1967 and 1972 floods on channel changes in the study reach during the 1972 flood could not be determined.” p. J12). Recognized changes in vegetation between floods included: (1) Eradicaton of trees in reach 1 between 1965 and 1967 floods; (2) Increase in foliage in reach 2 between 1965 and 1967; and (3) Eradication of trees in reach 2 between 1967 and 1972. Eradication of trees was caused by the following changes: Decrease in stage, increase in mean cross-sectional velocity, decrease in roughness (n-values), and a decrease in mean cross-sectional depth. Increase in foliage caused the following changes: increase in stage, decrease in cross-sectional velocity, increase in n value, and an increase in flow depth.

The study also looked at scour and fill patterns and was able in some cases to relate the behavior to seasonality of floods. For example, scour occurred during the December 1965 flood and fill during the August 1967 flood. Sediment concentrations during winter floods are about 20% of the average summer flow concentration and so the winter floods have a greater erosional capability. Some of the filling episodes were also explained by high lake levels at San Carlos Reservoir and local scouring by the influence of man-made structures such as bridges.

DATA:

Table 1. Hydraulic parameters for peak discharges, floods of December 1965, August 1967, and October 1972, Gila River

Table 2. Peak discharge, Gila River at Calva, Arizona, 1963-72

Figure 1. Photographs showing stream channel and flood plain of the Gila River in 1964 and 1967

Figure 2. Graphs showing the hydraulic characteristics at peak discharge for the floods of 1965, 1967, and 1972

Plate 1. Maps and aerial photographs of the study reach of the Gila River, showing station and cross-section locations, and area of flooding

Plate 2. Cross-sectional profiles and maximum stage for three floods at nine sections along the study reach of the Gila River, southeastern Arizona

Burkham, D.E., 1976, Effects of Changes in an Alluvial Channel on the Timing, Magnitude, and Transformation of Flood Waves, Southeastern Arizona - Gila River Phreatophyte Project: U.S. Geological Survey Professional Paper 655-K, 25 pp.

On the upper Gila River, channel changes have caused differences in the channel capacity and stage of peak flows as well as differences in the velocity of flood waves. Following periods of large floods, the channel is widened and straightened, while during a low-flow period, the channel is narrow with a meandering pattern. A system developed for low flows tends to reduce peak flows and decrease the velocity of flood waves (for discharges of 10,000 to 20,000 cfs). In a system developed for high flows, tributaries are greater contributors to peak flows, and the velocity of flood waves is also greater. Burkham also found that annual peak flows at the downstream end of the study reach are related to the flows upstream.

DATA:

Table 1. Streamflow-gaging stations in or near Safford Valley

Table 2. Velocity of the center of mass of flood waves and approximate values of Manning *n* for selected peak discharges

Figure 1. Index map of project area and map showing study reach and location of gaging stations, Gila River

Figure 2. Relations between average peak discharge and lag time of the center of mass of flood waves moving through a reach of the Gila River

Figure 3. Average peak discharge and differences in lag time of the center of mass of flood waves for four periods after 1927 compared with those for 1914-27

Figure 4. Relations between average peak discharge and lag time of the peak-discharge rates of flood waves

Figure 5. Annual floods, average stream-channel width, and lag time of center of mass of flood waves

Figure 6. Historical changes in the bottom land in three reaches of the Gila River

Figure 7. Average velocity of the center of mass of flood waves

Figure 8. Measured and synthesized floodflow, July 14-16, 1919, and September 3-5, 1925

Figure 9. Measured and synthesized floodflow, July 23-25, 1955

Figure 10. Measured and synthesized floodflow, January 11-19, 1960
Figure 11. Relation between inflow and outflow for peak discharges of floods moving through the study reach during 1914-27, 1930-32, and 1944-65

Burkham, D.E., 1981, Uncertainties Resulting from Changes in River Form: Journal of the Hydraulics Division, v. 107, No. HY5, p. 593-610.

Discusses the uncertainties associated with channel change. These uncertainties include changes in sediment yield and transport, channel capacity for floods, surface water yield and flow, and ground water supply and transport. The author uses a number of different examples to illustrate the uncertainties, one of which is the upper Gila River in Safford Valley. He mainly focuses on the effects of grazing on river behavior and the timing of flood waves in relation to changing channel form. Grazing has only been a minor factor, the author states, in generating channel changes on the Gila River. The more important factors are the extreme floods, which correspond to major episodes of channel widening. When a period of large floods occurs, the channel tends to widen and straighten; in periods with few large floods, the channel narrows and develops a meandering pattern. Large floods have also caused erosion in the tributaries by lowering the local base level of the main stem such that tributaries incise to reach the new base level. Channel changes also cause changes in the timing of flood waves. For example, velocities for flood waves during periods of large floods, such as 1914-27, may have been as much as 3 times the velocity of flood waves during low flow periods (1943-1970). Changes in channel form also may cause changes in the capacity of the channel to transport floods, as well as the infiltration rate into the underlying alluvium. Due to uncertainties caused by channel change, the author makes a case for consideration of those changes in flood routing, and flood frequency estimations.

Burkham, D.E., and Dawdy, D.R., 1970, Error Analysis of Streamflow Data for an Alluvial Stream– Gila River Phreatophyte Project: U.S. Geological Survey Professional Paper 655-C, p. C1-C13.

Purpose is to develop a method to determine the error in computing discharge at gaging stations in alluvial reaches. Results are to be used specifically in a water budget analysis associated with the Gila River Phreatophyte Project.

Computes the standard error for the stage discharge relation in percent of instantaneous discharge for the Gila River near Bylas, AZ and the Gila River at Calva, AZ. For summer flows, the standard error at Calva is about 5% for flows of 40-100 cfs and 6% for flows of 100-1,000 cfs. The standard error at Bylas is about 12% for flows of 40-100 cfs and 6% for flows from 100-1,000 cfs. These results are for reaches that are unaffected by artificial structures.

DATA:
Figure 4. Hydrograph showing summer flow, Gila River at Calva
Figure 6. Graph showing duration curves of summer flow, Gila River at Calva
Figure 7. Hydrograph showing winter flow, Gila River at Calva
Figure 8. Graph showing duration curves of winter flow, Gila River at Calva

Calvin, Ross, 1946, River of the Sun, Stories of the Storied Gila: Albuquerque, University of New Mexico Press. Ch. 10: “The World’s Muddiest River”, p. 135-153

The author's hypothesis is that grazing is the major cause of degradation of the Gila River and turbidity problems; these problems have been exacerbated by large floods. Overgrazing caused the change in vegetation from grass to barren land, and snakeweed.

Any effects from deforestation have been insignificant compared to overgrazing impacts.

Calvin mentions several floods in the text including June 21, 1895 , August, 1903, and September, 1941. Channel changes from floods include an increase in channel area in Township 7 South, Range 27 East from 104 acres in 1875 (Olmstead, 1916) to 1500 acres in 1916. From 1895-1905, the Big Ditch, or San Vincente Arroyo, was built from Main Street, Silver City. The flood of July 21, 1895 began incision in the Big Ditch; subsequent floods continued the process.

The Gila River is perceived as a monster that is out of control and uncontrollable. It is likened to a psychotic individual whose abnormal behavior needs to be corrected. To this author floods are a form of misbehavior.

Culler, R.C., and others, 1970, Objectives, Methods, and Environment – Gila River Phreatophyte Project, Graham County, Arizona: U.S. Geological Survey Professional Paper 655-A, 25 pp.

Describes the methodology behind the Gila River Phreatophyte Project. The water budget method depends on evapotranspiration, soil moisture, surface water and ground water measurements for studying the effect of phreatophyte removal. Of particular note, authors mention aggradation of channel during the 1960's. They attribute aggradation to: sediment deposition in San Carlos Reservoir during 1941-42 (period of maximum storage) and deposition from later flows in San Carlos and Gila River, decreasing river gradient, and growth of salt cedar, which traps debris, and creates natural levees and log jams which further trap sediment. Aggradation began in January 1963, when a log jam was observed 2.4 km (1.5 mi) above the mouth of San Carlos River, probably from flood of Sept. 27-30, 1962. Channel plugging progressed 8.8 km (5.5 mi) upstream by the summer of 1964.

Cushman, R.L., and Halpenny, L.C., 1955, Effect of Western Drought on the Water Resources of Safford Valley, Arizona, 1940-52: American Geophysical Union Transactions, v. 36, no. 1, pp. 87-94.

Studied effects on water resources through a wet period of 1940-41 and through a drought period, 1942-52. The authors felt that Safford Valley was an ideal place to conduct a study of this nature because irrigable area is limited naturally and also by court decree, and less than 1000 acres are irrigated by wells. During the wet period, flow in the Gila River was perennial; surface waters were mainly used for irrigation. The wet period delayed the onset of the drought by providing water resources that carried over into the drought years. During the dry period, there was a significant decrease in surface water resources, forcing farmers to rely on ground water and digging of new wells as the ground water source became depleted, the water table lowered, and wells yielded less water. As the water table lowered, many phreatophytes died when their roots could not extend as fast as the table lowered, and more areas in the channel served as recharge for the groundwater. Effects of the drought persisted several years after the dry period had ended.

DATA:

Figure 2. Precipitation at stations in vicinity of Safford Valley, Graham and Cochise Counties, Arizona
Figure 3. Discharge of Gila River at Solomon, Arizona, and combined surface-water diversions and ground-water pumpage, Safford Valley

Davidson, E.S., 1961, Facies Distribution and Hydrology of Intermontane Basin Fill, Safford Basin, Arizona: Short Papers in the Geologic and Hydrologic Sciences, Articles 147-292, U.S. Geological Survey Research, p. 151-153.

Davidson describes three sedimentary units in the Safford Basin basin fill: (1) deformed conglomerate or gravel, which is of limited area close to the edges of basin, and derived from local sources. Deformation occurred during period of block-faulting prior to deposition of basin fill; (2) basin fill, which is flat-lying, Pliocene to Pleistocene and composed of gravel & grit, sand & silt, clay, and limestone with interbedded lava flows, tuffs, and diatomite beds. The drainage was not through-flowing at the time of deposition; and (3) terrace gravel and alluvium, deposited by Gila River and tributaries. The terrace gravel and alluvium rests on an erosional contact with the basin fill.

Dobyns, H.F., 1978, Who Killed the Gila? *in* Water in a Thirsty Land, reprinted from the Journal of Arizona History: Pinon Press, pp. 17-30.

The author's view is that the Gila River has died from regulations imposed on the river and other human impacts. Dobyns states, "Erosive destruction of downstream riverine oases an upstream clear rivulets was not a natural, or geological, occurrence. It resulted from the actions of mankind in historic times. Hence, the question: who killed the Gila – and how?" (p. 17) Dobyns discusses what he believes to be the causes of erosion along the Gila River: grazing, farming, deforestation, European influence on traditional Indian farming practices (value of trees and shrubs over grasses), extermination of beaver, and hence, beaver dams (flood control) by trappers and hunters, mining (wind and water erosion along travel routes), and canal-irrigation works (wash outs accelerate erosion; incision into ditches).

Dove, Donald, 1890, Early White Settlements along the Gila River, Arizona, 1850-1890, 19 pp.

The article gives a brief history of development of towns along the upper Gila River. Dove mentions towns/settlements getting washed out by the Gila River:

> "The Coolidge Dam was built because of the constant threat of flooding after heavy rains. Before that time, the river was about forty to one hundred feet across and meandered through swamps and marshes. It was lined on either side with cottonwoods and willow trees with thickets of brush and reeds. Wildlife such as deer, antelope, bear, and turkey were plentiful in the foothills and mountains and moved frequently into the lower lands. Rabbits and quail were everywhere." (p.1)
>
> "The name of the settlement [Thatcher] was derived from Apostle Moses Thatcher, who visited the town on Christmas of 1882 with Apostle Erastus Snow. The townsite was selected on May 13, 1883 by President Layton…In 1885, a new townsite was selected about one-half mile south of the original settlement. The new site was on higher land due to the encroachments of the Gila River." (p.11-12)
>
> "…Disease (malaria) was common in many areas where water was not flowing and disease-carrying mosquitoes could breed. This was not very common along the Gila River because it always moved. Food was scarce and in most places, very expensive. Some of the early towns were damaged by river flooding forcing the population to evacuate." (p. 15)

Durrenberger, R.W., and Ingram, R.S., 1978, Major Storms and Floods in Arizona 1862-1977: Climatological Publications Precipitation Series No. 4, 44 pp.

Documents the precipitation, aerial extent and damage of floods that occurred in Arizona from 1862 through 1977.

Ely, L.L., 1992, Large Floods in the Southwestern United States in Relation to Late-Holocene Climatic Variations: Tucson, University of Arizona, Ph.D. dissertation, 326 pp.

A study and compilation of paleoflood chronologies in Arizona and southern Utah. Ely contends that these chronologies preserve floods that cluster in time over the last 5000 years with periods of increased large magnitude floods and periods of very few large floods, and that regional global and climatic fluctuations in the form of proxy records are consistent with the periods of increased and decreased large flood frequency. In other words, warm periods coincide with periods of decreased flood frequency and cool, wet periods coincide with periods of increased flood frequency. Ely also describes the meteorologic phenomena associated with large magnitude floods.

She describes two sites in the study area. On the Upper Gila River, the site described is 4 km downstream of confluence with San Francisco River and preserves 11-12 floods within the last 400 years. On the San Francisco River, the site is located 15 km upstream of Clifton, AZ and is composed of three exposures that preserve 11 floods within the last 400 years. Ely was also able to identify the most recent historic flood deposits of 1983, 1978, and 1972.

Ertec Western, Inc. (Earth Technology Corp.), 1982, Seismotectonic Study – Coolidge Dam, Arizona: Bureau of Reclamation.

Contains a 1:24,000 geologic map along the Gila River from Coolidge Dam to Dewey Flat.

Eychaner, J.H., Rehmann, M.R., and Brazel, A.J., 1988-1989, Arizona Floods and Droughts, *in* National Water Summary 1988-1989—Hydrologic Events and Floods and Droughts: U.S. Geological Survey Water Supply Paper 2375, pp. 181-188.

General information on floods and droughts in Arizona. Droughts affecting the Upper Gila River basin include 1932-36 and 1942-64, which was the major drought in the 20th century. Memorable floods include: February 18-26, 1891, October 1977, February 1980, and October 1-3, 1983.

DATA:

Table 1. Chronology of major and other memorable floods and droughts in Arizona, 1862-1988

Figure 3. Areal extent of major floods with a recurrence interval of 25 years or more in Arizona, and annual peak discharge for selected sites, water years 1891-1988

Figure 4. Areal extent of major droughts with a recurrence interval of 10 years or more in Arizona, and annual departure from average stream discharge for selected sites, water years 1905-88

Fletcher, J.E., 1941. Erodibility Investigations on Some Soils of the Upper Gila Watershed: U.S. Department of Agriculture Technical Bulletin 794, 31 pp.

Purpose of study was to determine what factors were responsible for the differences in erodibility of soils in the upper Gila River watershed. First, they surveyed the soils in the watershed to try to correlate their erodibility with field characteristics. Second, they performed lab investigations to look at some of the physical and chemical characteristics of the soils to see if these might be important factors in erodibility.

The authors made the following conclusions:

(1) Parent material:

(a)In southern Gray Desert soils: order from erodible to non-erodible is: 1) Limestone; 2)mixed origin; 3) granite; 4) rhyolite and basalt; 5) quartzite

(b)In southern Brown soils: order from erodible to non-erodible is: 1) granite; 2) rhyolite; 3) quartzite, limestone, and basalt

(2) Rocky soils (particle size greater than 4 cm) are more erodible than gravelly soils (particle size between 2 mm and 4 cm.
(3) Coarser soils are more erodible than finer textured soils
(4) Loose topsoils erode easily as well as very compact soils which have a low infiltration rate during precipitation events
(5) Ratio of colloid to moisture equivalent is significantly correlated with high erodibility
(6) High calcium or sodium content is significantly correlated with high erodibility
(7) As the ratio of iron to calcium decreases, erodibility increases
(8) One or more of the elements calcium, iron, sodium, and potassium are present when chemical ratios have significant correlations with erodibility.

Follett, R.H., 1969, Quality of Water of the Gila River in Arizona Above Ashhurst-Hayden Dam, Progress Report: November 1967-October 1968: Arizona State Department of Health, Environmental Health Services, Division of Water Pollution Control, variously paginated.

Assessed water quality above Ashhurst-Hayden Dam. Concluded that the water quality in the Gila and San Francisco Rivers has not changed much since the 1940's, TDS values increased significantly from the border with New Mexico to Bylas, AZ and the water passed the water quality standards.

DATA:
Appendix. Water quality data for selected dates in 1967 and 1968
Gila River near Bylas
Gila River near Thatcher
Gila River near San Jose
San Francisco River downstream from Clifton
Gila River near Guthrie (Old Safford Road Bridge)
Gila River at Arizona-New Mexico border

Garret, J.M., Roeske, R.H., and Bryce, B.N., 1986, Flood of October 1983 in Southeastern Arizona – Areas of Inundation in Selected Reaches Along the Gila River: U.S. Geological Survey Water Resources Investigations Report 85-4225-A, 3 sheets, various scales.

Discusses the hydrology of the October 1983 flood and its effects on basins in southeastern Arizona. In the study area, the flood occurred from September 28 through October 4, 1983. Total precipitation was 11.2 inches at Blue River near Clifton, and 6.2 inches at Safford. The main source of runoff was the San Francisco River. All highway bridges in Safford Valley were impassible during the flood. The inflow to San Carlos Reservoir was 450,000 acre-feet during the flood period; water began to flow over the spillway at 1330 hours on October 4. On October 6, the spill and release reached a maximum discharge of 5,020 cfs. This document also contains a delineation of inundation boundaries using photos taken on Oct. 7, 1983.

DATA:
Sheet 1. Reach one
Sheet 2. Reach two
Sheet 3. Reach three
Table 1. Peak discharge information
Figure 2. Location of sites in the study area

Garret, J.M., Roeske, R.H., and Bryce, B.N., 1989, Floods of 1983 in Southeastern Arizona: U.S. Geological Survey, Water Resources Investigations Report 85-4225-C.

Provides additional data and discussion on the floods of 1983 in southeastern Arizona. Rainfall was generally above normal for most gages before the storm began.

Precipitation from the storm of September 27-October 3, 1983 was the result of the interaction of a high-altitude, low-pressure trough with moist tropical air. On September 30, tropical Storm Octave arrived and brought additional moisture to the region. The most intense rainfall occurred on October 1 with most stations recording more than 2 inches of rain; a total maximum of 11 inches fell during the 7-day storm period. Several gages set records for volume of runoff and peak discharge magnitudes; gages which had the highest mean discharges for one, three, and seven consecutive days at gaging stations with 30 or more years of record and where mean discharges were new maxima during September 27 to October 3, 1983 include: San Francisco River near Glenwood, NM, San Francisco River at Clifton, Eagle Creek near Morenci, and Gila River at head of Safford Valley.

For the San Francisco River, the flood peak was the largest since at least 1870

Most rain fell between September 29-October 2, and led to three flood peaks, the largest of which occurred on October 1. The Gila River above the San Francisco River and the San Simon River contributed very little to the flood peaks on the Gila River downstream.

On October 4 at 1330 hours, water began to flow over spillway of Coolidge Dam.

Reservoir capacity had increased from 547,000 acre-feet to 937,000 acre-feet on Oct 4th to 967,000 acre-feet by Oct. 7. Cross section measurements made 2.8 miles upstream from the Gila River at Head of Safford Valley, near Solomon, Arizona, following large floods generally show erosion of mesquite covered terraces.

DATA:

Table 1. Highest mean discharge for 1, 3, and 7 consecutive days at gaging stations with 30 or more years of record and where mean discharges were new maxima during September 27 to October 3, 1983
Table 7. Summary of flood stages and discharges
Figure 4. Rivers where recurrence intervals of October 1983 floods exceeded 70 years
Figure 7. Total rainfall in southeastern Arizona and western New Mexico, September 27 to October 3, 1983
Figure 8. Cumulative rainfall at three precipitation stations in southeastern Arizona, September 27 to October 3, 1983
Figure 9. Comparison of September-October precipitation with annual precipitation at three long-term precipitation stations in southeastern Arizona
Figure 10. Total storm rainfall, September 27 to October 3, 1983, and streamflow-measuring sites in San Francisco River basin and Gila River basin above Coolidge dam
Figure 11. Cumulative rainfall at two precipitation stations in the San Francisco River basin, September 27 to October 3, 1983
Figure 12. Discharge of the Gila River at three gaging stations upstream from the San Francisco River in Arizona and New Mexico, September 30 to October 6, 1983
Figure 13. Discharge of the San Francisco River at Clifton and Gila River at Calva, Arizona, September 30 to October 5, 1983
Figure 22. Changes in channel geometry of Gila River 2.8 miles upstream from site 27, October 1972, December 1978, and October 1983
Appendix. Hydrograph Data

Gila Water Commissioner, 1935-1999 (published annually), Distribution of Waters of the Gila River to the United States District Court, variously paginated.

Basic flow data for each water year. This reference has numerous tables of canal diversion data, data on the canals, discharge records, consumptive use, etc.

Graf, W.L., 1981. Channel Instability in a Braided, Sand-Bed River: Water Resources Research, v. 17, no. 4, p. 1087-1093.

Characterizes the stability of river reaches of the Gila River between the Salt River and Gillespie Dam. The study seeks to answer two questions: (1) “How can channel instability be mapped in braided, sand bed channels?”; and (2)“Why are the stable and unstable zones distributed the way they are?”

In order to answer these questions, the location of the main channel from 1868 to 1980 was mapped. These maps were then compiled and a grid was overlaid. Each point on the grid was assigned a value, which corresponded to the probability that a main channel was located at that point during the past 112 years. The final step was to create a contour map of equal probability points.

The study found that stable zones corresponded to places were control is located (i.e., buttes or hills that abut against the channel or man-made structures). Unstable zones were located in sections dominated by deep alluvial fill, in areas with heavy human impacts, such as sedimentation behind Gillespie Dam, and in areas of dense phreatophyte growth. Sinuosity measurements varied within a narrow range of values with a mean value of 1.18 and was more variable in areas with the lowest gradients (i.e., sedimentation area behind Gillespie Dam). After the flood of 1941, sinuosity exhibited greater fluctuations than prior to 1941 and had a statistically significant correlation with areal extent of phreatophyte growth

Green, C.R., and Sellers, W.D., 1964, Arizona Climate: The University of Arizona Press, Tucson, Arizona, 503 pp.

General descriptions of the climate for various locations in Arizona. Includes a map of average annual precipitation for Arizona, other precipitation data, temperature data for Arizona, evaporation and wind movement data, Precipitation and temperature data for Duncan, AZ (1901-63), and precipitation and temperature data for Safford, AZ (1899-1963).

Greenlee County Flood Control District, 1995, Environmental Assessment for Gila River Floodplain Silt Removal and Dike Construction, Duncan, Arizona, 32 pp.

Summary of plan to remove sediment from the floodplain upstream of the State Highway 75 Bridge, and to remove old waste water treatment plant ponds. Goal was to increase river capacity to handle maximum historical flow (58,700 cfs). The river floodplain is currently constricted to 350 feet wide and capable of handling 14,000 cfs. Page 4 mentions over 10 feet of silt has accumulated under the State Highway 75 bridge since the 40’s. Also has a 100-year floodplain map from FEMA.

Harris, R.C., 1997. Land Use in the San Carlos-Safford-Duncan Nonpoint-Source Management Zone. Arizona Geological Survey Open-File Report 97-18, 7 pp.

Documents land use in the San Carlos-Safford-Duncan Nonpoint-Source Management Zone. The author divides land use into 5 categories: Agriculture, inactive Agricultural lands, mining, developed land, and grazing (grazing not depicted on map sheets). Most land in the management zone is used for Agriculture (67,000 acres). Morenci Mine is largest mining land use. Grazing occurs on most land within the

management zone, except National Forest land. Harris also briefly discusses impacts of land use on water quality.

Heindl, L.A., 1958, Cenozoic Alluvial Deposits of the Upper Gila River area, New Mexico and Arizona: Ph.D. Thesis, University of Arizona, Tucson, Arizona 249 pp.

Focuses on the Gila Conglomerate, characterizing the formation where it has been described and describing its relation to other alluvial deposits in the upper Gila River basin

Describes the relation of the Gila conglomerate to geologic structures in the vicinity and discusses the Tertiary/Quaternary history of the area. Heindl divides the alluvial deposits into an “upper and lower set.” The “upper set” is Pliocene to Pleistocene. The “lower set” is broken into three categories based on stratigraphic relationships and degree of deformation: the Gold Gulch/Hackberry Wash, Whitetail, and Pantano Formations.

Hickock, R.B., Keppel, R.V., and Rafferty, B.R., 1977, Hydrograph Synthesis from Small Arid-Land Watersheds, in Schumm, S.A., ed., Drainage Basin Morphology, pp. 330-336.

The authors discuss methods for estimating peak discharge and hydrograph shape by using synthesized hydrographs. Based on experimental watersheds located in Arizona, New Mexico, and Colorado, the authors develop synthetic hydrographs from basin parameters and lag time between rainfall maximums and peak discharges. Lag time is found to have the most influence on hydrograph shape; land slope is the most important in determining lag time. Their method of hydrograph synthesis is only applicable for watersheds that are relatively uniform and less than 1,000 acres and for convectional storms.

Hirschboeck, K.K., 1985, Hydroclimatology of Flow Events in the Gila River Basin, Central and Southern Arizona: Ph.D. Thesis, University of Arizona, Tucson, Arizona, 335 pp.

Makes a case for mixed distributions in the Gila River flood regime based on a hydroclimatological classification of flood events. Hirschboeck chose an arid region basin because it is most susceptible to violations in the basic assumptions behind flood frequency analysis. To conduct her analyses, she used mean monthly discharges, partial duration series (peaks above base), 38 precipitation and snow depth stations, and 700 milli-bar pressure heights. To look at hydrologic variations on longer time scale, she developed correlation fields, which related the monthly averaged upper air pressure patterns to the mean monthly streamflow data. To study flood genesis, she constructed flood maps, plotted daily precipitation totals, and interpreted daily weather maps for each flood event. She was then able to classify each flood event based on its hydroclimatology. She also performed a flood frequency analysis on the partial duration series.

The results of correlation fields study are split into summer/fall and winter categories. During the summer and fall, the general pattern is stronger than normal airflow from the south and southeast in the early part of the rainy season, and shifts to stronger than normal airflow from the south and southwest in the later part. Upper air flow configurations differ slightly among different parts of the basin. During the fall, the upper air pattern is a strong negative circulation anomaly off northern Baja California. The pattern is more similar throughout basin than in summer. During the winter, there is a homogenous response to the primary circulation pattern, which changes from a meridional pattern in December to zonal split flow pattern in January to frequent troughing and stronger than normal southwest flow in February and March. During the winter and fall months, runoff is basin wide response to regional storms while in the summer months, runoff is more localized in response to local storms.

For the stations of interest, the dominant storm types based on the hydroclimatic classification of flood events are tropical/cutoff, frontal, monsoon local, and monsoon widespread. Periods with high frequencies of flooding include the 1950's, in which an active monsoon circulation producing numerous July and August flows, 1966 which experienced frontal activity during November and December of 1965, the 1973 tropical storms and cutoff lows in October 1972, and the late 1970's winter frontal activity, especially in the northern part of the basin.

"These observations demonstrate clearly that variations in the seasonal timing and frequency of flooding are closely related to variations in atmospheric activity over time. An important related question, however, is whether or not variations in the magnitudes of floods are also related to the types of atmospheric processes which generate floods." P. 138

In her chapter on flood frequency analysis, Hirschboeck created histograms of each hydroclimatic subgroup to see if the categories produced distinct flood subgroups. The results of the eastern stations (Gila River near Clifton, San Francisco River near Clifton, San Carlos near Peridot) showed that the Monsoon widespread category had the most floods but a lower mean than the total population mean. Frontal storms ranked second in number at San Francisco and San Carlos and had highest mean discharge for these stations; they ranked third at Gila River near Clifton. Tropical storms/cutoff lows produced flooding in all three basins. The standard deviation was high for both the San Francisco River and Gila River; mean discharge ranked highest for the Gila River basin. Snowmelt generated a few floods in the San Francisco River basin, and consisted of a small distribution that plotted lower than other flood types.

Hirshboeck indicates that some of the assumptions of traditional flood frequency are violated including stationarity:

"The statistical tests for differences in the group means and variances resulted in relatively low tail probabilities, indicating that the observed differences among the subgroup histograms would probably not have emerged if the true means and variances of each subpopulation were, in fact, identical." p. 189

Hirshboeck proposes hydroclimatology as a way to address these concerns in flood frequency analysis. She concedes that fitting curves to multiple distributions is not a straightforward task and may complicate the mathematics considerably; nevertheless, she concludes that the best model for describing flooding behavior in the Gila River basin is one of "time varying mean and variance" rather than the Stationary Stochastic Process Model.

Hjalmarson, H.W., 1990, Flood of October 1983 and History of Flooding along the San Francisco River, Clifton, Arizona: Water Resources Investigations Report 85-4225B, 42 pp.

Summarizes the characteristics of floods and history of flooding along the San Francisco River at Clifton, Arizona. The largest flood in the gage record occurred on October 1-2, 1983 at Clifton and is the largest known since 1870. The flood has a return interval of 75 years based on flood frequency information. The report documents the impact of the 1983 flood on structures such as bridges and floodwalls, and provides historic photos to show the effects of other large floods as well.

Heavy rains associated with tropical storm Octave on September 29-October 2, 1983 caused two flood peaks at Clifton, the second of which was largest and measured 90,900 cfs on October 2, 1983. The first peak on October 1 measured 90,000 cfs. Based on hydrographs for selected gaging stations upstream of the San Francisco River at Clifton, the majority of runoff that caused the record flood peak was generated from the basin area between the gaging stations on the San Francisco River at Glenwood, New Mexico and at Clifton, Arizona. The Blue River was also a significant contributor to the flood peaks.

Hjalmarson also describes historic accounts of floods in the late 1800's and early 1900's on the San Francisco River. The floods he describes occurred in February 1891, December 1906, January 1916, and October 1972. He also mentions floods in the early 1870's, 1880, 1885, and 1890.

DATA:

Table 4.1-1 Annual and historic peak discharges, 1891-1984, San Francisco River at Clifton, Arizona
Table 4.2.1-1 Elevations of major flood crests at 145 Frisco Street, Clifton, Arizona, 1891-1983
Table 4.2.2-1 Elevations of major flood crests at the Central Hotel in east Clifton, Arizona
Table 4.3-1 Time of crests for major floods on the San Francisco River at Clifton, Arizona
Figure 3.1-1 Storm rainfall in the San Francisco River basin, Arizona and New Mexico, September 27 to October 3, 1983
Figure 3.1-2 Rainfall data from precipitation stations, Blue River near Clifton, Arizona, and San Francisco River at Clifton, Arizona, September 27 to October 3, 1983
Figure 3.2-1 Discharge from selected gaging stations on the San Francisco River, Arizona and New Mexico, September 29 to October 5, 1983
Figure 3.2.1-1 Routed discharge from Blue River near Clifton, Arizona, and San Francisco River near Glenwood, New Mexico, to Clifton, Arizona, September 29 to October 6, 1983
Figure 3.2.1-2 Computed discharge from local runoff, San Francisco River at Clifton, Arizona, September 30 to October 2, 1983
Figure 3.2.2-1 Frequency curves of annual, summer, and winter floods, San Francisco River at Clifton, Arizona
Figure 3.2.2-2 Annual peak discharges, San Francisco River at Clifton, Arizona
Figure 3.3.1-1 Flood elevations and boundaries at Clifton, Arizona
Figure 3.3.2-3 Cross section of the San Francisco River at bridge site 1, Clifton, Arizona

Hooke, J.M., 1994. Hydrological Analysis of Flow Variation of the Gila River in Safford Valley, Southeast Arizona: Physical Geography, v. 15, pp. 262-281.

Studied hydrologic variations from the late 1870's to 1990's to look for trends in precipitation and stream discharge data. Also examined climatic mechanisms for causal relationships with maximum and mean flows and looked for trends in the water budget to relate to land management and irrigation practices. The author identifies trends in the hydrologic data with a high flow period from 1905 to 1916, a low flow period from 1920 to 1965, and a high flow period from 1966 to 1992. By best-fitting a quadratic regression equation to both discharge and precipitation data, Hooke found that there was a general decrease in trend from 1868 to the 1920's, then a flattening off through the 1950's, followed by a rise into the 1990's. When comparing recent floods to records at the turn of the century, Hooke concludes, "The recent two decades appear to have been comparable in magnitude of total flows to the period 1874-1891 but not as high as the period 1905-1916." (p. 278)

DATA:

Table 1. Averages of annual discharges of the Gila River
Figure 3. Mean annual flow for station 4485, 10-year running means and cumulative deviations from the mean
Figure 4. Total annual flow at San Carlos Reservoir
Figure 5. Annual maximum daily discharges at Head of Safford Valley gauge on Gila River, 1921-1992
Figure 6. Smoothed residuals from non-linear trend of maximum, mean, and total discharges, Gila River, and total annual rainfall at Clifton, Arizona
Figure 7. Annual rainfall at Clifton, southeast Arizona, 1895-1990
Figure 8. Mean flow of Gila River at Head of Safford Valley gauge in relation to winter precipitation at Clifton

Hooke, J.M., 1996, River Responses to Decadal-Scale Changes in Discharge Regime: The Gila River, SE Arizona, from Branson, J., Brown, A.G., and Gregory, K.J., eds., 1996, Global Continental Changes: the Context of Paleohydrology: Geological Society Special Publication No. 115, p. 191-204.

Documented channel change in the Safford basin using aerial photographs. Found that channel width increased from 1905-20 and gradually narrowed until 1960. During the 1960-70's widening occurred and continued to1982. Major channel changes from high flows occurred in the 1972, 1974, and 1979 water years with some changes in response the lower flows.

The author questions Burkham's model of geomorphic threshold needed to induce major channel changes, or says that the relation is not simple: "The research has shown that the morphological response to high flow events depends on sequences of events and critical combinations of conditions." Hooke also mentions that vegetation may play a factor in channel change and that change does not correspond to size of event or wetness of period.

House, P.K., and Hirschboeck, K.K., 1995, Hydroclimatological and Paleohydrological Context of Extreme Winter Flooding in Arizona, 1993, *in* Larson, R.A., and Slosson, J.E., eds., Storm-Induced Geologic Hazards: Case Histories from the 1992-1993 Winter in Southern California and Arizona: Boulder, CO, Geological Society of America Reviews in Engineering Geology, v. XI, pp. 1-24.

The authors discuss the 1993 floods in Arizona and the meteorologic phenomena that were the cause of the extreme runoff events. Generally, floods resulted from an uncharacteristic series of winter storm fronts with repeated warming and cooling trends resulting in high rainfall amounts, snowpack accumulation, snow melting, and rain on snow. The meteorological pattern was influenced by the El Nino-Southern Oscillation in which the storm track over North America is displaced further to the south than would normally occur, steering a greater amount of storm activity over the state of Arizona. Most of the primary basins in Arizona were affected by the storms and floods of 1993, including the Gila River Basin. The authors discuss in detail the hydrology and hydroclimatology of four major storms which occurred during the winter and also place the events into paleohydrological context.

DATA:

Table 1. Summary of record discharges in Arizona, January and February 1993
Figure 5. Anomalous upper-level atmospheric circulation and low-level moisture transport
Figure 6. The relationship between precipitation and snow depth for two high-elevation stations in Arizona, December 1992 through February 1993
Figure 8. Isohyetal maps for the four periods of major regional flooding in Arizona, January through February 1993
Figure 9. Composite 500-mb pressure heights for the four 1993 flood-producing storm episodes

Huckleberry, Gary, 1993, Late-Holocene Stream Dynamics on the Middle Gila River, Pinal County, Arizona: Ph.D. dissertation, University of Arizona, Tucson, Arizona, 135 pp.

Explores late-Holocene channel activity and floodplain formation on the middle Gila River. Attempts to construct a model of Holocene channel behavior using archival records of floods and channel descriptions and overbank stratigraphy.

Huckleberry mapped surficial geology in the middle Gila River Basin, delineating four Pleistocene terraces which grade into one Pleistocene terrace (M) near Coolidge, which then grades into the regional basin floor. He also delineates four Holocene surfaces. During 1991 and 1992, he surveyed 20 cross sections and found that the cross-sectional area of low flow channel decreased downstream due to infiltration and lack of entering tributaries. The width-depth ratio also decreased downstream in the low flow channel. There was an increasing sinuosity in western part of project area, probably due to decreased sediment load and increased sedimentation around tamarisk. An abundance of historic information on floods in the Gila River and middle Gila River channel characteristics beginning in 1763 is also available in Huckleberry's dissertation.

The largest floods in the middle Gila River flood record have had varying impacts on channel morphology. In the 1833 and 1868 floods, the channel did not experience any appreciable widening; instead floodwaters inundated a wide portion of the floodplain. The most dramatic changes occurred during the 1905 floods. Drought conditions before the flood year may have reduced vegetation and resistance to erosion. The January 1993 flood caused more widening than the 1983 flood. This could be explained by flood seasonality; the greater flow volume and duration during winter storms may cause greater erosion. In addition, winter storms transport less suspended load and may have a greater capacity to transport bedload, thereby increasing erosion.

Huckleberry dug trenches in several of the Holocene terraces in order to look at the middle Gila River paleoflood record. He found that there were periods of reduced and increased flood frequency based on radiocarbon dating of the past 5,000 years. From 4-5 ka, channels widened in response to large floods. From 4-1 ka, there was a decrease in large flood frequency, followed by an increase in frequency in the past 1,000 years. In the historic period, the channel was relatively stable from 1697-1890. The river began to experience more large floods at the turn of the 20th century and appears to be in an unstable form to the present.

Huckleberry's model of Gila River streamflow consist of first, a wide, braided conditions during periods of above average streamflow. During periods of average streamflow, bars in the channel become vegetated, and attach to the floodplain. Channels are abandoned with the formation of a single thread. If there is a low frequency of large flow events, the main flow channel narrows until it "reaches a geometry suited for 'average streamflow'." (p. 93). Huckleberry ascribes to the "disequilibrium model" of channel behavior, in which channel morphology is controlled by the rare large floods. The river does not recover quickly, and large floods are more frequent than the time it takes for the flood plain to restabilize. Therefore, one can use paleoflood information to characterize prehistoric channel behavior because it records large magnitude floods. He adopts a modified disequilibrium model in conclusion because channel responses to large magnitude flows in the historic (archival) and modern record were not uniform. Huckleberry's model allows for other factors besides large magnitude flows to be important in controlling channel morphology.

Although Huckleberry does not claim floods as the cause of shifts in Hohokam populations, he does state that "Shifts in the spatial distribution of Hohokam archaeological sites and irrigation canals at approximately A.D. 1100 are penecontemporaneous with increased flooding on the middle Gila River" (p. 123).

Jakobsen, B.F., 1959, Report on Upper Gila River Flood Control Project, Safford, Arizona: B.F. Jakobsen Consulting Engineer, Menlo Park, CA, 16 pp.

The Gila Valley Irrigation District wanted to straighten channel bends in river and widen and deepen channel to a capacity of 20,000 cfs, and to eliminate heavy phreatophyte growth by permanently lowering the ground water table. Jakobsen investigated implementing new flood control structures to provide protection for irrigation district management design. He concludes: "In my opinion, a reservoir above Safford of at least 200,000 acre-feet capacity is economically justified and combined with a 20,000 cfs channel to San Carlos Reservoir, would protect the Upper Gila River Valley against a flood equal to the largest flood of the 90-year record." (letter to Sen. Carl Hayden, February 13, 1959).

JE Fuller/Hydrology and Geomorphology, Inc., 1997, Geomorphology of the Upper Gila and San Francisco Rivers, in SFC Engineering Company, preparers, Arizona Stream Navigability Study for the Upper Gila River and San Francisco River, Final Report: Arizona State Land Department, Drainage and Engineering Section, Phoenix, AZ, 23 pp.

Studied the geomorphology of the upper Gila River to aid in the determination of navigability. Split the study area into four reaches: (1)Safford to Gila Box, (2)Gila Box, (3)Gila Box to New Mexico Border, and (4)San Francisco-Gila River to New Mexico Border. Did not find any evidence to support dramatic changes in the geomorphology since statehood. Point bars, margins of terraces and riffles are eroded during floods with sufficient energy; however net changes are close to zero over the entire reach. Authors do not cite any specific examples. Shallow bedrock is present in reaches 2,3, and 4; precludes significant channel migration.

DATA:
Table 1. Upper Gila and San Francisco Rivers streamflow statistics and flow characteristics
Table 2. Geomorphic stream classification data for Reach 1: Gila River – Safford to Gila Box
Table 3. Geomorphic stream classification data for Reach 2: Gila River – Gila Box
Table 4. Geomorphic stream classification data for Reach 3: Gila River – Gila Box to Duncan
Table 5. Geomorphic stream classification data for Reach 4: San Francisco River
Figure 3. Gila River Longitudinal profile and valley width

JE Fuller/Hydrology and Geomorphology, Inc., 1997, Hydrology of the Upper Gila and San Francisco Rivers, *in* SFC Engineering Company, preparers, Arizona Stream Navigability Study for the Upper Gila River and San Francisco River, Final Report: Arizona State Land Department, Drainage and Engineering Section, Phoenix, AZ, 23 pp.

Documents the pre-statehood (February 14, 1912) and post-statehood hydrologic regime for the purposes of navigation. Primary conclusions are that the Upper Gila River and San Francisco River are perennial with median flow rates of 32 cfs on the San Francisco River at the New Mexico border and 174 cfs on the Gila River at Safford. Only small boats such as kayaks, canoes and inflatable rafts could utilize the Gila River at these discharges. By the time of statehood (1912), more than 40 diversion dams had been constructed on the Gila River, which would have impeded navigation. Irrigation diversions have decreased in volume over the last 60 years; the authors postulate a number of reasons for the decrease. The report includes gage descriptions that document location, history, and monthly stream flow statistics for both pre-statehood measurements, the year of statehood, and post-statehood measurements (1912-1989).

DATA:
Table 1. USGS stream gages in the Upper Gila River Watershed
Table 3. Seasonal variation in precipitation and temperature
Table 4. Gila River drainage area summary
Table 5. San Francisco River drainage area summary
Table 6. Diversion data, Gila River (1936-)
Table 26. Peak discharges at USGS gages in upper Gila River basin
Table 27. Historical flood peak discharge estimates at USGS gages

Figure 2. Duncan valley diversions as a percent of annual discharge at Gila River near Virden
Figure 3. Safford Valley diversions as a percent of annual discharge at Gila River near Solomon
Figures 6-17. Rating curves
Appendix B: Photos from the Gila River at Virden Bridge

Kelley, L.O., 1971. A Case Study of the Gila River Channel Improvement Project, Safford Valley, Arizona: M.S. Thesis, Arizona State University, Tempe, Arizona, 75 pp.

Reviews the proposal put forth by the Army Corps of Engineers to mitigate flooding on the Gila River through Safford Valley. This proposal consisted of clearing phreatophytes out of a 600-foot wide swath to provide a flood channel that would pass 16,000 cfs, which is the design flood for the proposed Camelsback Dam and reservoir. The author recounts the controversy surrounding this proposal with viewpoints from various agencies and private interests. He then proposes ways that this project could have been better thought out to circumvent the conflicts of interest that occurred.

Kingston, R.L., and Solomon, R.M., 1976. Erosion and Sedimentation in the Upper Gila drainage, A Case Study, in Hydrology and Water Resources in Arizona and the Southwest, vol. 6, Proceedings of the 1976 meetings of the Arizona Section of the American Water Resources Association an the Hydrology Section of the Arizona Academy of Science, April 29-May 1, 1976, Tucson, Arizona, pp. 103-111.

The case study area is located in the Lake Roberts Watershed, New Mexico in the main Gila River drainage. The purpose of study was to assess the sedimentation problem in Lake Roberts and sources of sediment that were contributing to the problem. The study considered factors of slope, soil characteristics, and proximity to the stream channel to assess each parent material's sensitivity to erosion. The study found that 82% of the watershed has a moderate to high runoff potential (Soil Conservation Service hydrologic soil groups C & D)

Soils that were most sensitive to erosion were developed on the Gila Conglomerate parent material, which comprises 71.1% of Lake Roberts watershed, 35.7% of the main Gila River drainage (NM), 22.3 % of San Francisco River drainage (NM). To a lesser extent, soils developed on rhyolite tuff were sensitive to erosion and comprise 11.6 % of Lake Roberts watershed, 6.3 % of main Gila River watershed (NM), and 16.8% of the San Francisco River watershed (New Mexico).

The factors used to assess erodibility included slope, soil characteristics, and proximity to the stream channel. The authors concluded, "Although there are no definite measurable soil properties related to increased on-site sediment yield from soils with Gila Conglomerate parent materials, there appears to be relationship between increased sensitivity to erosion and soils developing on Gila Conglomerate." (p. 110)

Surface area measurements suggested that Lake Roberts was filling fast (19% reduction in 12 yrs). However, once the actual change in lake volume was measured, researchers found that sedimentation rate was much less (9.4% reduction in 12 yrs). The discrepancy was caused by the irregular bathymetry of the lake, in which the shallow gradient on upper end allowed for most deposition of sediment to occur, reducing lake surface area on upper end. The depth of the lower end of the lake remained virtually unchanged between 1962 and 1975. Large storms appear to account for the majority of sedimentation in Lake Roberts. Measurements before and after the October 1972 event showed that runoff from the storm contributed over 77% of the average annual sediment load to the lake.

Kipple, F.P., 1977. The Hydrologic History of the San Carlos Reservoir, Arizona, 1929-71, with Particular Reference to Evapotranspiration and Sedimentation: U.S. Geological Survey Professional Paper 655-N, 40 pp.

Records of inflow, outflow, surface-water storage, and sediment deposition were used to evaluate reservoir evapotranspiration (ET) and the change in ET from 1929 to 1971 for purposes of examining the effects of phreatophytes in the water budget. The study also investigated sediment deposition in the reservoir and also looked at lake evaporation and reservoir bank storage. Sediment surveys used in this study are: the 1914-15 Indian Irrigation Service, 1935 Soil Conservation Service, 1937 Soil Conservation Service, 1941-42 Army Corps of Engineers, and the 1966 U.S. Geological Survey.

By 1966, 7.6% of reservoir storage had been lost to sedimentation. Much of the deposition occurred in the lower parts of the reservoir, corresponding to a 96% reduction in dead storage. The study also computed parameters for water budget analysis and developed surface-water storage-capacity ratings.

DATA:

Table 2. Storage capacities, sediment deposition, and streamflow data

Table 3. Volumes of sediment deposited by 5 ft elevation intervals in San Carlos Reservoir during different periods

Table 7. Estimated tributary inflow into San Carlos Reservoir

Figure 1. Vertical distribution of the volume of sediment deposited within 5 ft elevation intervals at San Carlos Reservoir for the periods 1928-47, 1947-66

Figure 18. Annual combined Gila River and San Carlos River inflows to San Carlos Reservoir for water years 1929-71

Knechtel, M.M., 1938, Geology and Ground-Water Resources of the Valley of Gila River and San Simon Creek, Graham County, Arizona, with a Section on the Chemical Character of the Ground Water by E.W. Lohr, in Contributions to the Hydrology of the United States, 1937: U.S. Geological Survey Water-Supply Paper 796-F, p. 181-222, 2 sheets, scale 1:96,000.

Information on the geology and ground water resources for the Gila River and San Simon Creek, with some discussion of water quality. Knechtel also addresses the recent cycle of erosion beginning in the 1880's and speculates on reasons why this occurred (grazing, climate change, tectonism), but does not provide any data to support his theories. Channelization may have been started by a channel excavated in 1883 near Solomonsville (20 ft wide and 4 ft deep) to confine flow (Olmstead, 1916); headcutting reportedly followed wagon roads for the most part. Stock trails did not seem to be important as incision began before stock were introduced in the area.

DATA:

Generalized well logs of Quaternary alluvium (p.201): Solomonsville and eastward; San Simon Creek to Safford

Lippincott, J.B., 1900, Storage of Water on Gila River, Arizona: U.S. Geological Survey Water-Supply Paper 33, 98 pp.

Focuses on Gila River Indian Reservation.

Maddock, T., Jr., Kimball, Frank, Cooperrider, C.K., Hathaway, G.A., and Hoyt, W.G., compilers, 1940, Upper Gila River Basin Report: National Resources Planning Board Water Resources committee, Sub-committee on Gila Basin, 227 pp.

Reviews precipitation, surface water, and ground water records. Looks at many factors which may effect water resources, sediment movement, land stability: soils, ground water resources, floods, land use practices, vegetation, rainfall, and climate change. Catalogues structures and/or type of structures that have been used to manage the upper Gila River basin resources.

Describes floods from 1833 to 1937. The following years are recorded as flood years in Maddock et al.:

1833	1905	1915	1920	1929	1935
1869	1906	1916	1921	1930	1937
1884	1911	1917	1923	1931	
1891	1912	1918	1925	1932	
1903	1914	1919	1926	1934	

Based on precipitation records in the Gila River basin, precipitation has fluctuated as follows:
1874-1884 - above normal
1891-1904 - severe drought
1913-1916 - wet
1920-1925 - drought
1931-1937 - below normal

Maddock et al. cites the largest sediment sources as the San Simon valley and headwater areas on the Gila River.

DATA:
Table 1. stream gradients of basin sections
Table 2. Precip. Stations in and near upper Gila River basin
Table 3. Distribution of annual precip. By month (big avg.)
Table 4. computed annual and seasonal precipitation (71-73 yr means)
Table 5. annual precip. And 5-yr progressive average
Table 6. summer precip. And 5-yr progressive average
Table 7. non-summer precip. And 5-yr progressive average
Table 8. summer & non-summer temp. and 5-yr progressive average (@ Phoenix, AZ)
Table 12. gaging stations as of July 1940
Table 13. discontinued gaging stations
Table 26. monthly runoff data @ San Carlos Reservoir
Table 43. Silting rate of San Carlos Reservoir—6 years of record
Table 44. Acreage of cultivated lands
Table 46. Present state of vegetation, effectiveness in erosion control
Table 53. Relations of erosion activity to erosion status, relief, soils, vegetation, and land uses
Descriptions of canal systems (p. 215-26)

McGinnies, W.G., and Douglass, B.K., 1934, Inspection Report of the Vegetative Conditions of the Safford Erosion Project, October 23-26, 1934, 13 pp., 9 photos.

This study monitors the response of natural vegetation to protection from overgrazing and the effect of the protection on artificial reseeding work. Some check dams and small embankment structures (basically rip rap) were seeded in 1934 while permanent photographic stations and fenced plots were set up to monitor vegetative conditions. Authors did notice some revegetation 6 months into the study (when this document was prepared). Their purpose was to stabilize channel banks to reduce erosion that had been

occurring along the Gila River. They allude to the effect of overgrazing that might be contributing to the erosion, but admit that there is no substantial evidence that overgrazing has caused the erosion.

Meko, D.M., and Graybill, D.A., 1993, Gila River Streamflow Reconstruction, Tucson, Arizona: Laboratory of Tree-Ring Research, 16pp.

Reconstructed streamflow using tree ring record from 1663-1985 for three gages on the Gila River: Gila River at Head of Safford Valley, Gila River near Clifton, and San Francisco River at Clifton.

They concluded that:
Low flows are more frequent in the modern period (1916-1985) than in the long-term period (1663-1985).
The long-term minimum annual flow is lower than modern minimum
Mean annual streamflow is highly variable
The largest multidecadal fluctuation occurred from the 1900's to the 1950's
The lowest reconstructed 10-yr mean was from 1947-1956
The highest reconstructed 10-yr mean was from 1906-1915
The peak annual flow signal correlated with the total annual flow. The relation between peak flow and ring width indices is too weak for accurate reconstruction of flood history before the period of gaged flow.

Michael Baker Jr., Inc., 1996, Final Scour Evaluation Report for Graham County, Structure No. 8661 Eden Road Over Gila River, Local Government Bridge Scour Evaluation Study: Arizona Department of Transportation Contract No. 95-42.

Based on a March 1997 inspection, the thalweg elevation for the Eden Road Bridge over the Gila River was 2730 feet (March 6, 1985), while the bed slope measured 0.0015. The report also noted that the river was cutting into agricultural field along upstream south bank severely threatening south approach. Also included in the report are some profiles, a geomorphic description, and topographic information. Discharge needed to overtop the bridge was calculated as 23,360 cfs.

Michael Baker Jr., Inc., 1996, Final Scour Evaluation Report for Graham County, Structure No. 9333 North Eighth Avenue Over Gila River, Local Government Bridge Scour Evaluation Study: Contract No. 95-42 for Arizona Department of Transportation.

Based on a 1995 inspection, the thalweg elevation at the North Eighth Avenue Bridge over the Gila River was 2881.6 feet from measurement at the site, while the bed slope measured 0.0028 from the Safford USGS 7.5' Quadrangle. Measurements were made at the bridge to estimate flow parameters from a flood occurring on August 14, 1996. The high-water elevation measured 2894 feet, the total scour depth measured 12.2 feet, and the water velocity averaged 4.56 feet/second. This report includes some cross sections, geomorphic description, and a bank protection map from 1939/1941. The discharge needed to overtop the bridge was calculated as 107,000 cfs.

Michael Baker Jr., Inc., 1996, Final Scour Evaluation Report for Graham County, Structure No. 9574 Bryce-Eden Road Over Gila River, Local Government Bridge Scour Evaluation Study: Contract No. 95-42 for Arizona Department of Transportation.

A 1995 inspection of the Bryce-Eden Road Bridge over the Gila River indicates that the thalweg elevation measured 2794 feet. The 1972 flood measured at 82,400 cfs was estimated to have a 100-year

return period. In 1985, the Bank Protection Project was begun and completed in May 1989. This work was performed 2000 feet upstream along the south bank and 1800 feet upstream along the north bank. This apparently was an emergency project in order to repair flood damage caused by the September-October 1983 flood. The report also includes cross sections, geomorphic information, and photos taken in 1995. The discharge needed to overtop the bridge was calculated as 26,400 cfs.

Michael Baker Jr., Inc., 1996, Final Scour Evaluation Report for Graham County, Structure No. 8824 Reay Lane Over Gila River, Local Government Bridge Scour Evaluation Study: Contract No. 95-42 for Arizona Department of Transportation.

Based on an inspection during 1995, the thalweg elevation was 2837 feet at the Reay Lane Bridge over the Gila River. The 500-year flood measured 150,000 cfs at the site; the 1983 flood measured 140,000 cfs. The report includes cross sections, Gila River grading plan map (anthropogenic channel changes), geomorphic information, five soil boring logs for piers, and photos taken on October 18, 1995.

Michael Baker Jr., Inc., 1996, Final Scour Evaluation Report for Graham County, Structure No. 8152 Old Safford Road Over Gila River, Local Government Bridge Scour Evaluation Study: Contract No. 95-42 for Arizona Department of Transportation.

Based on a 1995 inspection, the thalweg elevation for the Old Safford Road Bridge over the Gila River was 3345 feet. The channel appeared to be stable and vegetated with some scouring at abutment. The report includes some 1980 sketch profiles, geomorphic information, and photographs taken in 1995.

Arizona Department of Transportation, 1989;1993, Gila River Bridge at Duncan Office Memos: Arizona Department of Transportation, variously paginated.

Internal office memos from 1989 and 1993 document an aggraded area apparently caused by a constriction that occurs downstream of the bridge and/or dikes along river. The memos include 8.5 X 11 inch photos with debris piled up against the bridge (1979) and an old profile of the structure showing depth of riverbed (circa 1944/1947).

Molitor, Delbert, 1997, Suspended Sediment Monitoring Project, San Simon Watershed, Southeast Arizona: Bureau of Land Management, Safford Field Office, 71 pp.

Evaluated the effectiveness of control structures and management practices in retarding erosion in the San Simon watershed and reducing the amount of sediment actually leaving the watershed; they also were looking for an “upward trend in watershed condition.” (p. 3) Causes of severe erosion in the early 1900’s include ditch constructions which drained excess water off fields in San Simon Valley, the freight wagon trail to Bowie and Simon, 50,000 to 100,000 cattle in watershed, and severe droughts during 1903-1905 and 1914-1915. The Bureau of Land Management initiated this project following the construction of Barrier Detention Dam (1980) and installed monitoring equipment in 1982. In order to monitor the amount of sediment being transported through the San Simon watershed, they established five transects above Barrier Dam across the channel in July 1983 and resurveyed them in mid-1989 and mid-1995.

Established three transects near Bailey Well and Yellowhammer Well in late 1989; resurveyed in early 1992 and 1995. They reoccupied some transects established in 1953 upon completion of Fan Dam and also established photo points. Suspended sediment data was collected from Barrier Dam, Bailey’s Well, and Fan Dam. The study also utilized Weather Bureau and BLM raingages for precipitation data, and Barrier Dam, Yellowhammer, Fan Dam stream gages.

The authors found that at Barrier Dam, flow peaks decrease through time even when precipitation totals increase; suspended sediment yield also decreases through time. In other words, a unit volume of precipitation moved less sediment each year. At Bailey Well, sediment yield fluctuated. There was not a clear pattern of decline; however, data from downstream at Barrier Dam suggest that less sediment is leaving the watershed each year, so there may be sediment being trapped between Bailey well and Barrier Dam. At Fan Dam, the 1990's maximum sediment yield data was less than 1980's maximum sediment yield data (<1,000 vs. >12,000). In conclusion, the authors state that "The marked decline in stormflow, number of flow days, and sediment yield noted during this study are positive indications of the effects of the restoration projects and management programs that have significantly reduced or controlled erosion within the watershed." (p. 63)

DATA:
Plate 1. Location map

Murphy, E.C., and others, 1906, Floods in Gila River Basin: U.S. Geological Survey Water Supply Paper 162, p. 41-54.

Discusses floods during 1905 in the Gila River basin. The flood of January 10-11, 1905 was a major event at the Gila River near Solomonsville. The stream bed at least doubled in width and in some areas, 6 in. to 4 feet of siltation occurred on farmlands. Irrigation works were badly damaged and the railway bridge at San Carlos was washed away. The gage at San Carlos was also washed away; the gage was reinstalled and washed away again on March 17 at a stage of 8 ft. The authors state:

> "The bed of the stream was changing so much during these floods that reasonably accurate estimates of the daily rate of flow at this place cannot be given" p. 43 (referring to gage at San Carlos)

In Clifton, Arizona, damage occurred to the railway bridge and roadbed. Small buildings were swept away and smelters along river were damaged. Another large flood also occurred during the storm of November 27-December 2, 1905.

DATA:
Precipitation records in Gila River and Little Colorado basins, November 26-28, 1905
Daily discharge of Colorado, Salt and Verde rivers during flood of November and December, 1905
Daily discharge records for 1905 on the San Francisco River at Alma, NM.

Olmstead, F.H., 1919. Gila River Flood Control—A Report on Flood Control of the Gila River in Graham County, Arizona: U.S. 65th Congress, 3d Session, Senate Document No. 436, 94 pp.

Document prepared in response to erosion of farmlands, etc. during large floods at the turn of the century. The author proposes structures which could alleviate erosion both in alluvial areas (channelized reach and stabilized banks) and steep tributaries (check dams) in the upper watershed. Olmstead describes what is known about floods in the 1800's as well as in the early 1900's on the Gila and San Francisco Rivers and documents changes in channel width averages through this period. From 1904-1916, he concludes that there were 7 major floods.

DATA:
Precipitation data at San Carlos, Arizona and Clifton, Arizona.
Historic photos of rivers in flood, erosion, and engineering structures such as check dams

Patterson, J.L., and Somers, W.P., 1966, Magnitude and Frequency of Floods in the United States, Part 9. Colorado River Basin: U.S. Geological Survey Water Supply Paper 1683, 475 pp.

Provides station descriptions and peak stage and discharge information for gages in the Gila River basin and other sub-basins in the Colorado River basin.

Paulsen, C.G., 1950, Water Levels and Artesian Pressures in Observation Wells in the United States in 1950, Part 6 – Southwestern States and Territory of Hawaii, p. 6-10.

Precipitation plots in Safford Valley and Duncan Valley

Pfaff, Christine, 1994. The San Carlos Irrigation Project: An Historic Overview and Evaluation of Significance, Pinal county, Arizona: Bureau of Reclamation, Technical Services Center, Denver, Colorado, 94 pp.

Details the history of structures for the SCIP and the availability of water for Indian and non-Indian irrigation projects; notes that water resources were less than anticipated following the construction of Coolidge dam and therefore could not provide the full allotment of water to lands. The reservoir was filled and experienced damage during the floods of 1983 and 1993.

Pope, G.L., Rigas, P.D., and Smith, C.F., 1998, Statistical Summaries of Streamflow Data and Characteristics of Drainage Basins for Selected Streamflow-gaging Stations in Arizona through Water Year 1996: Water Resources Investigations Report 98-4225, 907 pp.

Provides gaging station information, annual peak discharges, rating curve data, basin characteristics, mean monthly annual and monthly discharge data, and other streamflow statistics for selected stations in Arizona.

Upper Gila River gages included in report:

- Gila River below Blue Creek near Virden, NM
- Gila River near Clifton, AZ
- Blue River near Clifton, AZ
- San Francisco River at Clifton, AZ
- Willow Creek near Double Circle Ranch, near Morenci, AZ
- Eagle Creek near Double Circle Ranch, near Morenci, AZ
- Eagle Creek above pumping plant, near Morenci, AZ
- Bonita Creek near Morenci, AZ
- Gila River at head of Safford Valley, near Solomon, AZ
- San Simon River near San Simon, AZ
- San Simon River near Solomon, AZ
- Deadman Creek near Safford, AZ
- Gila River at Safford, AZ
- Frye Creek near Thatcher, AZ
- Gila River at Calva, AZ

Rea, Amadeo, M., 1983. Once a River: Bird Life and Habitat Changes on the Middle Gila: University of Arizona Press, Tucson, Arizona, 285 pp. (Excerpt from Chapter 2: Changes in Bird Habitats: Historic Accounts, pp. 16-34)

Documents habitat on the middle Gila River. The chapter has some interesting repeat photography and accounts of what the river was like in the 19th century.

Robinson, T.W., 1965, Introduction, Spread, and Areal Extent of Saltcedar (*Tamarix*) in the Western States: U.S. Geological Survey Professional Paper 491-A, 12 pp.

Documents the introduction and spread of salt cedar in the western U.S.

Two types of saltcedar grow in the U.S. with two species described for each type: (1) evergreen (*T. aphylla*, *T. tetranda*) which is not aggressive, and (2) deciduous (*T. pentandra*, *T. gallica*). *T. pentandra* grows along river bottoms throughout west and is problematic. Nurserymen first introduced Tamarisk in the early 1800's. In the 1870's they escaped from cultivation. The 1920's was the beginning of public awareness of tamarisk spread and from the 1930's-50's: saltcedar spread rapidly through the western U.S. As of 1961, saltcedar occupied 118,000 acres in Arizona alone. Saltcedar uses 9 acre-feet/acre of water under favorable conditions; a study in Safford valley computed an average annual rate of 4 acre-feet/acre. Saltcedar invasion causes a depletion of streamflow, an increase in area inundated by floods, and an increase in deposition in areas of saltcedar growth.

DATA:
Plate 1. Map of distribution of saltcedar in the western U.S.

Rupkey, R.H., 1956, Recommendations of the Task Group for Studying the Effect of Bureau of Land Management Structures in the San Simon Valley on Contributions of San Simon Creek to San Carlos Reservoir, 14 pp.

Characterizes existing structures put in place to prevent head cutting. The task group recommends that the monitoring study take place in two phases:
Phase 1: measurement of water losses or gains due to existing structures
Phase 2: study of stream flow characteristics below the San Simon-Gila River confluence

Salmon, M.H., 1986, Gila Descending: High-Lonesome Books, San Lorenzo, New Mexico.

One man's lively account of his canoe trip down the Gila River with his dog and cat. The tale begins at the East Fork Bridge on the Gila River in New Mexico and ends about five miles downstream of Bonita Creek in the Safford Valley. This reference contains no data, but rather impressions of the river, its life and places.

Salmon, M.H., 1986, Gila River Odyssey: New Mexico Magazine, July, 1986, p. 37.

An account of M.H. Salmon and his dog's hike in the headwaters of the Gila River.

Secretary of the Army, 1962, Gila River, Arizona, Camelsback Reservoir, Letter from the Secretary of the Army: 87th Congress, 2d Session, Senate Document No. 127, Washington, U.S. Government Printing Office.

A compendium of public comments for proposed Camelsback Reservoir Construction from numerous agencies/entities. This report views the state of the river as follows:

p.15 (20.) "Safford Valley, the main agricultural area above Coolidge Dam, has an average width of about 1.5 miles and a maximum width of almost 4 miles. The river channel is 47 miles long. Flows in excess of about 12,000 cubic feet per second cause appreciable damage to agricultural land. The channel, which is unstable, meanders in a flood plain, which has a width ranging from one quarter to one and one half miles. Under present conditions, the channel has become overgrown with phreatophytes, principally saltcedar and mesquite, which have choked the channel to such an extent that small floods overtop the banks and cause damage to adjoining land. After the channel clearing authorized by the Flood Control Act of July 3, 1958, has been completed, appreciable damage would still occur with flows in excess of about 16,000 cubic feet per second."

The report also discusses diversions and pumping as well as precipitation records and various floods that have occurred. They also review the Probable Maximum Flood and standard design flood as well as estimate the amount of land in Safford valley that might be damaged as a result of large floods. Sedimentation is also discussed briefly and is cited as a major problem and expense.

DATA:
Water diverted and pumped in Safford Valley, 1940-1956

Smith, C.F., Sherman, K.M., Pope, G.L., and Rigas, P.D., 1998, Summary of Floods of 1993, January and February 1993 in Arizona, *in* Perry, C.A., and Combs, L.J., eds., Summary of Floods in the United States, January 1992 through September 1993: U.S. Geological Survey Water-Supply Paper 2499, pp. 185-193.

Floods in the Gila River Basin were caused by an abnormal weather pattern which persisted for 2 months, and sent storms through region which produced multiple peak discharges, some of which were peaks of records. Peak discharges with magnitudes greater than 100 year calculated recurrence intervals occurred at Eagle Creek near Morenci (January 18), Bonita Creek near Morenci (January 18), and San Carlos River near Peridot (January 8). The Gila River at Calva peak discharge measured 109,000 on January 20 (RI=60 years). San Carlos Reservoir reached a maximum capacity of 1,060,000 on January 20; outflow from the reservoir measured 29,300 cfs. Major factors in creating this large flooding episode included the duration and intensity of precipitation and rain-on-snow effects.

Smith, Winchell, and Heckler, W.L., 1955, Compilation of Flood Data in Arizona, 1962-1953: U.S. Geological Survey Open-File Report, 113 pp.

Provides information on the general characteristics of precipitation and floods, the location of gaging stations and miscellaneous flood records, the period of record for each gaging station, flood frequency curves for selected gages including the Gila River near the head of Safford Valley, and annual peak discharges and stages for gaging stations in Arizona.

Thomas, H.E., 1962, The Meteorologic Phenomenon of Drought in the Southwest: U.S. Geological Survey Professional Paper 372-A, 42 pp.

Defines drought as "a natural condition caused by less than average precipitation over a certain period of time". The author looks at the reasons or causes for drought from a meteorologic perspective and how it is expressed in nature. Drought is measured as changes in soil moisture, precipitation, stream flow, and groundwater levels. Other data sources for looking at long term record of drought include: tree rings, lake levels, weather records, stream flow records, historical documents, and pollen records. Droughts are generally 10 to 13 years in length and seem to correspond to the sunspot cycle. The greatest historical drought in the study area occurred from 1942-1956.

DATA:
Figure 3. Map showing mean annual precipitation in the Southwest
Figure 4. Map showing meteorologic zones in the Southwest
Figure 6. Map showing area of drought in the Southwest, 1942-56

Thorp, E.M., and Brown, C.B., 1951, Sedimentation in San Carlos Reservoir, Gila River, Arizona: U.S. Soil Conservation Service Technical Paper 91, 26 pp.

Used reservoir surveys from 1915 to 1947 to assess sedimentation and loss of storage in San Carlos reservoir. Between 1928 and 1947, the total loss of storage was 4.54 percent with an average annual loss of 0.25 percent or a volume of 3161 acre-feet. The average annual sediment concentration in the inflow was 1.24 percent.

DATA:
Table 1. Surface area, capacity increments, and cumulative capacity of original and all surveys by 5 ft contour intervals (1915, 1935, 1937, 1947)
Table 2. Ground water pumping and stream flow into and from Safford Valley
Table 3. Water inflow and sediment content between surveys and from beginning of storage
Table 4. Summary of pertinent data, San Carlos Reservoir, Arizona
Figure 2. Area-capacity curves
Figure 3. Sediment distribution according to depth and length of reservoir
Figure 4. Upper Gila River Watershed sediment production areas
Figure 5. Stream flow at San Carlos site, water years 1896-1947 (annual flow, I am not sure how they got the data for the early years.)
Figure 6. Water surface levels at San Carlos Reservoir (1930-1947)
Figure 7. Longitudinal profiles along principal axis of San Carlos Reservoir
Figure 8. Transverse profiles, San Carlos Reservoir, 1915, 1947

Turner, R.M., 1974, Quantitative and Historical Evidence of Vegetation Changes Along the Upper Gila River, Arizona: U.S. Geological Survey Professional Paper 655-H, 20 pp.

Used vegetation maps to study vegetation change along the upper Gila River from 1914 to 1964. Prior to 1900, stands of cottonwoods and willows, mesquite, seepweed and seepwillow dominated with very little saltcedar. From 1914-1964, saltcedar increased in abundance at the expense of seepwillow and cottonwood, while mesquite increased and replaced much of the arrowweed. Turner found that the reduction in channel area coincided with increased acreage of saltcedar and decrease in seepwillow and cottonwood acreage.

DATA:
Figure 4.Change in areas dominated by selected phreatophytes and in areas occupied by channel, subreach 1
Figure 6. Changes in channel configuration, sub-reach 1, 1914-62

Figure 7. Periods of no flow, April 1 through August 31, 1930-64, Gila River at Calva
Figure 9. Water surface level, San Carlos Reservoir

U.S. Army Corps of Engineers, Los Angeles District, 1941, Hydrologic Data, Storm of August 13-14, 1940, Arizona and New Mexico: Gila River and Tributaries Arizona and New Mexico, Survey for Flood Control: U.S. Army Corps of Engineers, Los Angelos, California, 14 pp., 23 plates.

Provides hydrologic data affecting the Santa Cruz River basin and Upper Gila River Basin, especially precipitation, discharge, and meteorological data. The meteorological data is the most detailed.

DATA:
Table 2. Precipitation observations, storm of August 13-14, 1940
Table 4. Flood of August 13-14, 1940, summary of run-off data
Plate 1. Isohyets, total rainfall, storm of August 13-14, 1940
Plate 18. Storm of August 13-14, 1940 hydrographs
Plate 22. Storm of August 13-14, 1940 peak discharges, streams in Arizona and New Mexico

U.S. Army Corps of Engineers, 1973, Flood Damage Report, Flood of October 1972, Gila River Basin above San Carlos Reservoir, Arizona and New Mexico.

Describes the storm and associated flooding that occurred from October 17-21, 1972. Abundant precipitation earlier in the month preceded the late-October 1972 storm and flood. The storm of October 3-7, 1972 was derived from tropical storm Joanne and caused heavy rains to fall over the Gila River basin. Additional precipitation fell from October 12-13, 1972, partially maintaining high soil-moisture and water table levels.

The October 17-21, 1972 storm was associated with a broad band of tropical moisture over Arizona and western New Mexico, which intensified over the storm period. Most of the precipitation fell between 12 a.m. October 18 and 12 a.m. October 19. Peak discharges were estimated as 82,400 cfs, 0800 October 20, 1972 at Gila River near Clifton and 64,000 cfs, 0300 October 20, 1972 at San Francisco River at Clifton. The overflow area extended from San Carlos Reservoir upstream to Cliff-Gila valley.

In the Safford Valley, Hollywood was inundated with depths exceeding 4 ft in places. Irrigation structures, and approaches to Solomon Bridge, Pima-Bryce Bridge, Reay Lane Bridge at Thatcher were heavily damaged. No bridges were washed out, but all bridges experienced damage to approaches and abutment erosion (exception was Safford Bridge). Other damages were reported included erosion of levees, washed out revetments, and channel siltation at lower ends of tributaries.

The report quoted the following in Duncan, AZ: “The residents of the town received several hours warning of the impending flood, but apparently the people had more faith in their levee than it deserved. Very few used the advance warning time to remove, raise or otherwise protect those possessions which could be protected. Most of the people were still in their homes when the levee finally failed.” (p. 16)

In Clifton, flotsam became trapped in the Southern Pacific RR and U.S. Highway 666 bridges and two upstream bridges. Floodwaters backed up behind bridges and overtopped and breached floodwalls.

In New Mexico, losses were limited to erosion of agricultural lands. Flood damage was incurred on both the Gila River and San Francisco River

In this report, the U.S. Army Corps of Engineers stated:

"Had Camelsback Dam and the Gila River channel clearing project, authorized projects of the Corps of Engineers, been completed prior to the October flood, most of the flood damages in the Safford Valley would have been prevented." (p. 27)

DATA:
Table 1. Precipitation for gages in region
Table 2. Peak discharges for the flood of 18-21 October 1972 (above San Carlos Reservoir)
Plate 2. Isohyets for total precipitation, storm of Oct. 17-21, 1972
Plates 4-12. Inundation maps for the Gila River flood of Oct. 1972
Plate 13. Inundation map for the San Francisco River flood near Duncan, AZ, Oct. 1972

U.S. Army Corps of Engineers, South Pacific Division, 1975, Water Resources Development, Arizona.

Description of floods on San Francisco River tributary near Clifton and Duncan areas.

Duncan-Virden valley: "In recent years, the flood hazard has increased as a result of the deposition of silt, the growth of phreatophytes (water-loving plants), and the accumulation of snags in the channel." (p. 53)

U.S. Army Corps of Engineers, Los Angeles District, 1984, Upper Gila River Basin Cooperative Study: Public Information Document: Presentation of a Basin Wide Comprehensive Plan for your Consideration, 26 pp.

Document geared toward public, review of alternatives for flood control and water supply on the upper Gila River. Alternatives involve building dams on the upper Gila River, channelization of specific reaches (such as the San Francisco River), and clearing of vegetation in the channel.

U.S. Army Corps of Engineers, 1987, Survey Report for Flood Control Related Purposes, Gila River and Tributaries, Arizona and New Mexico, Upper Gila Interim.

A survey of the characteristics of the upper Gila River and tributaries including general descriptions of the river reaches in the study area, accounts of major floods and their impacts on this reach, history of flood control and related activities, limited soils information, land planning sections, and inundation maps of the flooded reaches.

Table 1 has soil information on the upper reach. There is some land planning sections, flood accounts, descriptions of damage, etc.

DATA:
Inundation maps for the 1983 flood through Safford Valley

U.S. Bureau of Reclamation, 1960, Report on Water Salvage and Water Conservation Benefits from Channel Improvement, Gila River, Camelsback Reservoir Site to Salt River, Arizona.

Reports on the benefits channel improvements would have on the water source of the upper Gila River.

DATA:
Land classification map and class descriptions.

U.S. Bureau of Reclamation, 1963, Memorandum Report – Upper Gila River Investigations – New Mexico.

Contains some land use information and a description of the topography, drainage, salinity/alkalinity, soils, etc. for the San Francisco River tributary drainage basin (including that portion in Arizona), and for the Virden Valley.

DATA:
Table 3. Estimated Sediment Deposition at Five Dam Sites

U.S. Bureau of Reclamation, 1971, Upper Gila River Project, Regional Geology; Geology of Alma Dam and Reservoir Site, Geology of Reserve Dam and Reservoir Site, Geology of Camelsback Dam and Reservoir Site: Phoenix Development Office.

This document has a three page summary of geologic investigations (1929-1930) by BOR contained in November 15, 1930 "Upper Gila River Investigations of 1925-1930." In 1959, the COE augered 57 test holes along the Gila River 9-19 miles downstream for borrow data. The report includes a site plan, profiles, and soil logs for Camelsback Damsite by the Office of the District Engineer, Los Angeles, CA 1959.

U.S. Bureau of Reclamation, 1974. Upper Gila River Project, Concluding Report: U.S. Bureau of Reclamation, 79 pp.

Investigates structural solutions to water resource issues along the upper Gila River. Proposes the construction of dams on the San Francisco River (Alma Dam) and upper Gila River (Hooker Dam) and channelization of a 35-mile reach along the Gila River in Duncan/Virden Valley. Basically, the report reviews the water resources and needs for industry, agriculture, mining, and domestic purposes, exploring both surface water and ground water usage. It also outlines the potential resources and benefits which would be provided by proposed reservoirs.

It has been difficult to irrigate in the Gila River valley because of the seasonality of surface flow of the Gila River, limited shallow aquifers that may run dry during the dry season, and by floods that wipe out or damage and silt up irrigation canals, such that fields may not receive irrigation in the early part of the growing season.

DATA:
Table 1. Summary of Climatological Data
Table 4. Average annual ground-water pumpage
Table 5. Historic irrigation diversions-Gila River
Table 7. Streamflow records—Gila River and San Francisco Rivers
Table 9. Historic annual flow at dam sites—Gila and San Francisco Rivers
Table 10. Flood and sediment data

U.S. Bureau of Reclamation, 1977, Draft EIS, Upper Gila Water Supply Study, A Feature of the Central Arizona Project.

Report initiated to develop alternatives to Hooker Dam on the Gila River in New Mexico. The report primarily covers New Mexico (Grant County) but has excerpts of downstream (AZ) conditions. Also has an extensive bibliography.

U.S. Bureau of Reclamation, 1981, Final Environmental Assessment – Modification of Coolidge Dam, A Feature of the San Carlos Project: U.S. Bureau of Indian Affairs, 33 pp.

DATA:

Table 4. 100, 200, and 500 year inflow data for Coolidge Dam
Figure 8. Coolidge Dam, San Carlos Reservoir Elevations

U.S. Geological Survey, Arizona Bureau of Mines, and United States Bureau of Reclamation, 1968, Mineral and Water Resources of Arizona: Committee on Interior and Insular Affairs, United States Senate, Washington, U.S. Government Printing Office.

Generally documents the occurrence of minerals in Arizona, and water resources in Arizona.

DATA:

Table 46. Summary of streamflow data at selected gaging stations in the upper Gila River area, Arizona
Figure 79. Average annual streamflow and surface-water diversions at selected gaging stations for the 20-year period, water years 1947-66
Figure 81. Yearly discharge at three selected gaging stations in Arizona
Figure 82. Average annual runoff in Arizona

U.S. Department of Agriculture, 1941, Preliminary Examination Report, Runoff and Water-Flow Retardation and Soil Erosion Prevention for Flood Control Purposes, Upper Gila River Watershed.

Provides general information on erosion, flooding, damages, soils, storm systems, with minimal detailed data. One interesting observation was that the Gila River floods broke through to the Colorado near Yuma (into the Imperial Valley) during the flood of 1905 and also in 1891 (p. 17-18). This report's perspective on the state of the river is described as follows:

> "Historical records made by early explorers, travelers, United States Army officers, and Government surveyors point to the fact that these tributaries, under undisturbed natural conditions, ordinarily were clear permanent streams. But because of irrigation and because of soil erosion on extensive areas of severely overgrazed range lands, the flows of most of these tributaries have become ephemeral, with infrequent, destructive, flash-flood flows." (p. 3)
>
> "It is doubtful if the regimen of any major stream system in the United States or even the world has been so greatly modified by the works of man as has that of the Gila River." (p. 17)

U.S. National Park Service, Western Region, 1982, The Nationwide Rivers Inventory, Arizona Component, River Data Summaries, Chapter 8, Gila River: U.S. National Park Service, San Francisco, CA.

Provides descriptions of river segments. Segment A, which is our study area, has an average annual flow of 358 cfs for a 67 year period, a maximum recorded flow of 2700 cfs (March 10, 1980), and a minimum recorded flow of 0.04 cfs (several years) from the gage below Coolidge Dam. Land ownership is distributed as follows for segment A: 50% public; 35% reservation; 10% private; 5% state land.

DATA:

16 20-min. video tape cassettes of Gila River flown in August, 1979

U.S. Soil Conservation Service, 1954, Appendix Survey Report, Interim, Upper Gila River Watershed, Arizona and New Mexico: Program for Runoff and Waterflow Retardation and Soil Erosion Prevention: U.S. Soil Conservation Service, Washington, D.C., 83 pp.

Provides information on land ownership, floods, flooding problems and damages, sedimentation problems, sediment source areas, rates of sedimentation, changes in the volume of sediment in the channel, cost-benefit analysis for management decisions, systematic inventory of water resources in Safford and Duncan-Virden valleys between 1939 and 1941, relations between surface flow and groundwater, effects of floods, irrigation, pumping, evapotranspiration on the ground water table, seepage investigations (gains and losses in specific reaches), groundwater quality investigations, seasonal fluctuations, and water budget calculations for Safford Valley and Duncan-Virden Valley.

DATA:

Precipitation records
Mean daily discharge for Safford Valley (1940-41)
Results of seepage studies
Results of evapotranspiration studies
Water used for irrigation in Duncan Virden Valley
Table 2. Approximate acreage of cropland in upper Gila River watershed, and croplands served by San Carlos Reservoir, 1946 (irrigated and non-irrigated categories, principal crops)
Table 11. Sediment volume eroded annually by place and kind
Figure 10. Stage-volume relationships
Figure 13. Cross sections through Gila River flood plain, Safford Valley
Figure 15. Cross sections through Gila River flood plain, Duncan-Virden Valley
Land use maps and descriptions
Annual precipitation contours
Sediment production rates over the Gila River Basin
Stream gaging stations
Total rainfall for the storm of Sept. 27-29, 1942

War Department, United States Engineer Office, Los Angeles, Calif., 1945, Estimates of Long-term Seasonal Precipitation and Run-off, Gila River and Tributaries Above Coolidge Dam, Arizona and New Mexico, Report by the United States Department of the Interior, Geological Survey, Enclosure 6.

This study seeks to answer the question, "What is the average rainfall over the basin and how much of this becomes runoff?" Stations used for the study include: Gila River at Red Rock, NM, Gila River at Guthrie, San Francisco River at Clifton, Gila River at, Solomonsville, Gila River at Calva, San Carlos River at Peridot, and Inflow to San Carlos Reservoir. They compute statistics for the period June 1, 1867-June 1, 1941 and conclude that between 3 and 7% rainfall is converted to runoff; water losses between gages are due to evaporation, transpiration, and groundwater recharge. Large amounts of error may be present in the results; the limiting factor is the precipitation data because their coverage is limited: "Not only are many of the values computed from seasonal indices of wetness, but in several cases the coverage by stations is so sparse that rainfall over areas of several hundred square miles in extent was estimated from a single station." (p. 45)

DATA:

Isohyets for the 73-year mean summer seasonal precipitation
Isohyets for the 72-year mean winter seasonal precipitation
Precipitation-runoff curves for the above gages
Runoff relationships

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TECHNICAL SERVICE CENTER
DENVER, COLORADO

UPPER GILA RIVER FLUVIAL GEOMORPHOLOGY STUDY

BACKGROUND INFORMATION AND SUMMARY ADDENDUM

PREPARED BY

RODNEY J. WITTLER, PH.D.
JEANNE E. KLAWON, M.S.
FLUVIAL HYDRAULICS & GEOMORPHOLOGY TEAM

US Department of the Interior
U.S. Bureau of Reclamation

MARCH 21, 2001

RECLAMATION'S MISSION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

DEPARTMENT OF THE INTERIOR'S MISSION

The mission of the Department of Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

ARIZONA WATER PROTECTION FUND

GRANT NO. 98-054WPF

The Arizona Water Protection Fund Commission has funded all or a portion of this report or project. The views or findings represented in this deliverable are the Grantees and do not necessarily represent those of the Commission nor the Arizona Department of Water Resources.

GRAHAM COUNTY, ARIZONA

COST SHARE AGREEMENT 00-GI 32-0054

Graham County, Arizona, and Reclamation are Cost Share Partners in the Upper Gila River Fluvial Geomorphology Study. The views or findings of Reclamation presented in this deliverable do not necessarily represent those of Graham County.

UPPER GILA RIVER FLUVIAL GEOMORPHOLOGY STUDY

Background Information and Summary Addendum

Prepared By
The Fluvial Hydraulics & Geomorphology Team

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Rodney J. Wittler, Ph.D.
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AUTHORS

Members of the Fluvial Hydraulics & Geomorphology Team from the Technical Service Center are leading the Upper Gila Fluvial Geomorphology Study. The team is a multidisciplinary group of engineers, geomorphologists, and biologists. The members have expertise in water resources management, fluvial geomorphology, paleohydrology, hydraulics, sedimentation, photogrammetry, mapping, fisheries biology, wildlife biology, and riparian vegetation management.

The team members are:

- Dr. Rodney J. Wittler, Hydraulic Engineer. (Hydraulics, Water Resources Management)
- Dr. Daniel R. Levish, Geologist. (Paleohydrology, Fluvial Geomorphology)
- Ms. Jeanne E. Klawon, Geologist. (Fluvial Geomorphology, Geology)
- Dr. Ralph E. Klinger, Geologist. ((Paleohydrology, Fluvial Geomorphology)
- Dr. Blair P. Greimann, Hydraulic Engineer. (Hydraulics, Sediment Transport)
- Mr. Matt B. Jones, Computer Specialist. (Photogrammetry, Mapping)
- Ms. Susan C. Broderick, Fisheries Biologist. (Fisheries Biology, Endangered Species Recovery)
- Mr. Larry H. White, Wildlife Biologist. (Wildlife Biology, Riparian Vegetation Management)

BACKGROUND INFORMATION AND SUMMARY ADDENDUM

INTRODUCTION

This addendum to the deliverable for Task 2 of the Upper Gila Fluvial Geomorphology Study, "Background Information and Summary" (Klawon, 2000) addresses Arizona Water Protection Fund comments. The first section of the addendum addresses applicability of the background information to the project goals and objectives, as well as the relationship of the background information to the development of the Field Data Collection Plan (FDCP), Task 3. The second section of the addendum addresses communication with the Arizona Game and Fish Department regarding on-going fisheries studies.

RELATION TO PROJECT GOALS, OBJECTIVES, AND FDCP

This section addresses the first part of AWPF comment 2 from the January 2, 2001 letter from Rodney Held to Will Wright.

> 2. …The contract requires…a discussion on the applicability of reviewed information tot he project goals and objectives, or demonstrate how the information will be used in developing the Field Data Collection Plan (Task 3).

There are several premises of the Upper Gila River Fluvial Geomorphology Study that differentiate it from previous studies. First, previous studies had their own purpose and objectives, expressed in the types of information produced and published. Second, the purpose of the Upper Gila Geomorphology Study is to support and assist the future management of the Gila River. Third, the current study requires products that until recently were economically and technically unfeasible. Fourth, merging technical innovations of the paleohydrology and river restoration disciplines creates new means for assessing the current conditions of large river systems, and further to support adaptive management of river and watershed resources. Previous studies focused on flood control, water supply, habitat, water quality, and other subjects. The purpose of the current study is to support future management of the water resources of the Gila River in light of the increasing legal, contractual, aesthetic, regulatory, urban, and agricultural demands on the river and watershed.

The purpose of the Background Information and Summary (Klawon, 2000) was to catalog available information pertaining to the upper Gila River, ensuring that data production tasks in the current study are not repetitive. Previous studies may supplement the hypotheses of the current study. Examples of previous products include historical aerial photography, maps, geometry of selected cross sections, and some channel geometry trend analyses. The purpose of the Background Information and Summary task was to discover and review these previous works, assimilate their relevant portions into the current study, and identify additional data needs. Although the Background Information and Summary task identified many useful sources of information, they are not adequate to prove or disprove the current study hypotheses.

RELATION TO ARIZONA GAME & FISH ACTIVITIES

This section addresses the second part of AWPF comment 2 from the January 2, 2001 letter from Rodney Held to Will Wright.

> 2. …The contract also requires…a discussion regarding the on-going fisheries study being conducted by the Arizona Game and Fish Department, Region V. In addition, the contract requires…an analysis of available hydrological data, including discharge, sediment transport and water quality data to be used in developing the Field Data Collection Plan.

The Arizona Game and Fish Department Region V recently completed reports for an angler survey (Porath and Blasius, 1999) and species composition and distribution (Blasius and Porath, 1999) in the Upper Gila River. Low flow conditions in 1999 and 2000 in the Upper Gila River have impeded attempts to determine the populations and movement of catfish. Providing there is sufficient runoff, they anticipate trapping and tagging the fish during April and May of 2001. The Arizona Game and Fish will also be surveying fish and habitat at 20 locations in the Gila Box RCNA during 2001 in conjunction with the BLM-Safford. Following the References in this report are reproductions of the e-mail communications between Reclamation and the Arizona Game and Fish Department relating to on-going studies on the part of the Arizona Game and Fish Department.

Since publication of the Background Information and Summary final report (Klawon, 2000) we have discovered the report "Basin characteristics and streamflow statistics in Arizona as of 1989" (Garrett, 1991). This USGS Water Resources Investigations Report is a significant analysis of the hydrology of the upper Gila River watershed through 1989. We plan to update the analysis of this report through the year 2000 and perform some additional analysis in fulfillment of Task 9, the Hydrologic Analysis of the upper Gila River.

The Background Information and Summary (Klawon, 2000) also guided the development of the Field Data Collection Plan (Task 3). By identifying information gaps in previous studies and confirming data needs outlined in the current scope of work, the Background Information and Summary provides quality assurance. The Field Data Collection Plan followed from the Background Information and Summary, as well as general data needs of the disciplines of river restoration and paleohydrology, and others. Execution of the plan will provide the additional information necessary to prove or disprove the hypotheses of the current study. This information includes a map of the surficial geology, bed material, detailed topography, recent low-altitude aerial photography, and infrastructure geometry.

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COMMUNICATIONS WITH ARIZONA GAME AND FISH DEPARTMENT

Reclamation and the Arizona Game and Fish Department exchanged the following e-mails in regard to documenting on-going studies and regulatory requirements for the Upper Gila Fluvial Geomorphology Study. Arizona Game and Fish states that no state permits are necessary for the types of field data we have specified.

From: Joan Scott [JScott@gf.state.az.us]
Sent: Wednesday, February 21, 2001 1:21 PM
To: 'rwittler@do.usbr.gov'
Cc: Will Hayes
Subject: upper gila studies

Rod:

The Arizona Game and Fish Department has been conducting fish studies for some time on the Gila River. The person who can give you details on these studies is the Fish Program Manager in our Tucson Office, Will Hayes. I suggest you contact him directly for more details. His email is whayes@gf.state.az.us. His phone number is 520.628.5672 Ext. 135. Will tells me that the studies we have worked on are:

* Angler creek surrvey 1998-99
* Extensive catfish collection and tagging 1998
* Species composition and distribution report
* New contract with BLM to sample fish at sites on the Gila and to replicate catfish tagging

Why don't you contact Will directly for more details.
Thanks.
Joan Scott

****
Joan E. Scott
Regional Habitat Program Manager
Arizona Game and Fish Department
555 N. Greasewood
Tucson, AZ 85745
Phone: 520/628-5672 Ext. 133
Fax: 520/628-5080
Email: jscott@gf.state.az.us
****

From: Will Hayes [WHayes@gf.state.az.us]
Sent: Tuesday, March 06, 2001 4:16 PM
To: 'rwittler@do.usbr.gov'
Subject: RE: upper Gila studies

Hi Rod,
I haven't been ignoring you just very busy with field activity and personal business. As I stated earlier, the Region has done a lot of work on the Upper Gila River since the spring of 1998. We have completed and published reports for an angler survey and species composition and distribution. We did a lot of catfish tagging in hopes of determining population numbers and movements but the river did not run in 1999 or 2000. The snow pack should be adequate for the river to run this spring and we set up for catfish trapping and tagging in April and May. Also, the Region has a small contract with the BLM-Safford to survey fish and habitat at 20 locations in the Gila Box RCNA. I hope these reports are what you were looking for? The memo lists dates and locations for this spring's survey if you'll be in the neighborhood let me know and will put you to work.

<<ugrsurvey help.doc>>
<<Evaluation of the channel and flathead catfish populations in the Upper Gila River.doc>>
<<Upper Gila River Angler Survey 1998.doc>>
<<Upper Gila River Map.tif>>

Will Hayes
Fisheries Program Manager
AGFD, Region V
555 N. Greasewood
Tucson, Az. 85745
(520) 628-5672 ext.135
whayes@gf.state.az.us

-----Original Message-----
From: Rodney J. Wittler [SMTP:rwittler@kayak.do.usbr.gov]
Sent: Wednesday, February 21, 2001 2:20 PM
To: Will Hayes
Subject: RE: upper Gila studies

Mr. Hayes

I am Rod Wittler, a hydraulic engineer with the US Bureau of Reclamation in Denver. I am engaged in a hydraulics and fluvial geomorphology study of the upper Gila River between the San Carlos Reservation and the Arizona state line. You may have discussed this project with my colleague, Jeanne Klawon.

One of our background tasks is to identify any other ongoing studies on the river relating to our study.

Are you aware of any on-going studies?

I already posed this question to Joan Scott and she directed me to you. Any information that you are willing to share will be greatly appreciated.

Please call me at 303-445-2156 to discuss. Thanks in advance.

Rodney J. Wittler, Ph.D.
Hydraulic Engineer
US Bureau of Reclamation
D-8560
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Denver, CO 80225
303-445-2156
rwittler@do.usbr.gov

-----Original Message-----
From: Joan Scott [mailto:JScott@gf.state.az.us]
Sent: Wednesday, February 21, 2001 1:21 PM
To: 'rwittler@do.usbr.gov'
Cc: Will Hayes
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Joan Scott

****
Joan E. Scott
Regional Habitat Program Manager
Arizona Game and Fish Department
555 N. Greasewood
Tucson, AZ 85745
Phone: 520/628-5672 Ext. 133
Fax: 520/628-5080
Email: jscott@gf.state.az.us
****

From: Will Hayes [WHayes@gf.state.az.us]
Sent: Thursday, March 08, 2001 1:51 PM
To: 'rwittler@do.usbr.gov'
Cc: Don Mitchell; Heidi Blasius; Mike Holloran; Devin Skinner
Subject: RE: upper Gila studies

Rod,

You don't need permits to collect sediment and water samples but you would need a wildlife collecting permit to take and process fish and other animals. I can send you the application form if needed.

I would like your field schedule (dates, times, location) to share with the fish program staff and Safford area officers. These officers are the Departments contact to the private land owner for access permission. You may know that the public in the Gila watershed is not very cordial to Federal and State agencies. But Department Officers can and do help with the guiding and interpreting when conducting field activities.

Looking forward to sharing a day in the field.

Our survey schedule might have common dates and locations where we can pool resources to collect data.

Will Hayes
Fisheries Program Manager
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555 N. Greasewood
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-----Original Message-----
From: Rod Wittler [SMTP:rwittler@do.usbr.gov]
Sent: Wednesday, March 07, 2001 11:10 AM
To: Will Hayes
Subject: RE: upper Gila studies

Will,

Thank you for your response. The reports will fill in our background.

Are there any coordination issues between us? Do we need your permission to view the river or take sediment samples?

Rod Wittler

-----Original Message-----
From: Will Hayes [mailto:WHayes@gf.state.az.us]
Sent: Tuesday, March 06, 2001 4:16 PM
To: 'rwittler@do.usbr.gov'
Subject: RE: upper Gila studies

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<<Upper Gila River Map.tif>>

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-----Original Message-----
From: Rodney J. Wittler [SMTP:rwittler@kayak.do.usbr.gov]
Sent: Wednesday, February 21, 2001 2:20 PM
To: Will Hayes
Subject: RE: upper Gila studies

Mr. Hayes

I am Rod Wittler, a hydraulic engineer with the US Bureau of Reclamation in Denver. I am engaged in a hydraulics and fluvial geomorphology study of the upper Gila River between the San Carlos Reservation and the Arizona state line. You may have discussed this project with my colleague, Jeanne Klawon.

One of our background tasks is to identify any other ongoing studies on the river relating to our study.

Are you aware of any on-going studies?

I already posed this question to Joan Scott and she directed me to you. Any information that you are willing to share will be greatly appreciated.

Please call me at 303-445-2156 to discuss. Thanks in advance.

Rodney J. Wittler, Ph.D.

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-----Original Message-----
From: Joan Scott [mailto:JScott@gf.state.az.us]
Sent: Wednesday, February 21, 2001 1:21 PM
To: 'rwittler@do.usbr.gov'
Cc: Will Hayes
Subject: upper gila studies

Rod:

The Arizona Game and Fish Department has been conducting fish studies for some time on the Gila River. The person who can give you details on these studies is the Fish Program Manager in our Tucson Office, Will Hayes. I suggest you contact him directly for more details. His email is whayes@gf.state.az.us. His phone number is 520.628.5672, Ext. 135.

Will tells me that the studies we have worked on are:

* Angler creek surrvey 1998-99
* Extensive catfish collection and tagging 1998
* Species composition and distribution report
* New contract with BLM to sample fish at sites on the Gila and to replicate catfish tagging

Why don't you contact Will directly for more details.
Thanks.
Joan Scott

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