TECHNICAL SERVICE CENTER
DENVER, COLORADO

UPPER GILA RIVER FLUVIAL GEOMORPHOLOGY STUDY

STABLE CHANNEL ANALYSIS
ARIZONA

PREPARED BY

FLUVIAL HYDRAULICS & GEOMORPHOLOGY TEAM
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US Department of the Interior
U.S. Bureau of Reclamation

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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

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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.

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FLUVIAL HYDRAULICS & GEOMORPHOLOGY TEAM

The Fluvial Hydraulics & Geomorphology Team from the Technical Service Center is leading the Upper Gila Fluvial Geomorphology Study. The team consists of geomorphologists, engineers, 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. Mitchell R. Delcau, Hydraulic Engineer. (Hydraulics, Sediment Transport)
- Ms. Susan C. Broderick, Fisheries Biologist. (Fisheries Biology, Endangered Species Recovery)
- Mr. Larry H. White, Wildlife Biologist. (Wildlife Biology, Riparian Vegetation Management)

STUDY BACKGROUND

The Arizona Water Protection Fund, US Bureau of Reclamation, and the Safford / San Carlos / Duncan Watershed Group are sponsoring the Upper Gila River Fluvial Geomorphology Study in Arizona. The US Bureau of Reclamation in an agreement with Graham County, Arizona, began the fluvial geomorphology study of the Gila River in Arizona between the San Carlos Reservation and the Arizona-New Mexico State line in October 1999. The Reclamation Study Manager is Mary Reece, Phoenix Area Office (PXAO). Co-Principal Investigators from the US Bureau of Reclamation Technical Service Center (USBR-TSC) in Denver, Colorado, are Dr. Daniel Levish, Fluvial Geomorphologist, and Dr. Rodney J. Wittler, Hydraulic Engineer.

The goal of this study is to diagnose the fluvial geomorphological attributes of the upper Gila River. These attributes are a function of the physical processes at work in the stream corridor. The stream corridor includes the mainstem of the Gila River at flood stage and the associated riparian area, as well as tributaries within the valley of the mainstem. The purpose of the study is to increase the awareness of these processes enabling improved local, state, and federal management of the stream corridor. The study includes background information gathering, field data collection, photographic analyses, and a variety of topographic, geomorphic, hydraulic, and hydrologic analyses.

The downstream limit of the study is the San Carlos Reservation. The practical upstream boundary of the study is the Arizona-New Mexico State line. The length of river channel in the study area is roughly 102 miles.

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Stable Channel Analysis

EXECUTIVE SUMMARY

This report presents an analysis of the stability of the Gila River between the San Carlos Apache Reservation and the lower end of the Gila Box, and between the upper end of the Gila Box and the Arizona-New Mexico state line. Stability, according to Mackin (1948), "occurs when, over a period of time, the slope is adjusted to provide, with available discharge and the prevailing channel characteristics, the velocity required to transport sediment supplied from the drainage basin." Lane (1953) defines stability as "an unlined earth channel which carries water, the banks and bed of which are not scoured objectionably by the moving water, and in which objectionable deposits of sediment do not occur." Chien (1955) contends that "…the equilibrium state of an alluvial channel is attained by adjusting the dimensions of the cross section and the slope of the channel to the natural conditions imposed on the channel by the drainage basin."

This analysis utilizes an analytical tool named SAM, developed by the US Army Corps of Engineers, to analyze the channel roughness, sediment transport, and discharge in four reaches of the Gila River in the study area. Input into SAM includes hydraulics produced by the HEC-RAS backwater model, bed material gradation data gathered during the Field Data Collection portion of the Upper Gila Fluvial Geomorphology study, and hydrology analyzed for this report based upon US Geological Survey stream gaging data collected at several gaging stations in the study area. The analysis uses hydrological data from water years 1965-2000.

This analysis indicates that the results of the stable channel modeling are consistent with the geometry of the Gila River in the study area. The modeling indicates that the river is moderately unstable at the effective discharge in many sub-reaches, mostly in the area downstream of Safford and upstream of Sheldon. The modeling shows that the river is stable in a few sub-reaches, mostly between York and Sheldon, possibly due to bed-rock controls in the area. The instability is greatest with respect to the width and sinuosity of the stream. In general the channel has widened in response to an increase in the magnitude and frequency of floods since 1965. Without large floods in the future the channel will narrow and may locally aggrade, similar to the 1935-1965 period.

STUDY AREA & REACHES

The downstream limit of the study area is the San Carlos Apache Reservation. The upstream boundary of the study is the Arizona-New Mexico State line. Figure 1 shows the study area and several landmarks, tributaries, towns, and highways. The analysis excludes the Gila Box area.

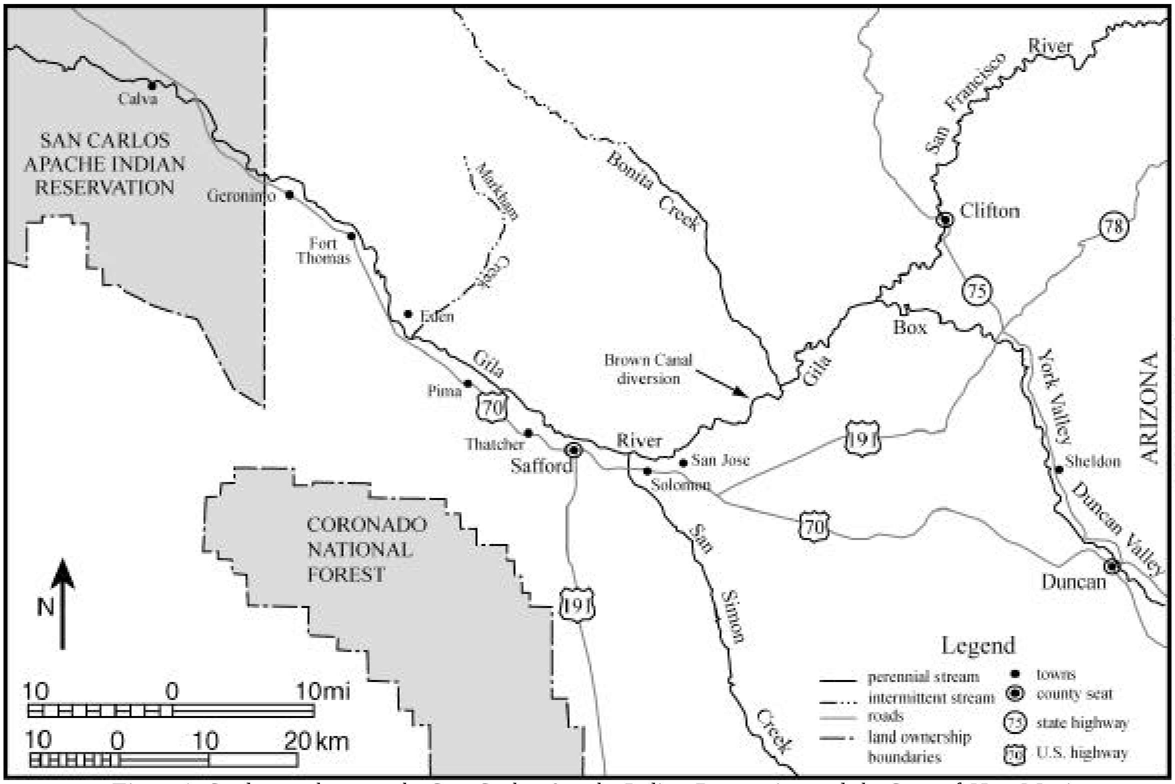


Figure 1. Study area between the San Carlos Apache Indian Reservation and the State of New Mexico.

The length of river channel in the study area is roughly 102 miles. There are two reaches in the study area under analysis, an upper and lower reach. The upper reach includes the study area between York and the New Mexico State line. There are four sub-divided reaches in the lower reach of the study area between the San Carlos Apache Reservation and the head of the Safford valley. The upper reach of the study area uses hydrologic data from the USGS stream gage near Virden, New Mexico. The lower reaches of the study area use hydrologic data from the USGS stream gage at Calva, Arizona, inside the reservation, and the USGS stream gage at the head of the Safford Valley.

REACH DELINEATION

Figure 2 shows the four sub-reaches in the lower reach, all located in the Safford Valley. Beginning at the downstream boundary, the San Carlos Apache Reservation, Lower Reach 1 continues upstream roughly 5.28 river miles or 8.5 km, with the upstream boundary due east of Emery. Lower Reach 2 begins at the Fort Thomas road crossing of the Gila River and continues upstream roughly 5.11 river miles or 8.2 km, with the upstream boundary just northeast of Ashurst, AZ. Lower Reach 3 begins east of Ashurst and continues upstream roughly 11.75 river miles or 18.9 km, with the upstream boundary just upstream of the Dodge-Nevada canal diversion. Lower Reach 4 begins just upstream of the Graham canal diversion, northeast of Safford, and continues upstream roughly 10.83 river miles or 17.4 km, with the upstream boundary just below the San Jose canal diversion dam.

Figure 2. Lower Reaches 1 through 4, delineated by red squares. Note USGS gages at Calva and Head of Safford Valley.

Figure 3 shows the upper reach, located in the York-Sheldon-Duncan-Virden valley. The downstream boundary of the Upper Reach is between Bitter Creek and Sanders wash, downstream of Sheldon. The Upper Reach continues upstream roughly 17.14 river miles, or 27.6 km. The upstream boundary is the Arizona-New Mexico State line.

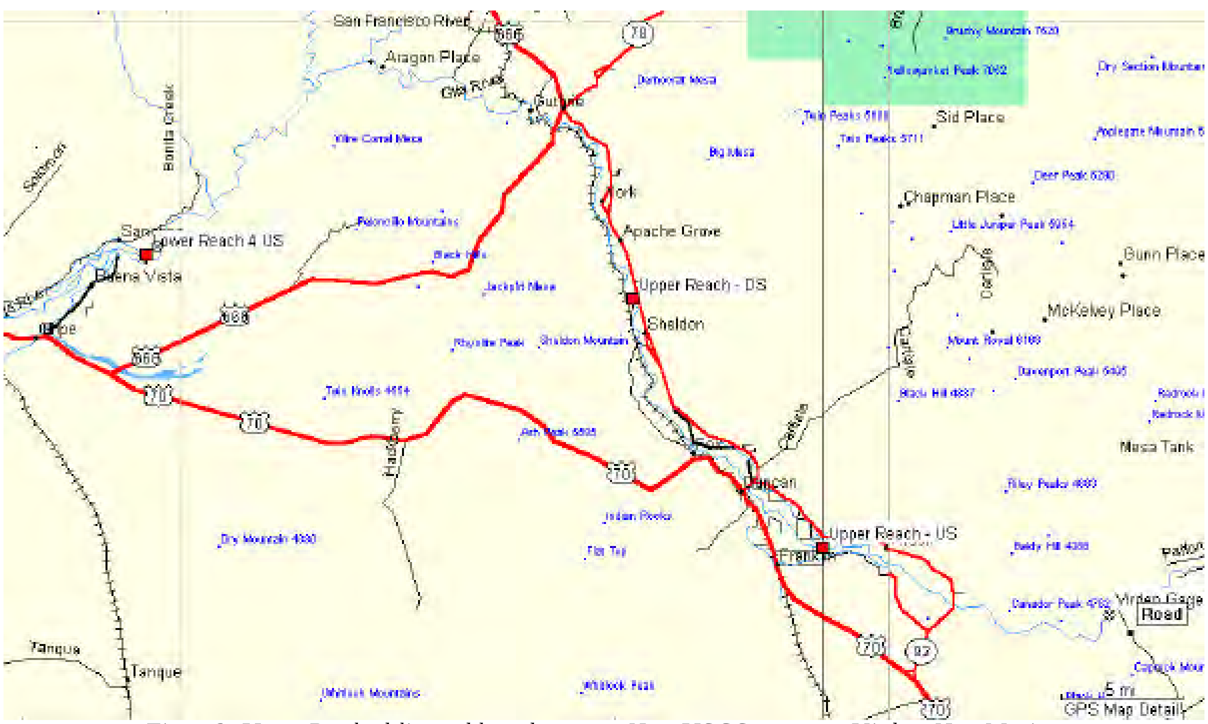


Figure 3. Upper Reach, delineated by red squares. Note USGS gage near Virden, New Mexico.

STABLE CHANNEL CONCEPTS

BACKGROUND DEFINITIONS AND CONCEPTS

A river channel is stable if the river bed is neither aggrading or degrading. It is normal for banks to build, destabilize, collapse, and then rebuild, especially if the river bed is stable. Most abnormal bank behavior is associated with instability in the bed.

A balanced sediment budget is necessary if a river bed is to neither aggrade or degrade. A balanced sediment budget indicates that on average, through time, sediment is not stored in a channel reach, that is that sediment transported into the reach is transported out of the reach.

Water discharge in the river is a function of the hydrology of the watershed. Sediment supply from the watershed uplands is a function of the soil conditions and hydrology in the watershed. Sediment supply from river banks is a function of the relative stability of the river banks. Water discharge in the river channel governs the transport of sediments and the relative stability of the banks.

Velocity of water discharge in the river is a function of discharge, channel shape, valley slope, sinuosity of the plan form of the channel, and the roughness of the river channel boundary, including the bed and banks. An alluvial river channel is formed in alluvium, that is material that is deposited along the banks of a river as a result of erosion. Alluvium consists of different components -- sand, gravel, and topsoil. In the case of the Nile and Mississippi Rivers, rich topsoil from upstream farmland has been deposited as alluvium and created a rich area of agricultural land that is sufficient for growing crops.

Stability, according to Mackin (1948), “occurs when, over a period of time, the (river) slope is adjusted to provide, with available discharge and the prevailing channel characteristics, the velocity required to transport sediment supplied from the drainage basin.” Lane (1953) defines stability as “an unlined earth channel which carries water, the banks and bed of which are not scoured objectionably by the moving water, and in which objectionable deposits of sediment do not occur.” Chien (1955) contends that “…the equilibrium state of an alluvial channel is attained by adjusting the dimensions of the cross section and the slope of the channel to the natural conditions imposed on the channel by the drainage basin.”

Stability of a river reach is dependent upon the following factors:

1) Valley, channel, and water surface slope (sinuosity of the plan form of the river)
2) Channel cross sectional dimensions (width and depth)
3) Roughness of the channel bed, banks, and overbanks
4) Sediment supplied to the reach; transported through the reach; transported out of the reach
5) Discharge into the reach; through the reach; out of the reach

CHARACTERIZING THE CHANNEL WITH A SINGLE DISCHARGE

Rivers have seasonal, annual, and episodic variations in discharge. It is useful, for the purpose of analysis, to derive a single discharge that represents the variation. Hydraulic Engineers and Fluvial Geomorphologists call this single discharge the channel forming or dominant discharge. Researchers have formulated multiple methods for determining the channel forming discharge. Some of those methods are:

1) Average discharge
2) Bank Full discharge
3) Effective discharge

Averaging discharge over a period is the simplest method. This method is the also the least relevant. Average discharge considers only hydrologic response of the watershed reflected in the discharge in the channel. It ignores the channel itself.

According to Copeland (Copeland, 2000), "Bank-full discharge is the maximum discharge that the channel can convey without overflowing onto the floodplain. This discharge is considered to have morphological significance because it represents the breakpoint between the processes of channel formation and floodplain formation." Figure 4 shows the Gila River at the Pima bridge at roughly bank full conditions.

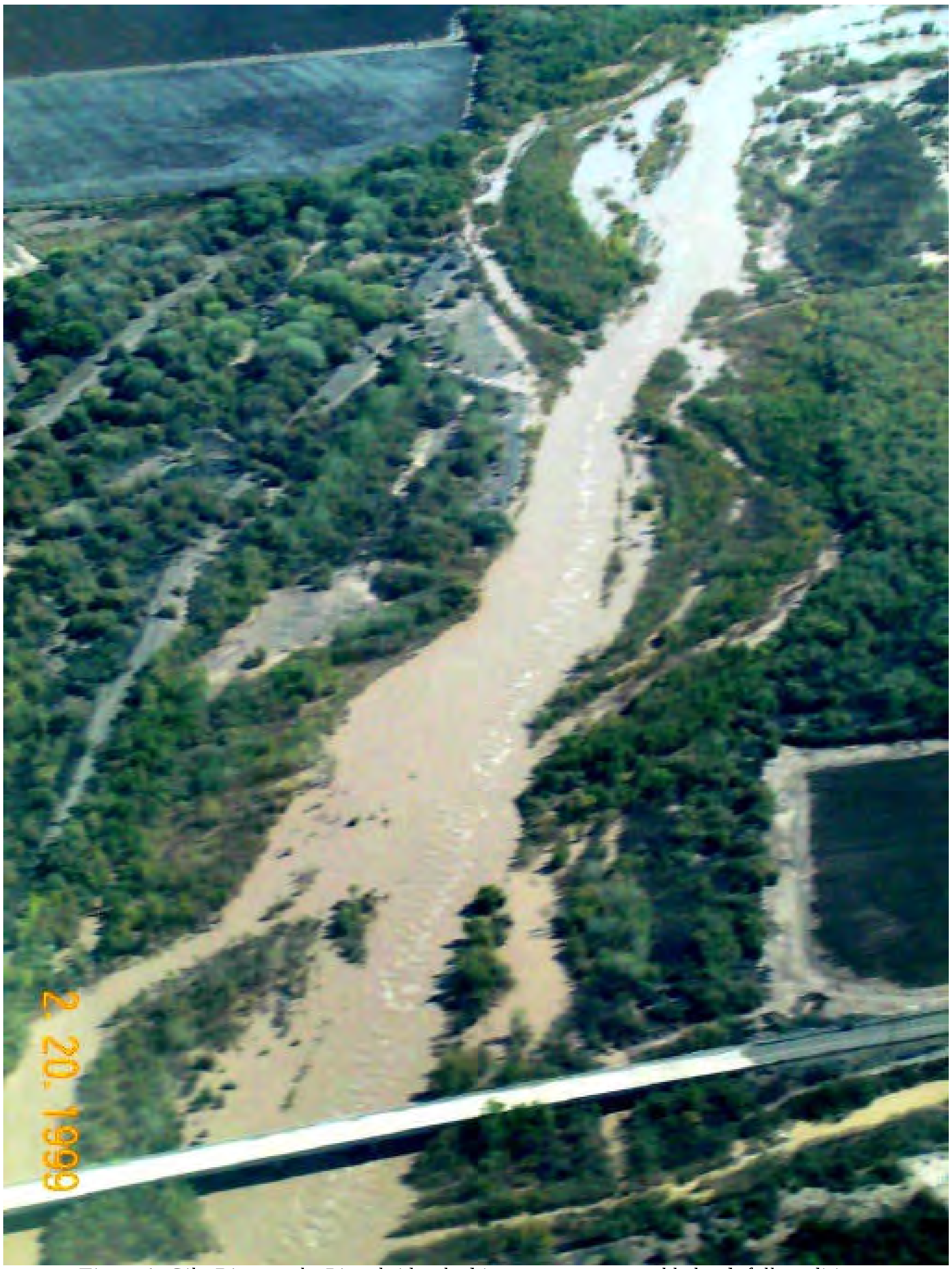


Figure 4. Gila River at the Pima bridge, looking upstream at roughly bank full conditions.

Andrews (Andrews, 1980) defines effective discharge as the mean of the discharge increment that transports the largest fraction of the annual sediment load over a period of years. The effective discharge incorporates the principle prescribed by Wolman and Miller (Wolman, 1960) that the channel-forming discharge is a function of both the magnitude of the event and its frequency of occurrence. It is calculated by convoluting the flow-duration curve and a bed-material-sediment rating curve.

Figure 5 is a USGS illustration of the temporal distribution of suspended sediment transport over the course of several years at the Head of Safford Valley (USGS Gage 09448500).

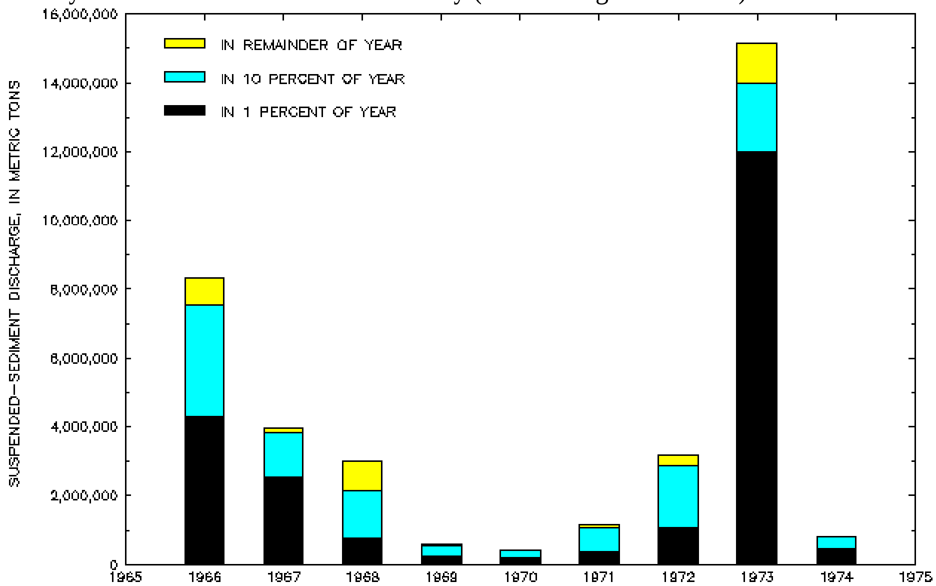


Figure 5. Gila River at Head of Safford Valley suspended sediment discharge (USGS, 2001).

In many years, a single storm may be responsible for transporting the majority of sediment transported during the entire year. The effective discharge accounts for this temporal variation in sediment transport as well as hydrological variation of the discharge. This analysis calculates the effective discharge at three points, representing the five study sub-reaches. They include, at Calva, representing Lower Reaches 1 & 2, at the Head of Safford Valley, Near Solomon, representing Lower Reaches 3 & 4, and Below Blue Creek, Near Virden, NM, representing the Upper Reach.

Figure 6, Figure 7, and Figure 8 show the discharges during their periods of records for the Gila River at Calva, AZ, the Gila River at the Head of the Safford Valley, Near Solomon, AZ, and the Gila River Below Blue Creek, Near Virden, NM. The three records all show an obvious change in the magnitude of the annual peaks following the mid 1960's.

Figure 9 shows Klawon's (Klawon, 2001) analysis of the width changes in the Safford Valley since the 1930's. Klawon reported general widening of the channel beginning in the mid-1960's.

Figure 10 shows the cumulative sediment transport over the entire record (1929-2000) for the Gila River at Calva, AZ (USGS Gage 09466500). The discharges corresponding to the 75th and 25th percentile of total sediment transport are 2,189 m^3/s (77,300 ft^3/s) and 116 m^3/s (4,100 ft^3/s). The mean of these discharges is 1,152 m^3/s (40,700 ft^3/s). The discharge at the 50th percentile is 815 m^3/s (28,800 ft^3/s), a difference of roughly 41%. The range of discharges between the 75th and 25th percentiles and the difference between the mean and the 50th percentile discharge indicates that the entire record does not represent the last 35 years of the record. Using the discharges between 1965 and 2000, the difference is roughly 16%. Based upon these observations, this analysis uses the period of record beginning with water year 1965 for the effective discharge calculations.

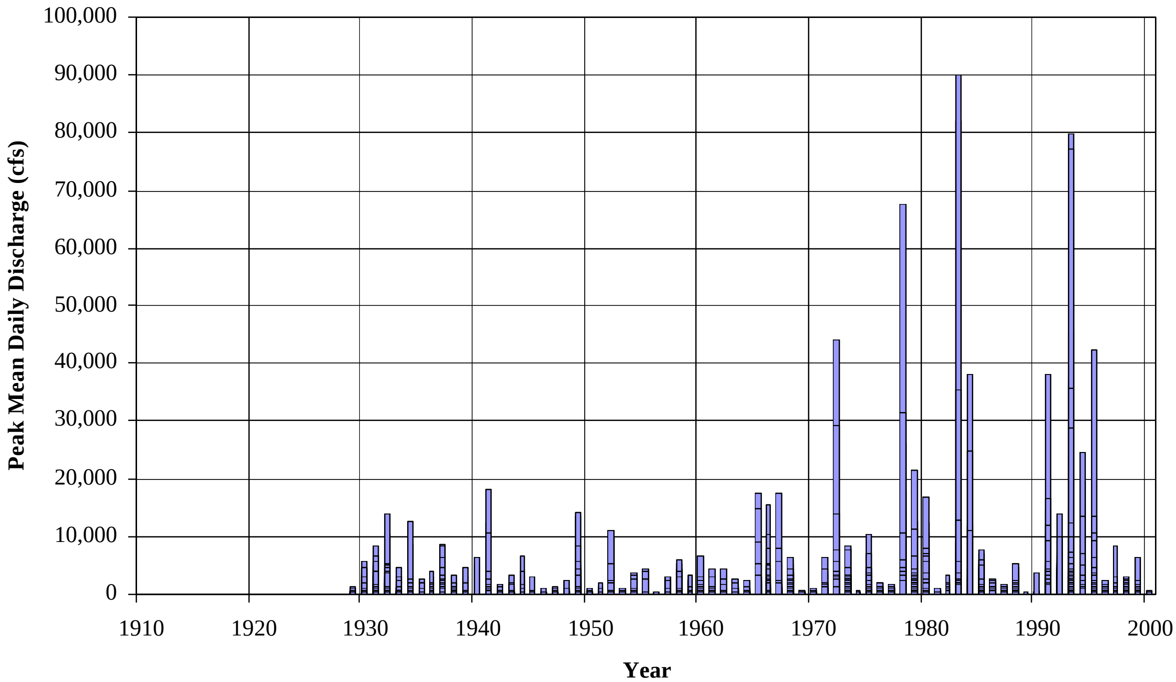


Figure 6. Peak discharges from 1929-2000 for Gila River at Calva, AZ.

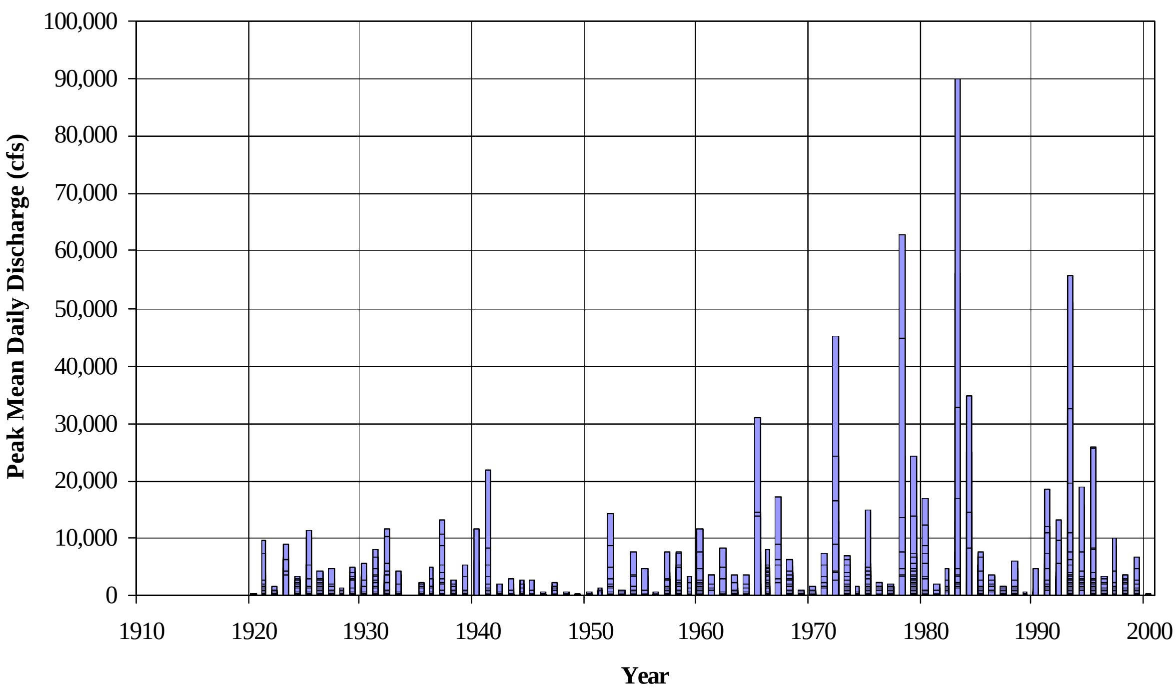


Figure 7. Peak discharges from 1914 to 2000 for Gila River at Head of Safford Valley.

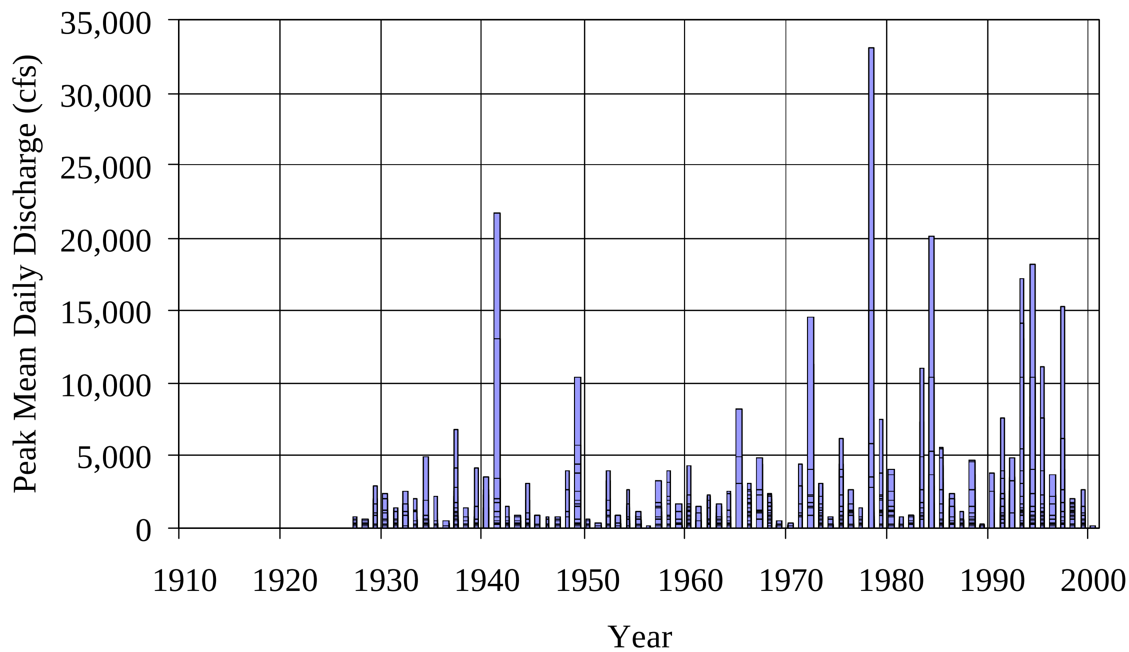


Figure 8. Peak discharges from 1927-2000 for Gila River Below Blue Creek, Near Virden, NM.

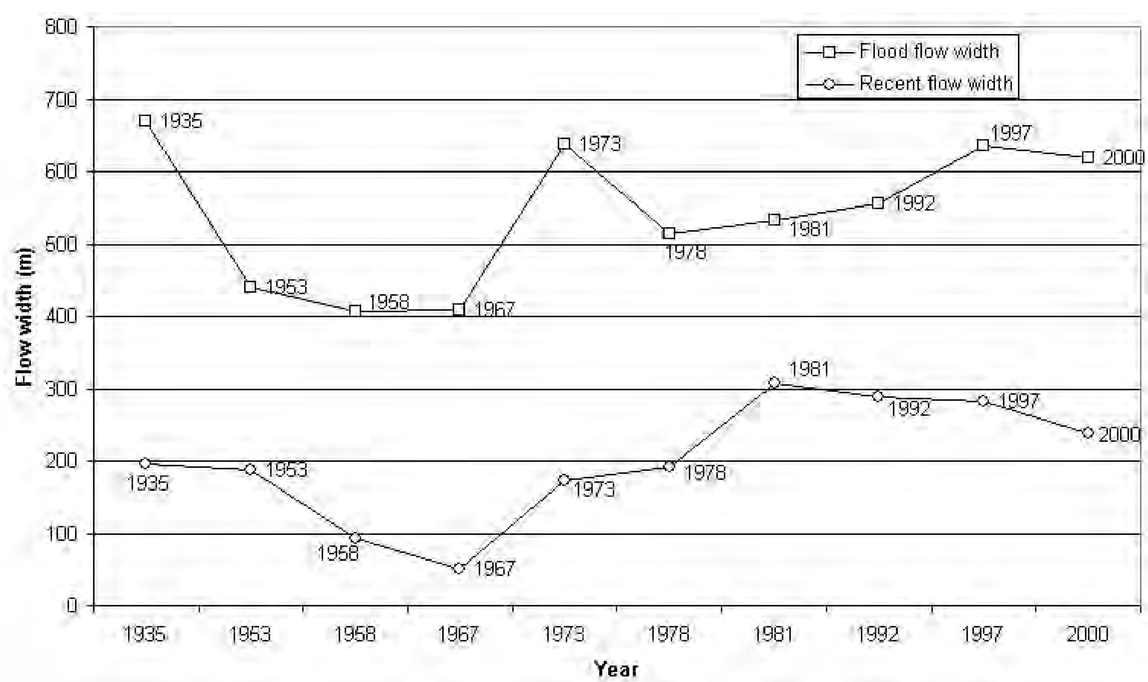


Figure 9. Channel widths in the Safford Valley. (Klawon, 2001)

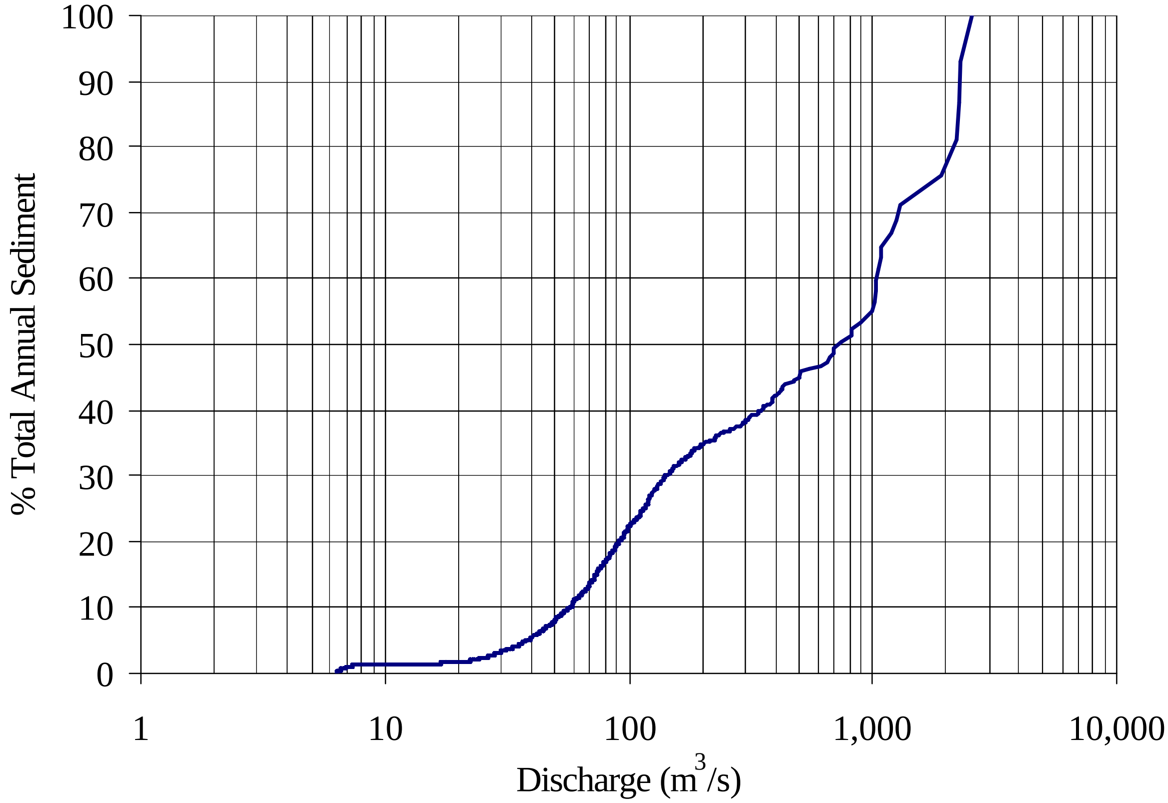


Figure 10. Cumulative sediment transport at Calva from 1929 to 2000.

SAM & RISAD

The SAM model is an integrated system of programs developed through the US Army Corps of Engineers Flood Damage Reduction and Stream Restoration Research Program to aid engineers in analyses associated with designing, operating, and maintaining flood control channels and stream restoration projects. SAM is designed to run on PC computers and is primarily for the design of stable channels. The package satisfies the need for qualitative, easy-to-use methodology, especially for use in preliminary screening of alternatives where funds for more extensive investigations are not available. The Stable Channel Design Method for Gravel Bed Streams, named RISAD, is a Windows version of the SAM - Copeland Stable Channel Design option.

RISAD has additional equations for use in the design of gravel bed streams, utilizing the Meyer-Peter Mueller gravel transport equation. Its design determines the stable width, depth, and slope of a stream given a few characteristics of the study reach. The gravel bed stream equations are not available in the SAM.hyd version of this option.

The graphical user interface (GUI) for this module consists of two windows – the Stable Channel Design Input window and the Stable Channel Design Output window. RISAD, using the effective discharge, HEC-RAS results, and bed material information described in the next section, is the primary tool of this stable channel analysis.

GRADATION OF THE RIVER BED MATERIAL

BACKGROUND

Wittler and Levish (Wittler, 2001) describe the methods, purposes, and intentions of the bed material sampling plan for the Upper Gila Fluvial Geomorphology study. Wittler and Baca, of the US Bureau of Reclamation Technical Service Center Water Resources Research Laboratory, collected the samples according to the procedures specified in the Field Data Collection Plan (Wittler, 2001). Appendix B tabulates all of the sediment samples collected by Wittler and Baca by sample number, date, name, description, latitude, longitude, UTM northing, UTM easting, location in the stream, sample depth, and type, either grab or photographic. Photographic samples were collected in places where the largest particle sizes would not fit into the sample bag. In the numbering system, sample numbers alone generally indicate a grab sample, while a numeric sample number followed by an alphabetic modifier, e.g. 5A, indicates a photographic sample.

Photographic samples were collected first. Then, after removing the large surface particle, a volume of one to three times of the largest particle of finer particles beneath the large particle was collected into a plastic sample bag, using a hand trowel. Care was exercised to collect material immediately below the surface by keeping the walls of the excavation vertical. Photographs of the river in the upstream and downstream directions were also taken from the sample location. Samples were logged and transported to the laboratory for analysis. Figure 11 shows Photographic Sample 44A, near Holyoke, Arizona.

The US Bureau of Reclamation Phoenix Area Office Materials Laboratory, and Gary Stevens, analyzed the grab samples following established Reclamation procedures. Wittler analyzed the photographic samples using the GoldSize program produced by Golder Associates of Seattle, Washington.

Figure 11. Photographic sample 44A near Holyoke, Arizona.

LOCATION MAPS OF BED MATERIAL SAMPLING

The following maps show the locations of the individual samples, indicated by the flag symbol.

Figure 12. Study reach between San Carlos Reservation and the Eden area.

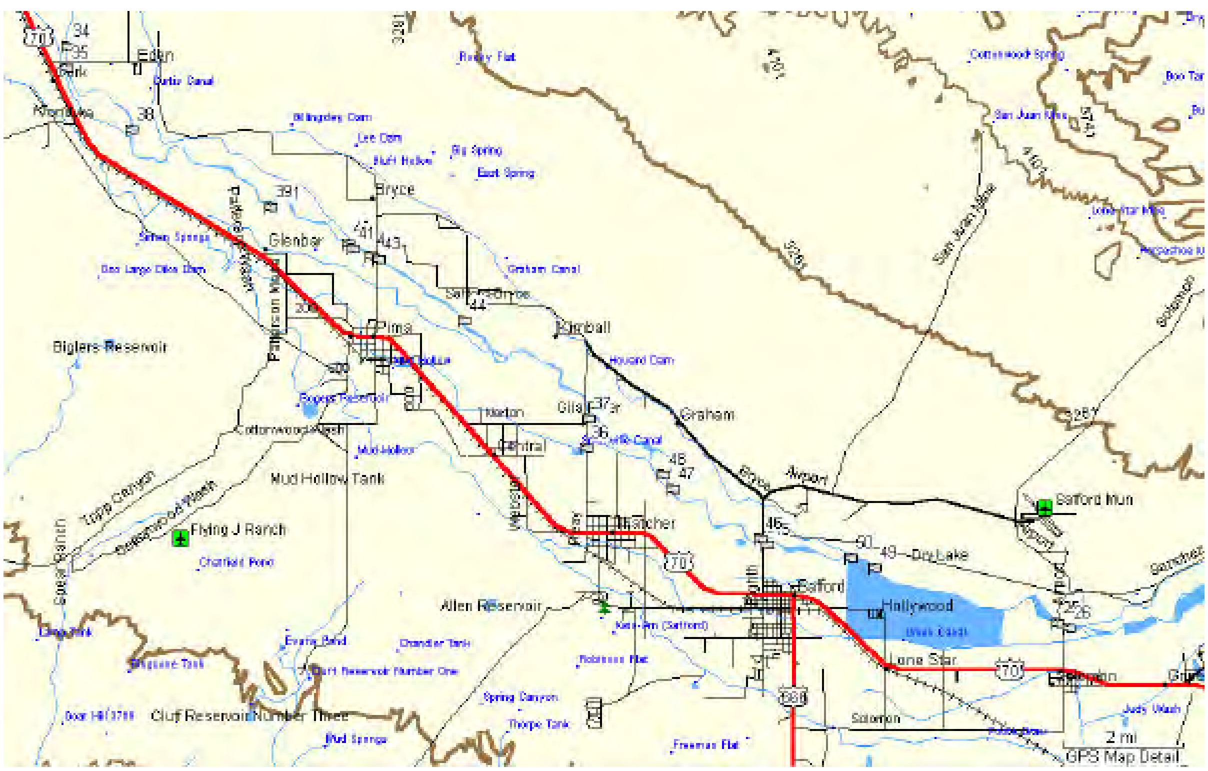


Figure 13. Study reach between the Eden and Solomon areas.

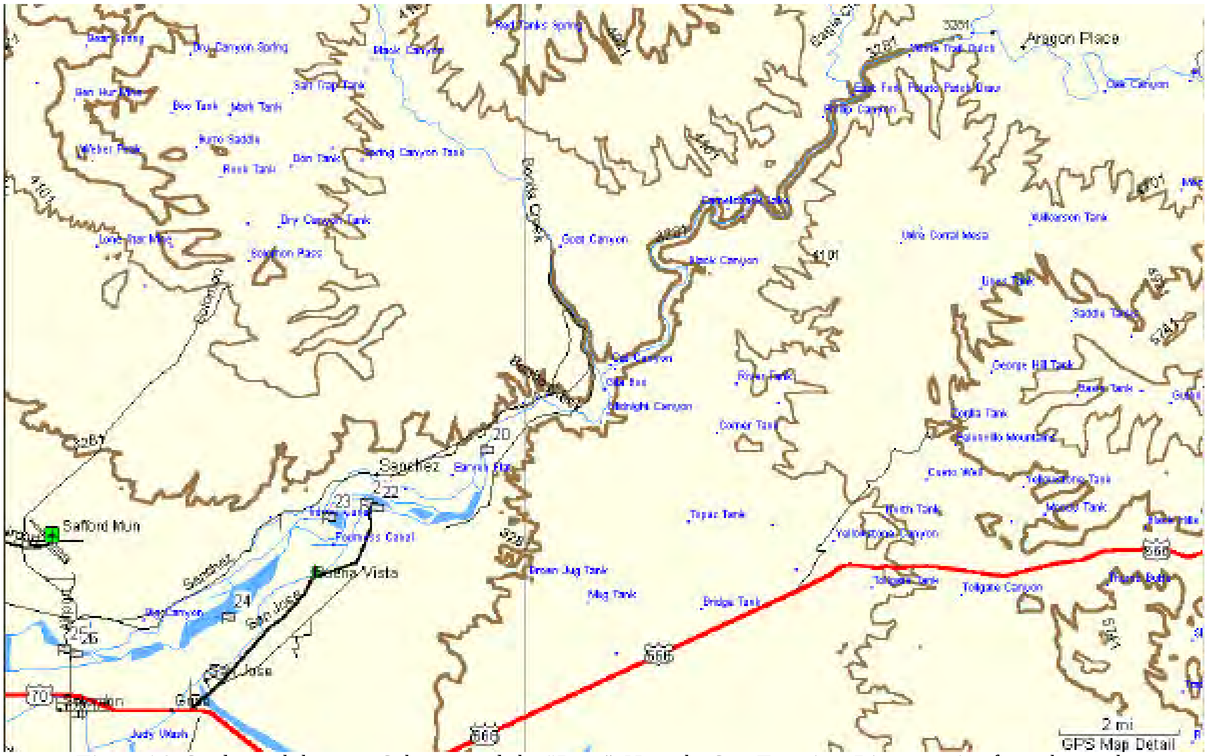


Figure 14. Study reach between Solomon and the “Box.” Note the San Francisco River entering from the north.

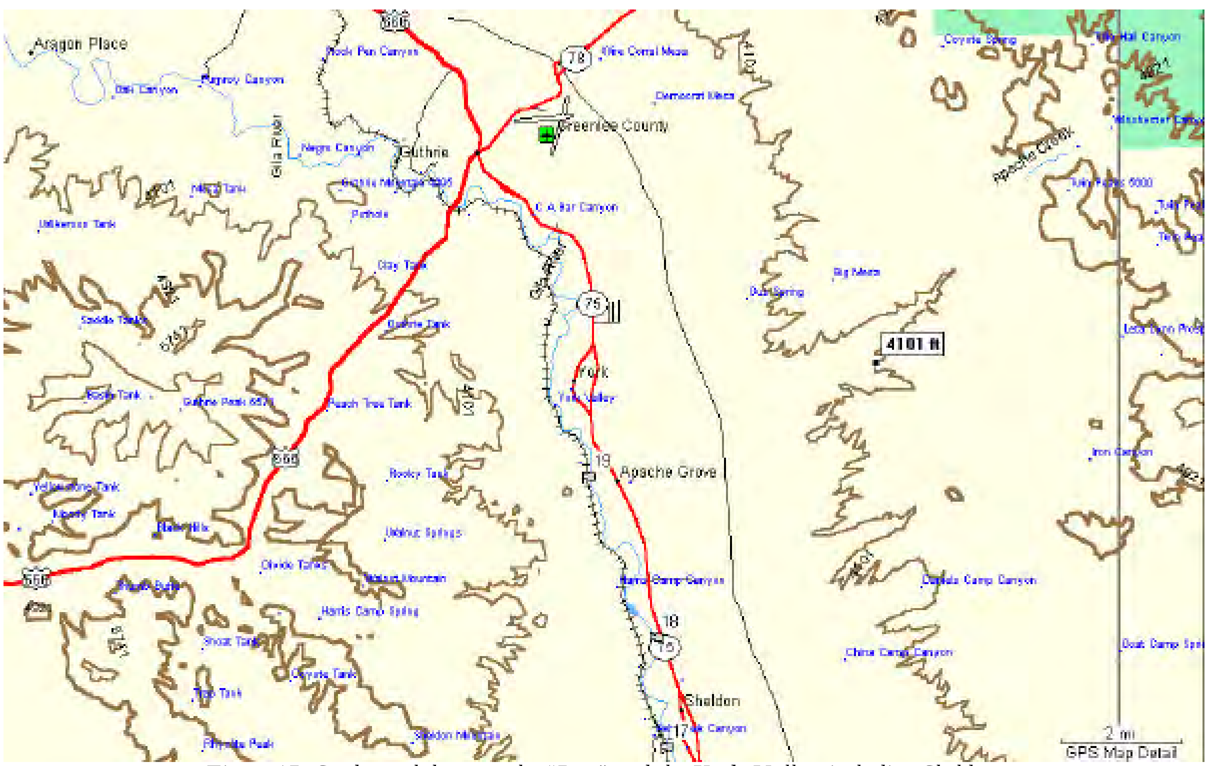


Figure 15. Study reach between the “Box” and the York Valley, including Sheldon.

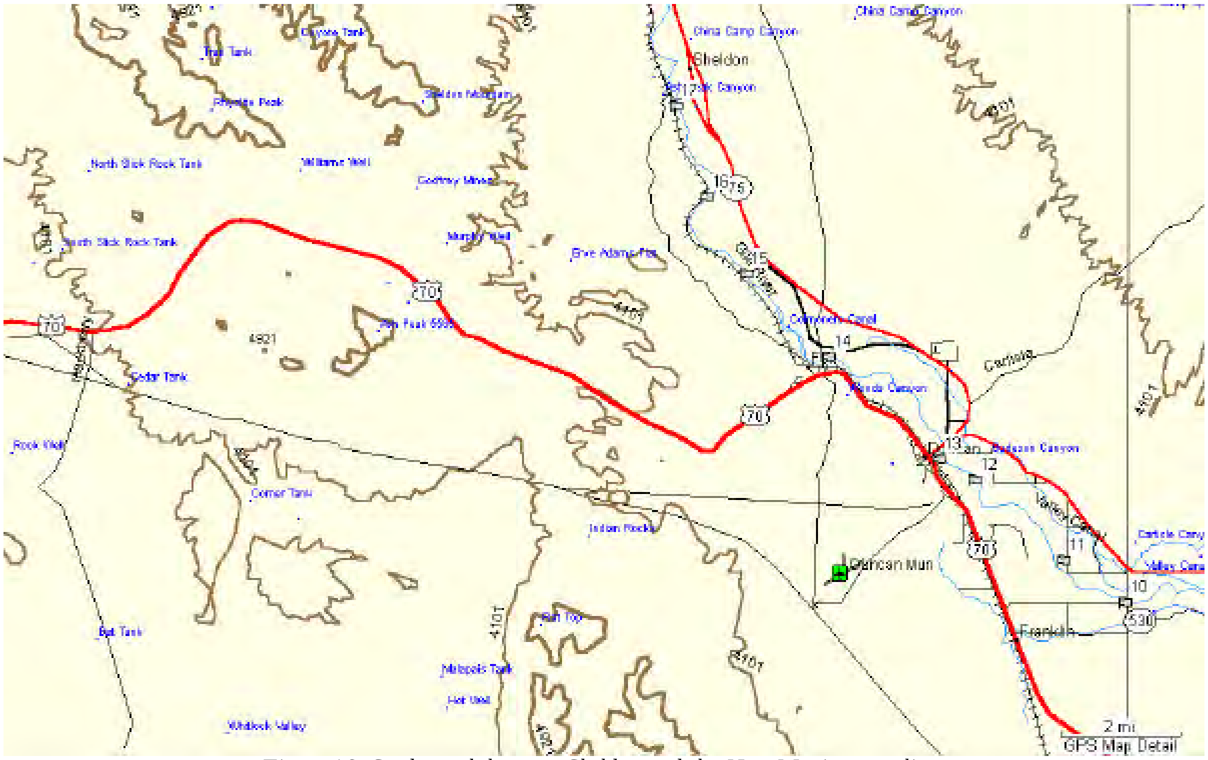


Figure 16. Study reach between Sheldon and the New Mexico state line.

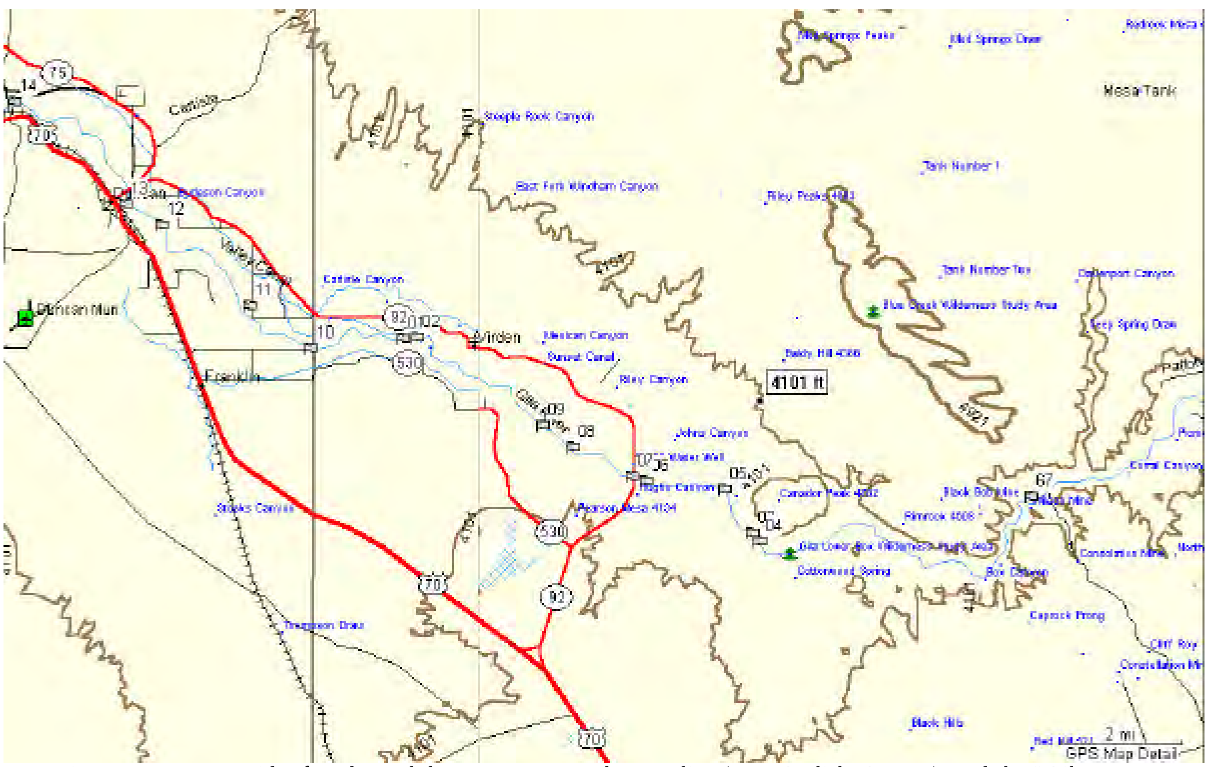


Figure 17. Area outside of study reach between Duncan, the state line (near Carlisle Canyon), and the "Gila Lower Box" in New Mexico, including the Gila River below Blue Creek, Near Virden, New Mexico gaging station.

SELECTED BED MATERIAL SAMPLES

The stable channel analysis and RISAD require a gradation of the bed material as well as a maximum size, D_{100}, and median size, D_{50}. After review of the sample locations and types in each of the four lower sub-reaches and the Upper Reach, the following representative samples were selected for the analysis.

LOWER REACH 1

Grab samples 27 and 28 represent the gradation of the bed material in Lower Reach 1. Sample 27 was collected near the Geronimo USGS gaging station. Sample 28 was collected at the San Carlos Apache Reservation boundary. Figure 18 show the gradations.

Figure 18. Gradations of grab samples 27 and 28, and their mean.

LOWER REACH 2

Grab samples 31 and 33 represent the gradation of the bed material in Lower Reach 2. Sample 31 was collected near upstream of the Fort Thomas River Road.. Sample 31 was collected at Forty Lane. Figure 19 shows the gradations.

LOWER REACH 3

Grab samples 34, 39, and 44, and photographic samples 44A and 44B, and their combinations, represent Lower Reach 3. Figure 20 shows the gradations. The bi-modal nature of the bed material was especially pronounced in Lower Reach 3. There was a large difference, up to four orders of magnitude, between the maximum and minimum sizes of sediment in all of the reaches. The bi-modal nature of the bed material, split between a fine sub-surface layer and a coarse surface layer, made combining grab and photographic samples necessary to characterize the bed material.

Grab samples 34 and 44 are similar. Photographic samples 44A and 44B are similar. Grab sample 39 fell in between the two. The combination gradation consists of a 33.3% portion of grab samples 34 and 44, and a 66.7% portion of photographic samples 44A and 44B. Both the combination gradation and grab sample 39 were applied in the RISAD analysis, with no appreciable difference. The combination gradation was chosen for the final analysis.

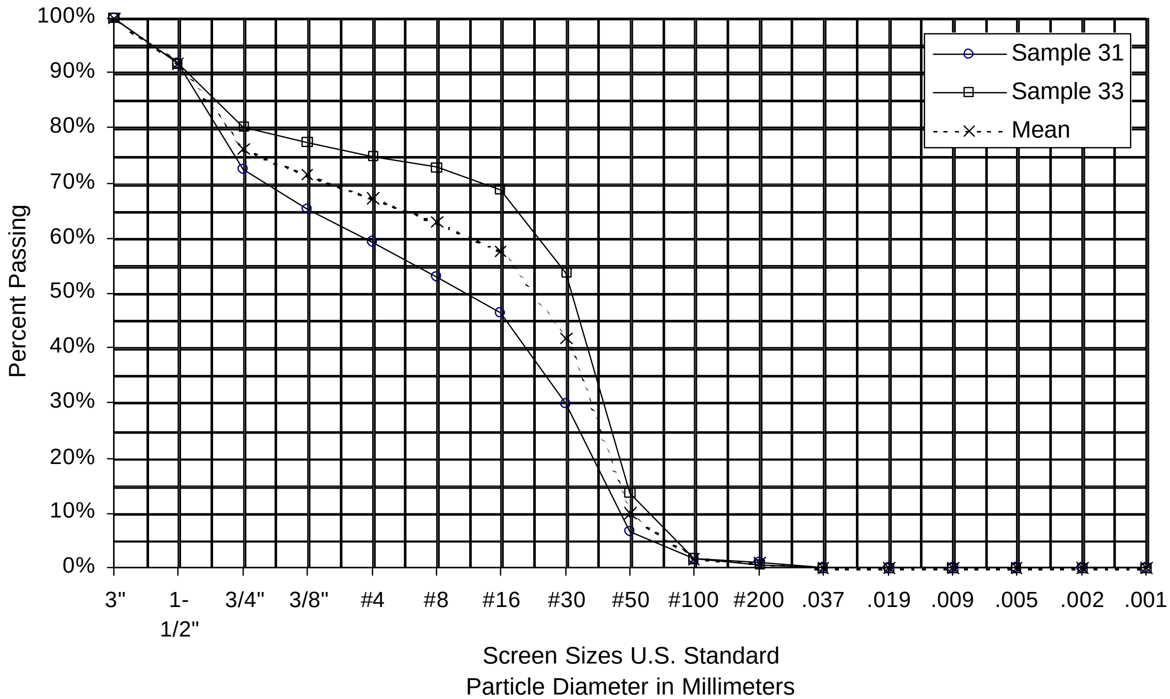


Figure 19. Gradations of grab samples 31 and 33 and their mean.

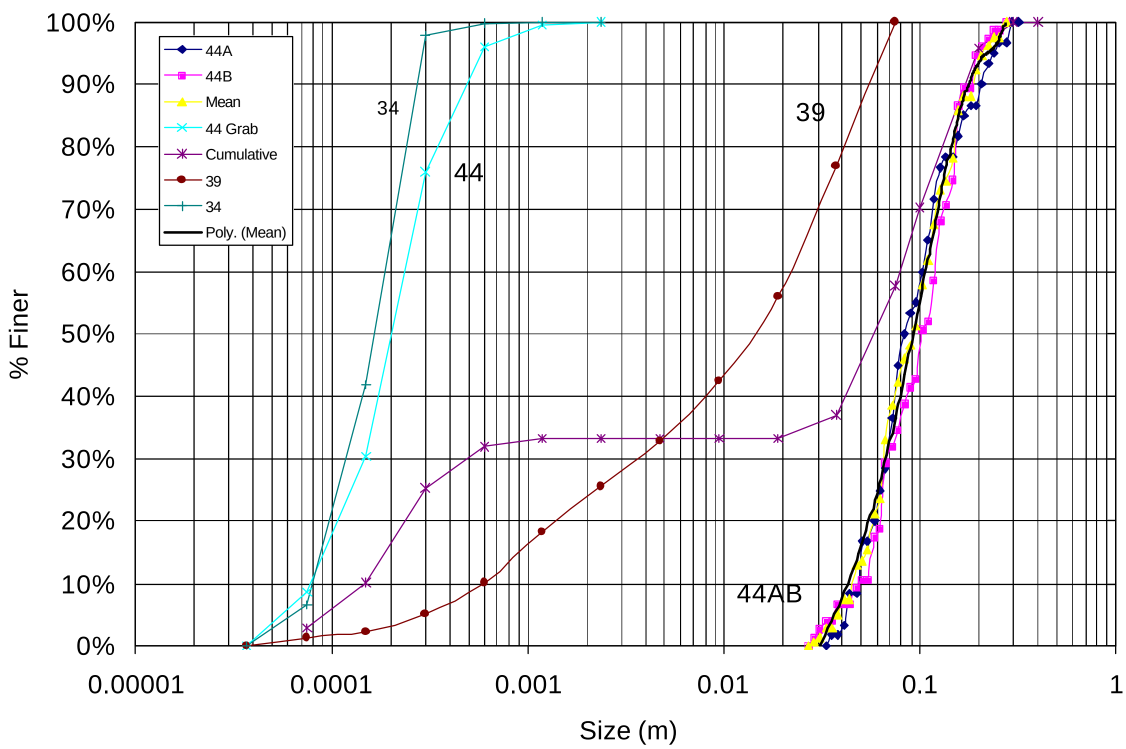


Figure 20. Gradations of grab samples 34, 39, and 44, and photographic samples 44A and 44B, and their combinations.

LOWER REACH 4

Grab samples 23 and 24 represent the gradation of the bed material in Lower Reach 4. Sample 23 was collected near the Brandau farm below the San Jose diversion. Sample 24 was collected near the "runway" below Brandau's farm. Sample 24 was one of the few attempts to collect both the surface and sub-surface material. A single particle greater than 3” (75 mm) in diameter was collected in the grab sample. That is why the sample is designated 24/w, indicating that the sample was analyzed “with” the large particle. The laboratory also analyzed the sample without the large particle. The USGS (USGS, 2001) sampled bed material near the gage at the head of the Safford Valley. That material, collected upstream of the San Jose diversion, is much finer than the bed material collected in samples 23 and 24 below the San Jose diversion.

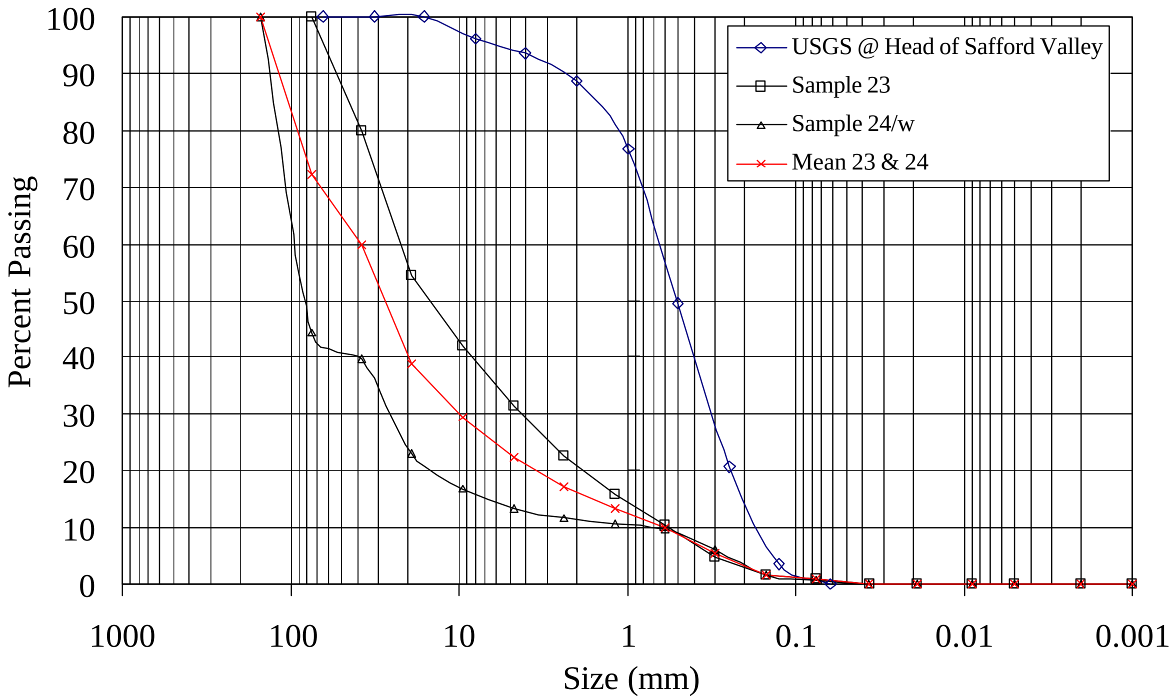
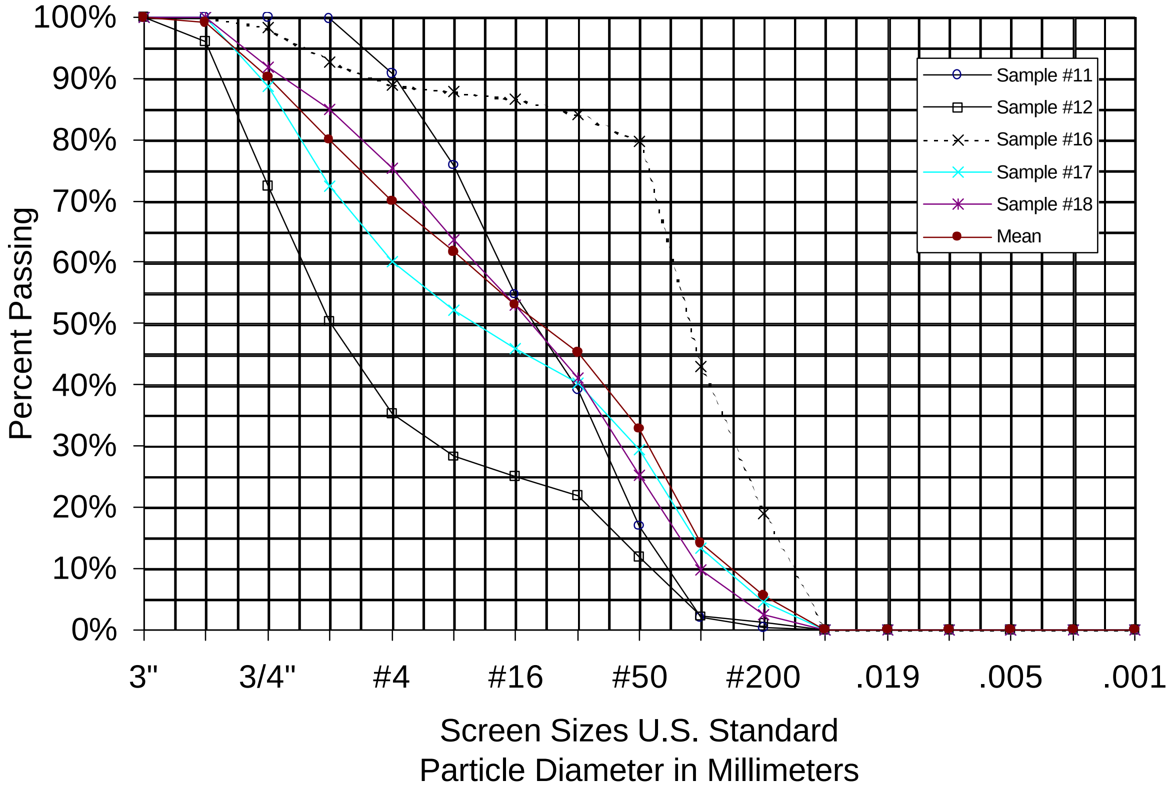


Figure 21. Gradations of grab samples 23 and 24/w, their mean, and the mean USGS gradation from near the gaging station at the head of the Safford Valley.

UPPER REACH

Grab samples 11, 12, 16, 17, and 18 represent the gradation of the bed material in the Upper Reach. Sample 11 was collected near the Lunt farm, upstream from Duncan, Arizona. Sample 12 was collected near Deadman’s Corner, downstream from the Lunt farm. Sample 16 was collected near the Sandia wash levee. Sample 17 was collected near Sheldon, Arizona, and Sample 18 was collected near the flatcar bridge downstream of Sheldon.

The mean of these five gradations appears to represent the range of bed material sizes in the individual samples, being similar to samples 11, 17, and 18, and splitting the difference between the extremes of samples 12 and 16.



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Passing
Sample #11
Sample #12
Sample #16
Sample #17
Sample #18
Mean
3"
3/4"
#4
#16
#50
#200
.019
.005
.001
Screen Sizes U.S. Standard
Particle Diameter in Millimeters

HEC-RAS, River Analysis System, Version 3.0, calculates water surface profiles for both steady and unsteady gradually varied flow. The system can handle a full network of channels, a dendritic system, or a single river reach. Cross sections were developed from the Digital Terrain Models (DTM's) produced under Tasks 5 and 6, Orthophotography and Topography, of the Upper Gila River Fluvial Geomorphology Study. The cross sections were checked against aerial photographs and orthophotographs to insure accuracy of the ground terrain. The Manning roughness, *n*, for the main channel was designated to be 0.035, and 0.080 for the left and right overbanks. HEC-RAS uses a local coordinate system for measuring the channel distance and thus the cross sectional stationing. In each modeling reach HEC-RAS begins at Cross Section 1, and begins measuring upstream along the centerline of the channel. The stationing accumulates from "0" and is labeled in each of the cross-section figures. The stationing in HEC-RAS does not relate to other stationing systems. The stationing begins at zero in each of the four separate reaches analyzed in this study.

LOWER REACH 1

Figure 22 illustrates in plan view the cross sections and thalweg of Lower Reach 1. The arrow indicates the flow direction. The thalweg is the lowest point in the cross section. The blue line indicates the location of the low-flow channel thalweg. The reach length is roughly 8.5 km. The green lines indicate the locations of the cross sections. The first downstream section is at station 156.1907 meters. The upstream section is at station 8502.539. The pair of red dots on each green cross section indicates the location of the left and right banks of the active channel.

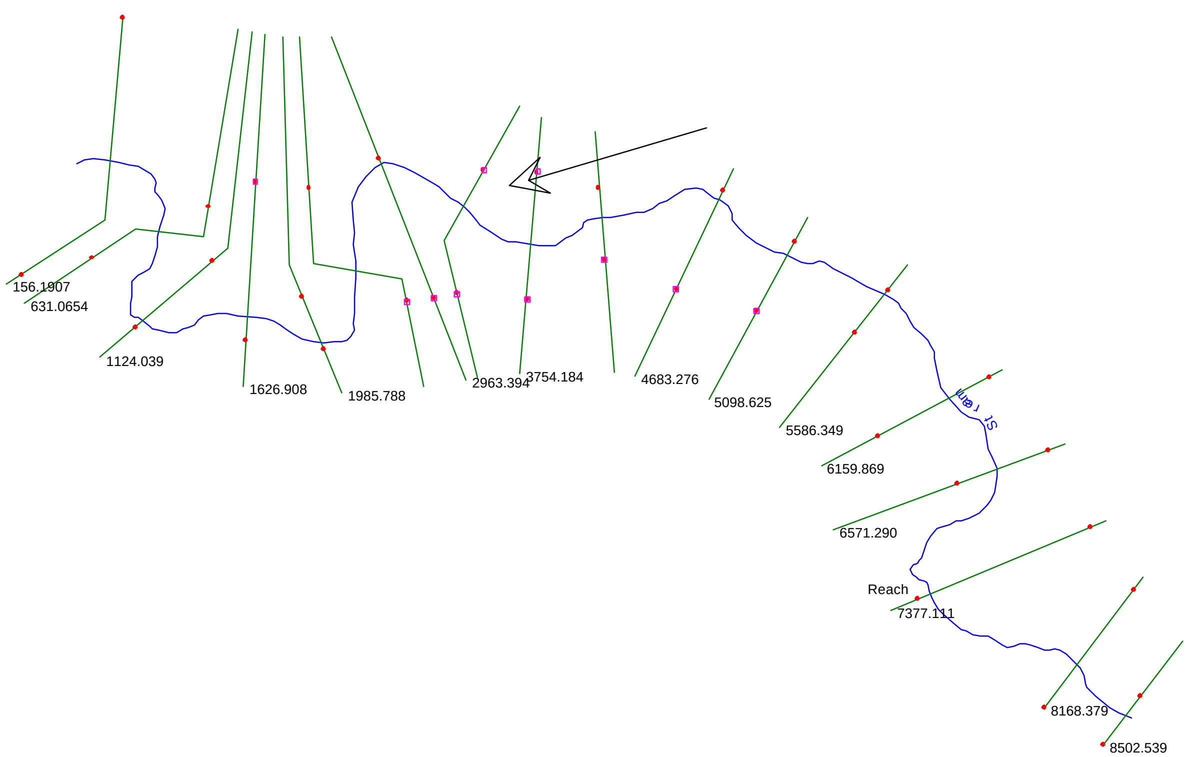


Figure 22. Plan view of HEC-RAS sections and thalweg in Lower Reach 1.

Figure 23 plots the longitudinal profile of the stream and three water surface profiles (PF), corresponding to discharges of 2,329 m^3/s (82,252 ft^3/s) (PF 1), 422 m^3/s (14, 907 ft^3/s) (PF 3), and 0.002 m^3/s (0.08 ft^3/s) (PF 19).

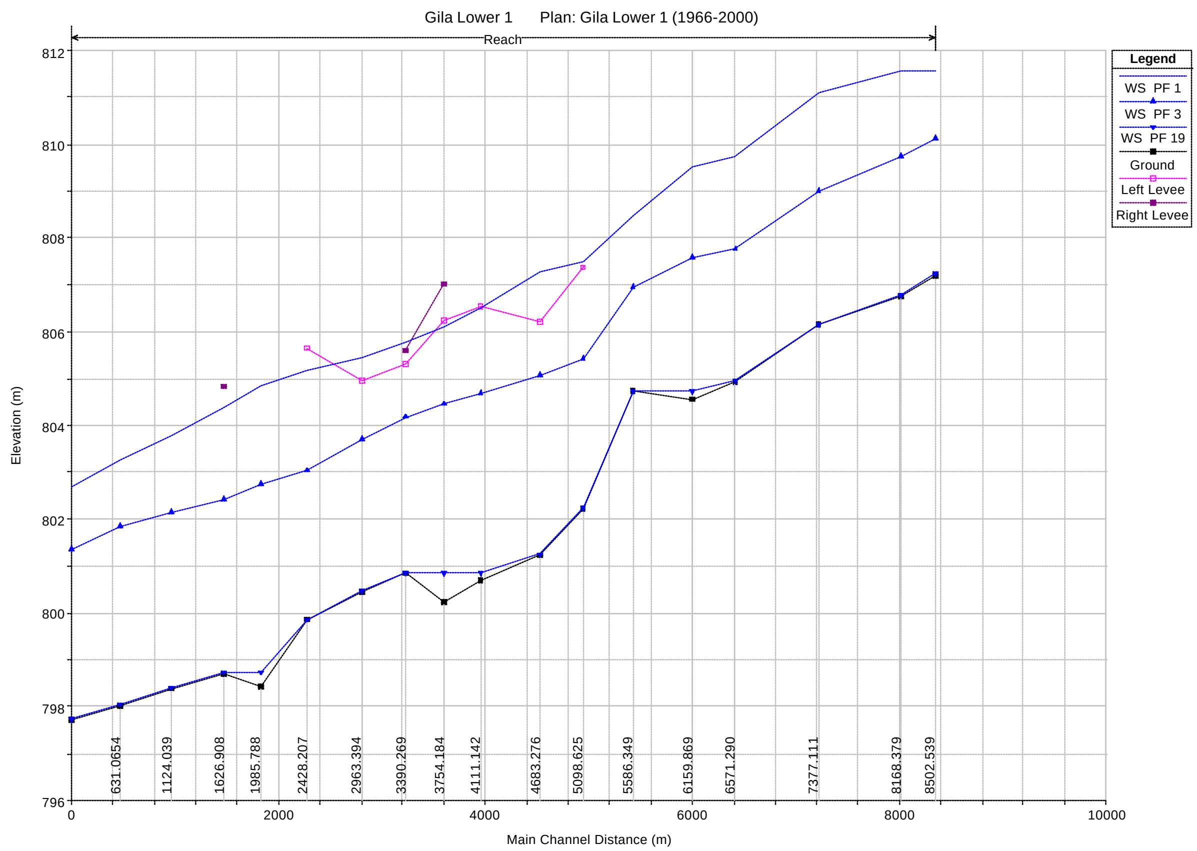


Figure 23. Profile of Lower Reach 1, showing water surface profiles at 2,329 m^3/s (82,252.68 ft^3/s) (PF1), 422 m^3/s (14,907.88 ft^3/s) (PF 3), and 0.002 m^3/s (0.08 ft^3/s) (PF 19).

LOWER REACH 2

Figure 24 illustrates in plan view the cross sections and thalweg of Lower Reach 2. The thalweg is the lowest point in the cross section. The solid blue line indicates the location of the low-flow channel thalweg. The reach length is roughly 8.2 km. The green lines indicate the location of the cross sections. The downstream section is at station 0, the first upstream section is at station 29.5708. The upstream section is at station 8221.621. The pair of red dots on each cross section indicates the location of the left and right banks of the active channel.

Figure 25 plots the longitudinal profile of the stream and three water surface profiles, corresponding to discharges of 2,329 m^3/s (82,252.68 ft^3/s) (PF1), 422 m^3/s (14,907.88 ft^3/s) (PF 3), and 0.002 m^3/s (0.08 ft^3/s) (PF 19).

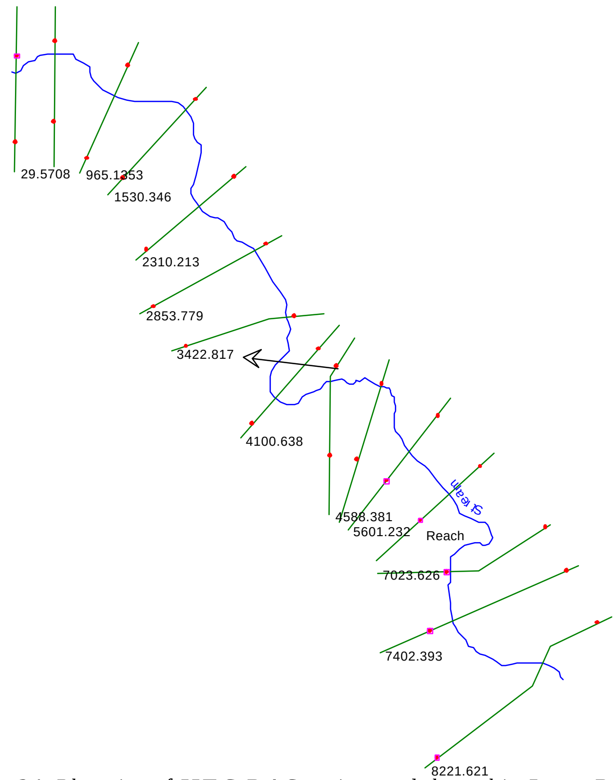


Figure 24. Plan view of HEC-RAS sections and channel in Lower Reach 2.

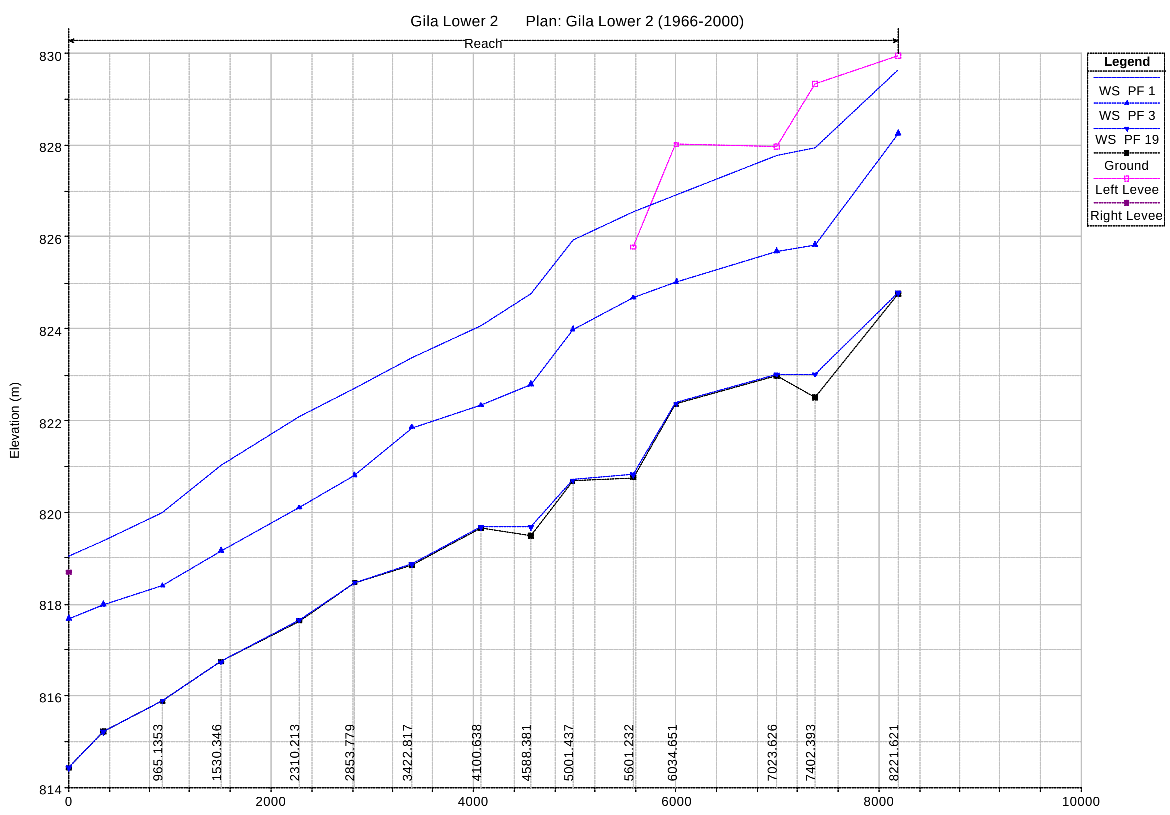


Figure 25. Profile of Lower Reach 2, showing water surface profiles at 2,329 m^3/s (82,252.68 ft^3/s) (PF1), 422 m^3/s (14,907.88 ft^3/s) (PF 3), and 0.002 m^3/s (0.08 ft^3/s) (PF 19).

LOWER REACH 3

Figure 26 illustrates in plan view the cross sections and thalweg of Lower Reach 3. The thalweg is the lowest point in the cross section. The blue line indicates the location of the low-flow channel. The thalweg in this reach is roughly 18.9 km in length. The green lines indicate the location of the cross sections. The downstream section is at station 0, the first upstream section is at station 93.9761. The upstream section is at station 18193.84. The pair of red dots indicates the location of the left and right banks of the active channel.

Figure 27 plots the longitudinal profile of the stream and four water surface profiles, corresponding to discharges of 1,924 m^3/s (67,932.73 ft^3/s) (PF 1), 1,197 m^3/s (42,286.92 ft^3/s) (PF 2), 426 m^3/s (15,045.98 ft^3/s) (PF 3), and 0.52 m^3/s (18.40 ft^3/s) (PF 19).

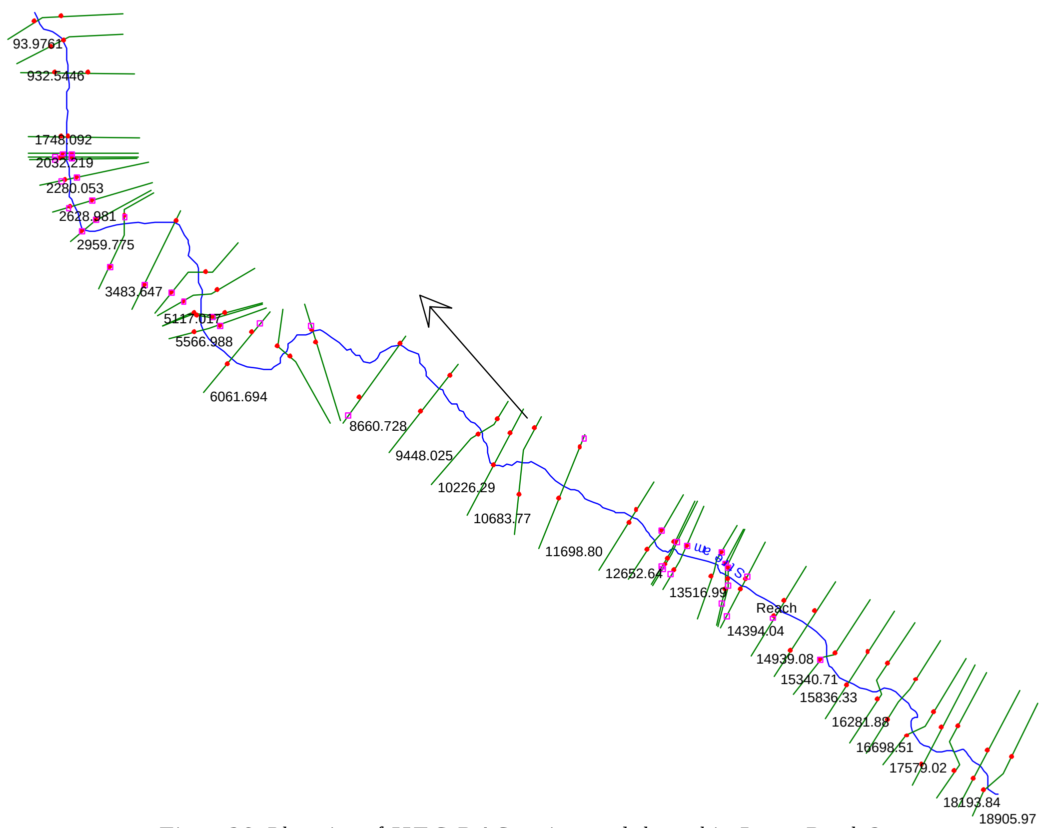


Figure 26. Plan view of HEC-RAS sections and channel in Lower Reach 3.

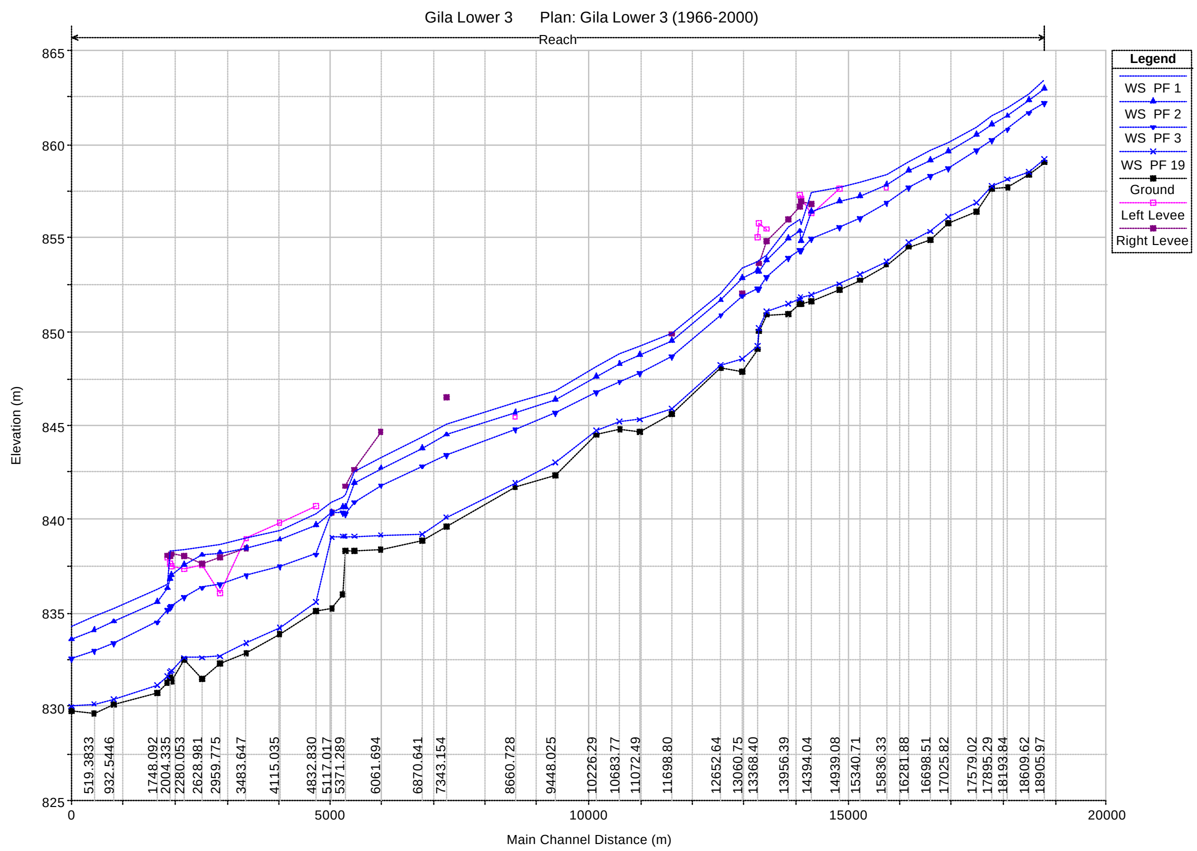


Figure 27. Profile of Lower Reach 3, showing water surface profiles at 1,924 m^3/s (67,932.73 ft^3/s) (PF 1), 1,197 m^3/s (42,286.92 ft^3/s) (PF 2), 426 m^3/s (15,045.98 ft^3/s) (PF 3), and 0.52 m^3/s (18.40 ft^3/s) (PF 19).

LOWER REACH 4

Figure 28 illustrates in plan view the cross sections and thalweg of Lower Reach 4. The thalweg is the lowest point in the cross section. The thalweg in this reach is roughly 17.4 km long. The downstream section is at station 0, the first upstream section is at station 46.5883. The upstream section is at 17428.

Figure 29 plots the longitudinal profile of the stream and four profiles, corresponding to discharges of 1,924 m^3/s (67,932.73 ft^3/s) (PF 1), 1,197 m^3/s (42,286.92 ft^3/s) (PF 2), 426 m^3/s (15,045.98 ft^3/s) (PF 3), and 0.52 m^3/s (18.40 ft^3/s) (PF 19).

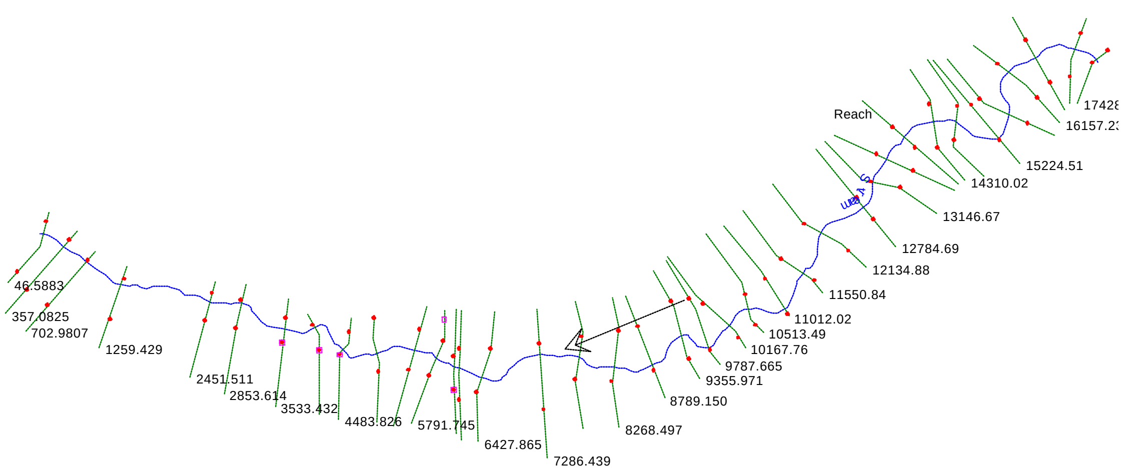


Figure 28. Plan view of HEC-RAS sections and channel in Lower Reach 4.

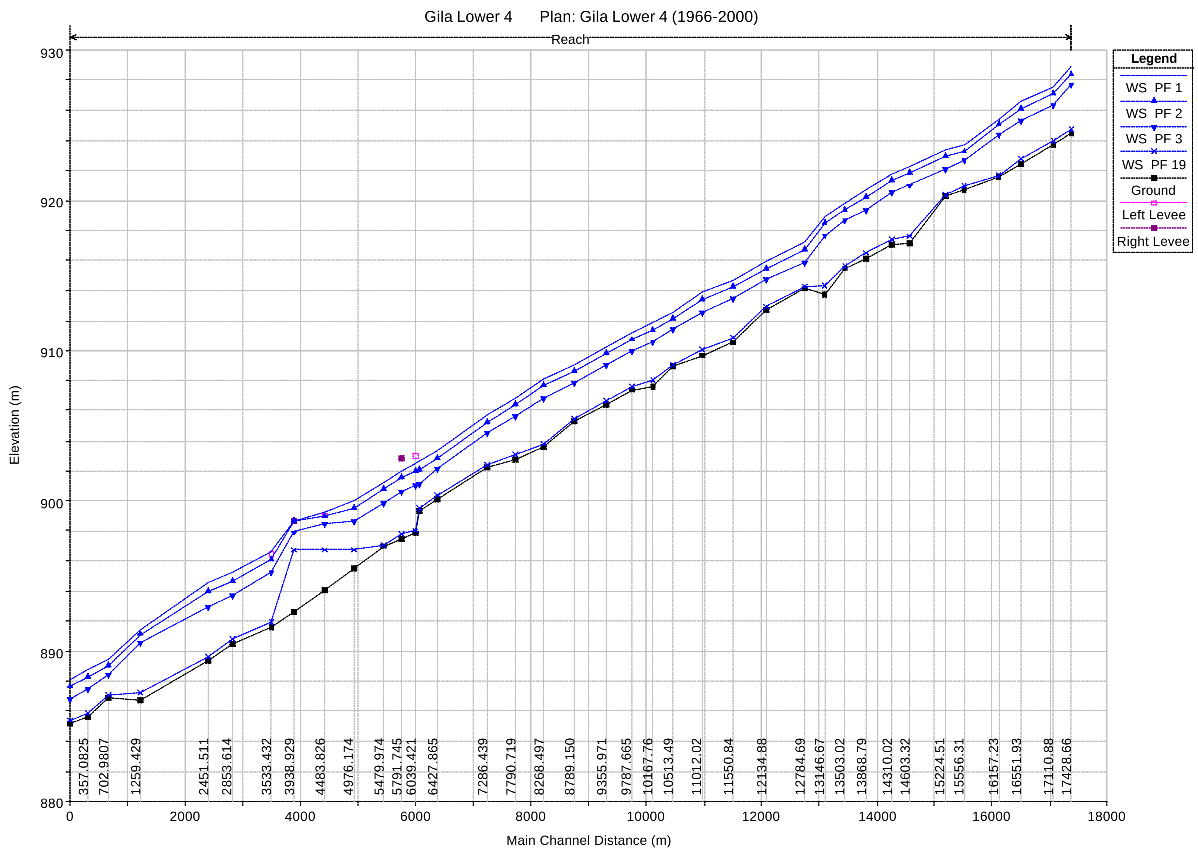


Figure 29. Profile of Lower Reach 4, showing water surface profiles at 1,924 m^3/s (67,932.73 ft^3/s) (PF 1), 1,197 m^3/s (42,286.92 ft^3/s) (PF 2), 426 m^3/s (15,045.98 ft^3/s) (PF 3), and 0.52 m^3/s (18.40 ft^3/s) (PF 19).

UPPER REACH

Figure 30 illustrates in plan view the cross sections and thalweg of the Upper Reach. The thalweg is the lowest point in the cross section. The thalweg in this reach is roughly 27.6 km in length. The downstream section is at station 0, the first upstream section is at station 484.3019. The upstream section is at station 27581.31.

Figure 31 plots the longitudinal profile of the stream and four water surface profiles, corresponding to discharges of 652.26 m^3/s (23,034.46 ft^3/s) (PF 1), 402.72 m^3/s (14,221.95 ft^3/s) (PF 2), 152.47 m^3/s (5,384.36 ft^3/s) (PF 3), and 0.033 m^3/s (1.17 ft^3/s) (PF 19).

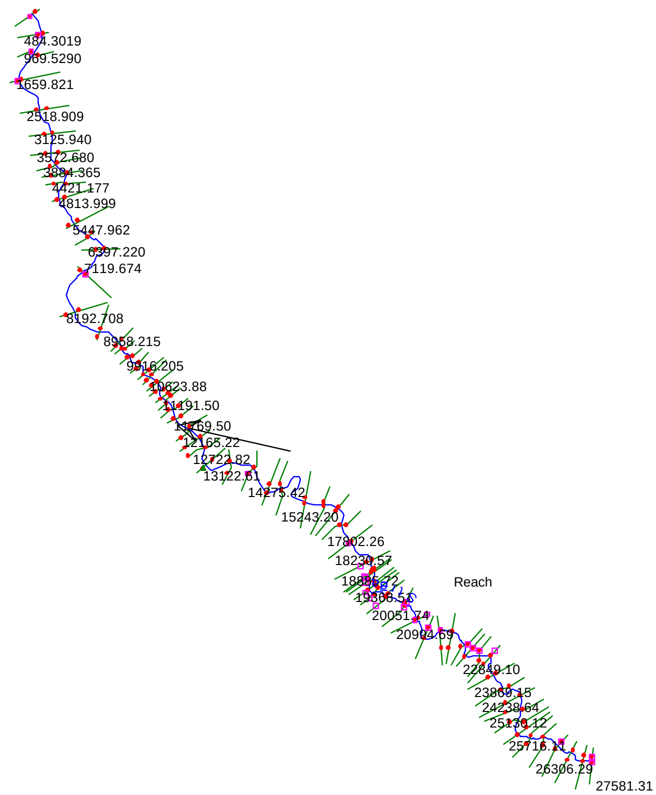


Figure 30. Plan view of HEC-RAS sections and channel in Upper Reach.

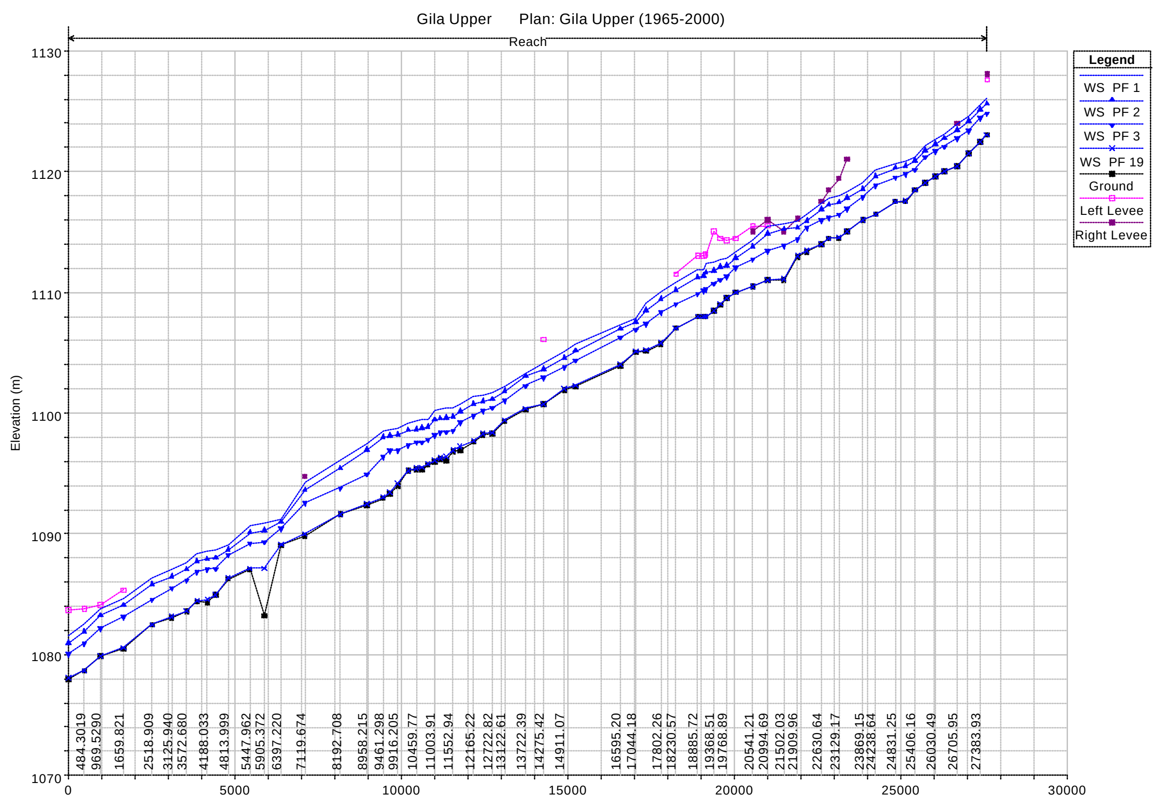


Figure 31. Profile of Upper Reach, showing water surface profiles at 652.26 m^3/s (23,034.46 ft^3/s) (PF 1), 402.72 m^3/s (14,221.95 ft^3/s) (PF 2), 152.47 m^3/s (5,384.36 ft^3/s) (PF 3), and 0.033 m^3/s (1.17 ft^3/s) (PF 19).

TRIBUTARY INVENTORY & HYDRAULIC CONTROLS

TRIBUTARY INVENTORY

Table 1 and Table 2 list major tributaries to the Gila River in the study reach. Major tributaries are tributaries that are readily visible from the aerial photographs, contribute significant quantities of sediment during and after rainfall events, and have been observed by the study team to be hydraulically or geomorphologically significant to the study. The table lists the tributaries by sub-reach, i.e. L-1, L-2, etc. for Lower Reach 1, 2, and so on. The inventory includes bridges and diversions. The table also includes the rough location (Lat/Long (WGS 84)) of each feature. The names of the features follow from the USGS Topographic maps of the area.

Table 1. Tributary inventory of lower reaches, with rough location (Lat/Long) of tributary confluence, diversion, or bridge.

Reach	Tributaries Entering Left Bank	Bridges/Diversions	Tributaries Entering Right Bank
L-1			Dry Mine Wash N33° 04.291′ W109° 59.960′
L-1	Fine Wash N33° 03.401′ W109° 58.820′		
L-2	Black Rock Wash N33° 02.287′ W109° 57.069′		Burton Wash N33° 03.207′ W109° 58.081′
		Fort Thomas Bridge (Box Culvert) N33° 02.970′ W109° 58.026′	
		Colvin Jones Diversion (Lift Pump) N33° 03.004′ W109° 57.585′	
			Clay Mine Wash N33° 02.949′ W109° 57.445′
			Teague Spring Canyon N33° 01.361′ W109° 55.768′
L-2			Oliver Spring Canyon N33° 00.692′ W109° 55.243′
L-3		Eden Bridge N32° 57.708′ W109° 54.900′	
		Fort Thomas Canal Diversion N32° 56.539′ W109° 53.815′	
	Tripp & Underwood Wash N32° 56.251′ W109° 53.244′		Markham Wash N32° 56.289′ W109° 53.263′
		Curtis Canal Diversion N32° 55.063′ W109° 49.998′	
			Peck Wash N32° 55.123′ W109° 50.082′
		Pima Bridge N32° 34.899′ W109° 49.611′	
L-3			Butler Wash N32° 53.556′ W109° 47.109′
			Watson Wash N32° 53.353′ W109° 46.523′

Reach	Tributaries Entering Left Bank	Bridges/Diversions	Tributaries Entering Right Bank
		Thatcher Bridge N32° 52.897′ W109° 46.040′	
			Talley Wash N32° 52.694′ W109° 45.938′
		Smithville Diversion N32° 51.590′ W109° 44.614′	
			Peterson Wash N32° 51.112′ W109° 43.620′
		Safford Bridge N32° 50.854′ W109° 42.982′	
			Wilson Wash N32° 50.754′ W109° 42.180′
			Lonestar Wash N32° 50.754′ W109° 42.180′
L-4	Graveyard Wash N32° 50.639′ W109° 41.963′	Graham Canal Diversion N32° 50.603′ W109° 41.399′	
	San Simon River N32° 49.846′ W109° 38.894		
			Tidwell Wash N32° 49.770′ W109° 38.070′
		Solomon Bridge N32° 49.656′ W109° 37.856′	
L-4	San Jose Wash N32° 49.682′ W109° 35.958	San Jose Diversion N32° 51.713′ W109° 32.636′	
		Brown Diversion N32° 52.617′ W109° 30.674′	

Table 2. Tributary inventory of upper reach, with rough location (Lat/Long) of tributary confluence, diversion, or bridge.

Reach	Tributaries Entering Left Bank	Bridges/Diversions	Tributaries Entering Right Bank
Gila Box			San Francisco River N32° 58.563′ W109° 22.299′
York Valley			Apache Creek N32° 52.110′ W109° 11.868′
			Stove Wash N32° 51.284′ W109° 11.197′
York Valley			Bitter Creek N32° 50.282′ W109° 11.037′
U-1			Sanders Wash N32° 49.525′ W109° 10.867′
			Harris Wash N32° 47.812′ W109° 10.408′
			Sandia Wash N32° 47.222′ W109° 09.892′

Reach	Tributaries Entering Left Bank	Bridges/Diversions	Tributaries Entering Right Bank
	Whitefield Creek N32° 44.266′ W109° 06.750′		Little Sand Wash N32° 45.745′ W109° 09.252′ Waters Wash N32° 45.238′ W109° 08.741′
		Duncan Bridge N32° 43.490′ W109° 06.003′	
	Rainville Wash N32° 42.575′ W109° 05.359′		
U-1	Burro Wash N32° 41.757′ W109° 04.127′		Carlisle Canyon Wash N32° 41.302′ W109° 02.859′

HYDRAULIC CONTROLS

A Hydraulic Control is any feature that determines a depth-discharge relationship (Henderson, 1966). This inventory counts two types of hydraulic controls, man-made and geologic. Man-made hydraulic controls include diversion dams and bridges. Geologic hydraulic controls are geologic features intersecting the Gila River that display a resistance to erosion over long periods, and in particular, govern a non-alluvial reach of the river.

Each of the diversion structures listed in Table 1 acts as a hydraulic control, with the exception of the Colvin-Jones diversion. That diversion is a lift-pump, not a dam across the channel. During the pumping season there is a small diversion across the low-flow channel. This low-flow diversion dam probably washes out at flows significantly less than bank-full.

The degree of hydraulic control may decrease as the stage, or discharge in the main channel, increases. The increasing role of channel and vegetation roughness at higher flows ameliorates the effect of low diversion dams as controls. However, following observation of the diversion dams during the Field Data Collection Plan execution, we hypothesize that all of the diversions, with the exception of Colvin-Jones, in the Safford Valley are significant hydraulic controls at even the highest discharges.

The bridges act as hydraulic controls beginning below the effective discharge and up to the highest discharges.

GEOLOGIC CONTROLS

The following figures show the longitudinal profile of each of the five sub-reaches studied in this analysis. The longitudinal profile illustrates the thalweg of the channel, the thalweg being the lowest point in the channel. The thalweg profiles vividly shows abrupt changes in the bed of the channel, indicating probable hydraulic control points, either man-made or geologic.

Geologic controls are prevalent in the reach very near the San Carlos Apache Reservation, at the downstream end of the study reach, Lower Reach 1. We have no information on the makeup of the geologic controls in this area at this time.

The Gila Box serves as a regional control for the York and Duncan valleys. There are significant sections of bedrock channel in the Apache Grove area (Upper Reach), indicating geologic controls.

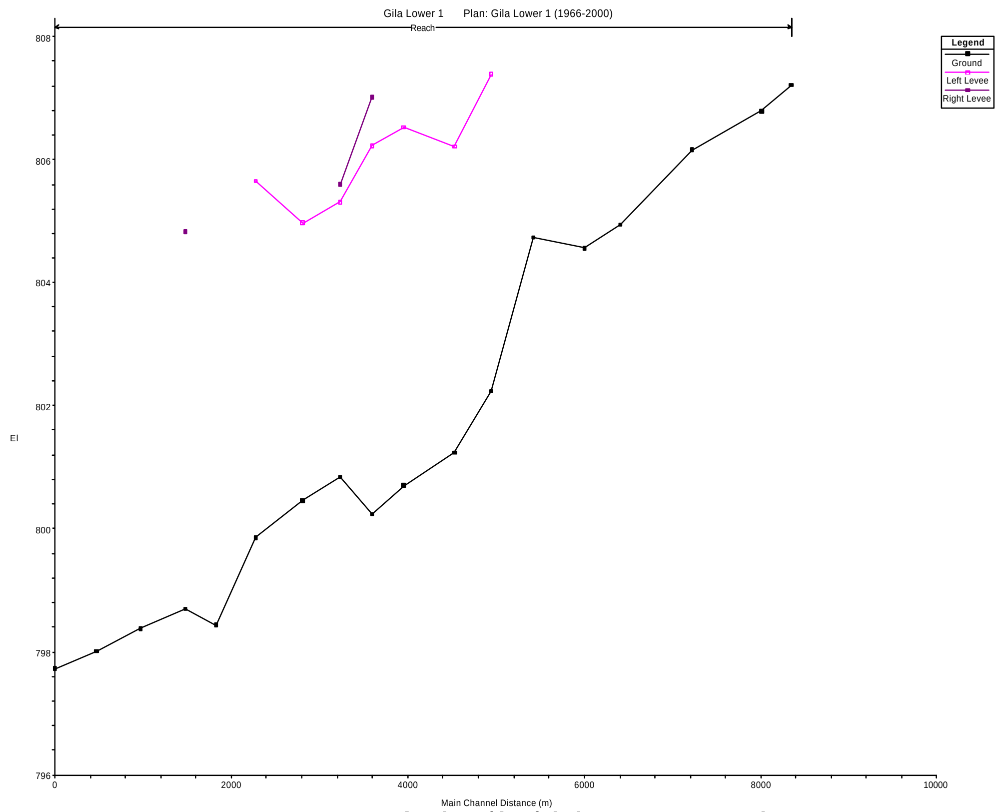


Figure 32 . Longitudinal profile of thalweg in Lower Reach 1.

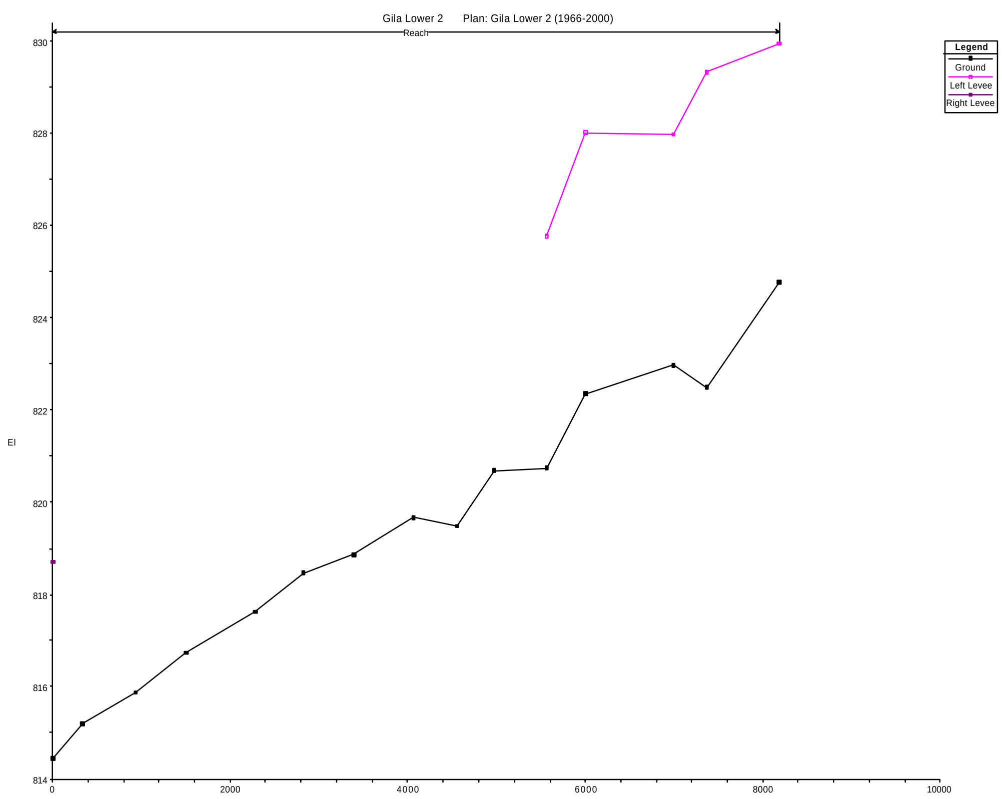


Figure 33. Longitudinal profile of thalweg in Lower Reach 2.

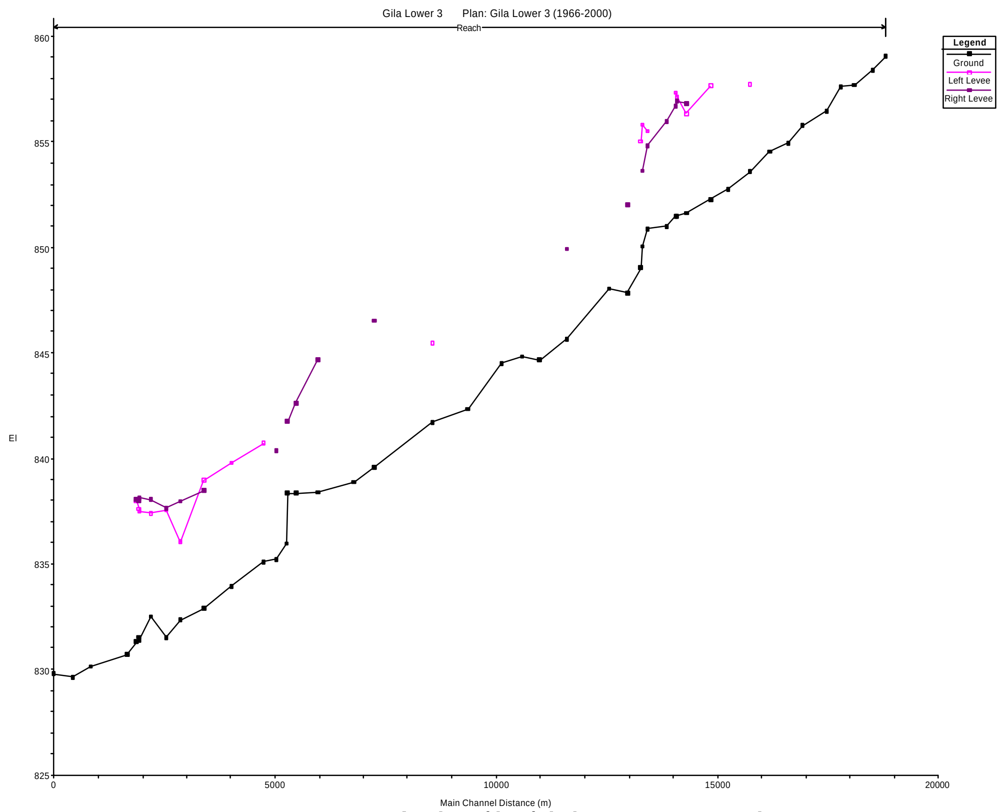


Figure 34. Longitudinal profile of thalweg in Lower Reach 3.

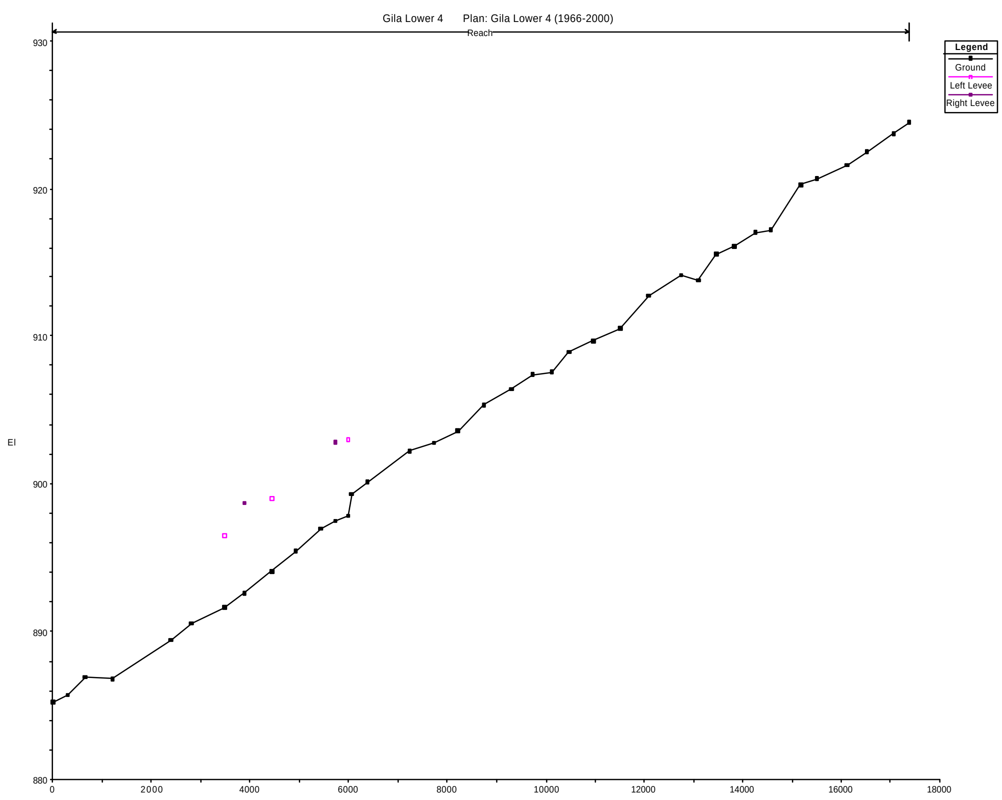


Figure 35. Longitudinal profile of thalweg in Lower Reach 1.

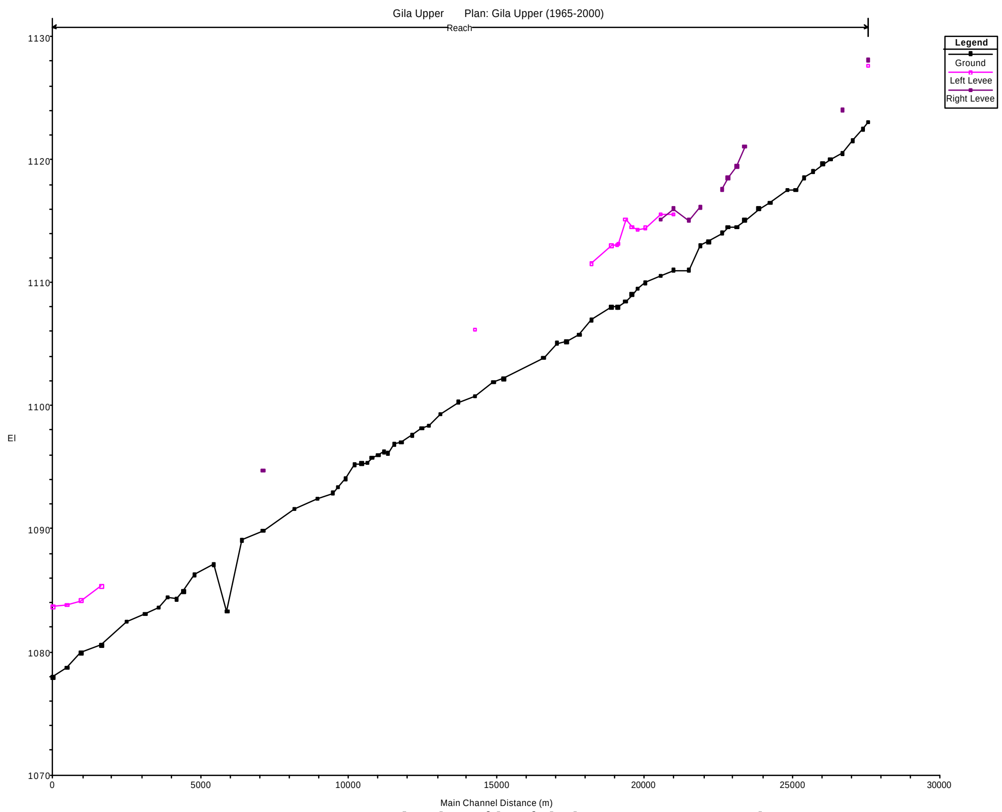


Figure 36. Longitudinal profile of thalweg in Upper Reach 1.

EFFECTIVE DISCHARGE

Andrews (Andrews, 1980) defines effective discharge as the mean of the discharge increment that transports the largest fraction of the annual sediment load over a period of years. The effective discharge incorporates the principle prescribed by Wolman and Miller (Wolman, 1960) that the channel-forming discharge is a function of both the magnitude of the event and its frequency of occurrence. It is calculated by convoluting the flow-duration curve and a bed-material-sediment load rating curve. Figure 37 (Watson, 1999) shows how the effective discharge derives from the flow frequency and sediment transport curves. Smaller discharges may happen more frequently, but they carry less sediment. Larger discharges may transport more sediment, but they occur less frequently.

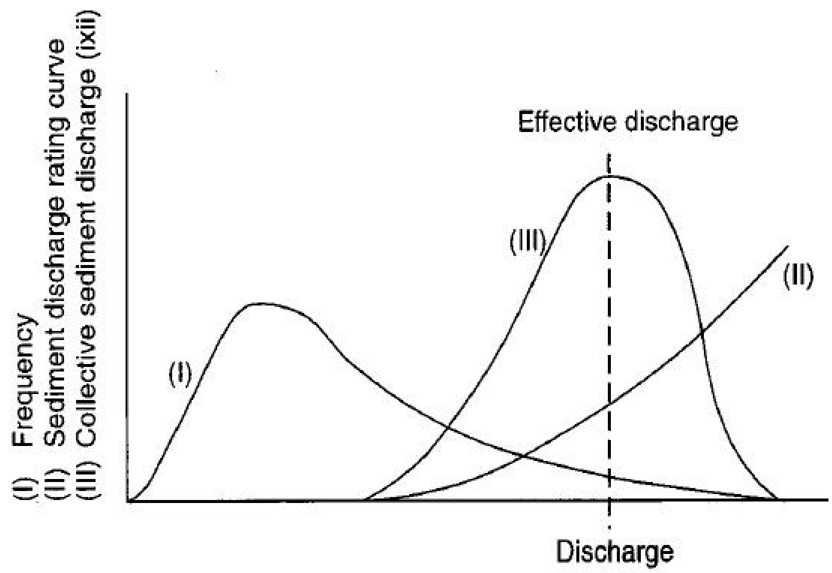


Figure 37. Derivation of Bed Material Load-discharge Histogram (III) From Flow Frequency (I) and Bed Material Load Rating Curves (II). (Watson, 1999)

Watson (1999) presents "A Practical Guide to Effective Discharge Calculation." This guide is Appendix A of the *Demonstration Erosion Control, Design Manual*, produced by the U.S. Army, Engineer Research and Development Center, Vicksburg, Mississippi. This, and the *Reservoir Sedimentation* Technical Guideline for Bureau of Reclamation (Strand, 1982), provide the methodology used in this analysis of the effective discharge.

GAGING STATION DESCRIPTIONS

The following section describes the USGS gaging stations from which daily mean discharges were used for calculating the discharge exceedance or flow duration curves. The descriptions come from the USGS (USGS, 2001) web pages for each particular station. Figure 38 shows the USGS gaging stations in the upper Gila River watershed.

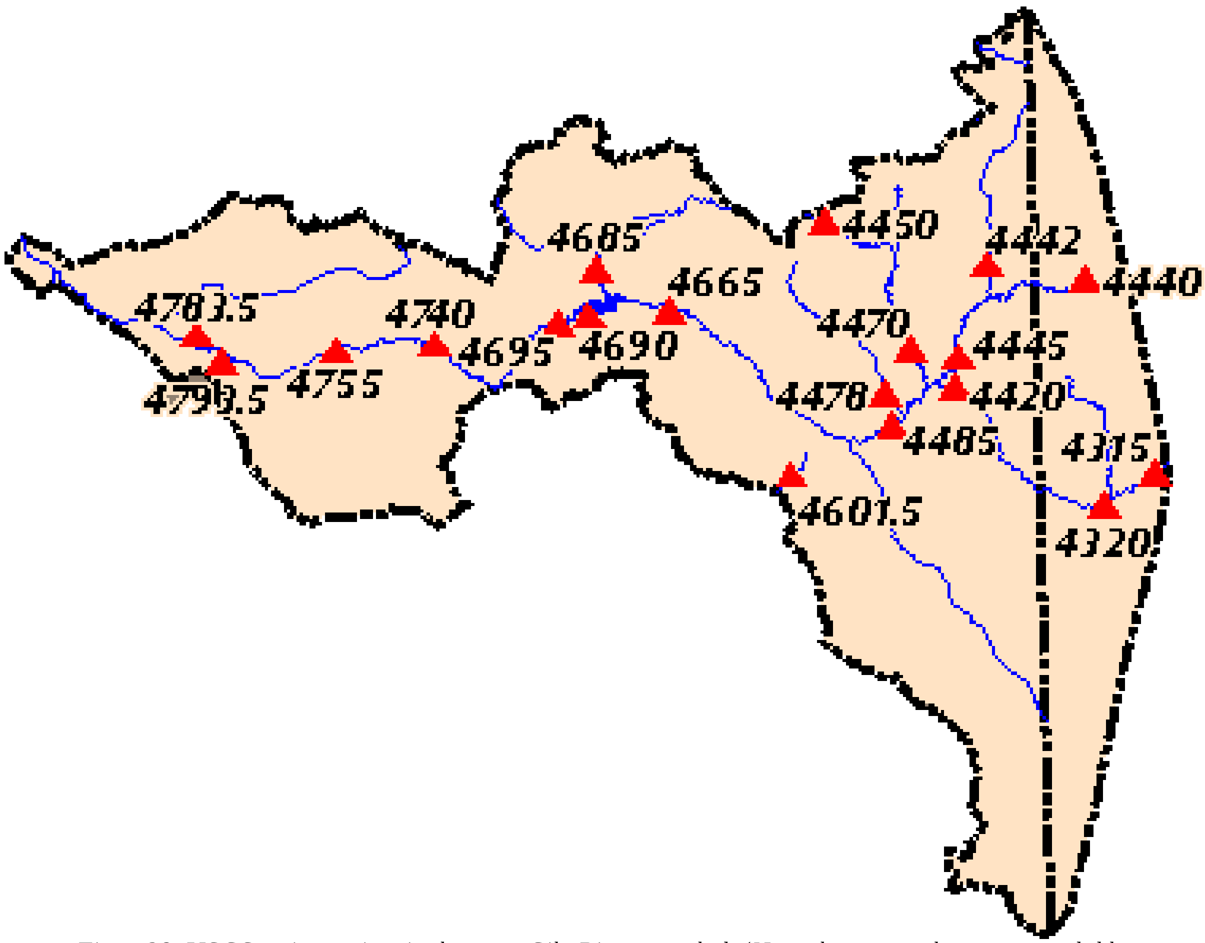


Figure 38. USGS gaging stations in the upper Gila River watershed. (Note: the gage numbers are proceeded by the digits "09" and followed a "00" when referenced in USGS records.)

STATION:--09466500 Gila River at Calva, AZ

LOCATION.--Lat 33°:11'08", long 110°:13'10", in SW$1/4$ sec.8, T.3 S., R.21 E. (unsurveyed), Graham County, Hydrologic Unit 15040005, in San Carlos Indian Reservation, on Southern Pacific Railroad bridge at head of San Carlos Reservoir, 2.0 mi west of Calva.

DRAINAGE AREA.--11,470 mi^2.

PERIOD OF RECORD.--October 1929 to current year.

GAGE.--Water-stage recorder. Datum of gage is 2,517.29 ft above sea level. Prior to Oct. 1, 1954, and Aug. 25, 1958, to Dec. 31, 1962, at datum 2.52 ft lower. Oct. 1, 1954, to Aug. 24, 1958, at datum 5.52 ft lower. Dec. 31, 1962, to Oct. 20, 1972, at site 530 ft downstream at datum 3.65 ft lower. Oct. 20, 1972, to Sept. 30, 1974, supplementary gage at bridge on U.S. Highway 70, 6.2 mi upstream at datum 2,560.19 ft, NGVD.

REMARKS.--Records good except for estimated daily discharges, which are fair. Diversion above station for irrigation of about 69,000 acres, metallurgical treatment of ores, and municipal uses.

STATION:--09458500 Gila River at Safford, AZ

LOCATION.--Lat 32°50'50", Long 109°42'55" NAD27, Graham County, Arizona, Hydrologic Unit Code 15040005.

DRAINAGE AREA. --10,459.00 mi^2

GAGE DATUM. --2,880.07 feet above sea level NGVD29

STATION DATA: --Begin Date 1940-06-01; End Date 1965-09-30; Count 6268

STATION:--09451000 Gila River near Solomon, AZ

LOCATION.--Lat 32°52'00", Long 109°31'00" NAD27, Graham County, Arizona , Hydrologic Unit 15040005.

DRAINAGE AREA. --7,950.00 mi^2

STATION TYPE:--Surface Water

STATION DATA: --Begin Date 1914-04-01; End Date 1951-09-30; Count 10775

SITE OPERATION: Site is located in Arizona; record is maintained by Arizona

STATION:--09448500 Gila River at head of Safford Valley, near Solomon, AZ

LOCATION.--Lat 32°52'06", long 109°30'38", in SE1/4NE1/4 sec. 3l, T.6 S., R.28 E., Graham County, Hydrologic Unit 15040005, on left bank 0.6 mi downstream from intake of Brown Canal, 8 mi northeast of Solomon, and 17 mi downstream from San Francisco River. Records include flow of Brown Canal, which is measured 2,000 ft downstream from intake.

DRAINAGE AREA.--7,896 mi^2.

PERIOD OF RECORD.--April 1914 to current year. Monthly discharge only for some periods, published in WSP 1313. Prior to October 1932 and October 1940 to September 1949 published as "near Solomonsville" and October 1932 to October 1933 and May 1935 to September 1940 as "below Bonita Creek near Solomonsville."

REVISED RECORDS.--WSP 1059: 1914, 1916-17, 1923(M), 1924-25, 1927, 1929-31(M). WSP 1179: 1915, 1918-19(M). WSP 1313: 1934. WSP 1733: 1923.

GAGE.--Water-stage recorder. Datum of gage is 3,059.92 ft above sea level. Prior to July 8, 1980, at datum 4.96 ft higher. See WSP 1733 for history of changes prior to Jan. 1, 1941. Supplementary water-stage recorder and Parshall flume on Brown Canal.

REMARKS.--Records show water reaching head of Safford Valley and include water diverted to Brown Canal. Diversions above station for mining, municipal use, and for irrigation of about 17,500 acres, much of it by pumping from ground water.

COOPERATION.--Record for Brown Canal furnished by Gila Water Commissioner.

AVERAGE DISCHARGE.--80 years, 507 ft^3/s, 367,300 acre-ft/yr; median of yearly mean discharges, 340 ft^3/s, 246,000 acre-ft/yr.

STATION:--09444500 San Francisco River at Clifton, AZ

LOCATION.--Lat 33°02'58", long 109°17'43", in SW1/4SE1/4 sec. 30, T.4 S., R.30 E., Greenlee County, Hydrologic Unit 15040004, on downstream side of right pier at Railroad Boulevard Bridge (U.S. Highway 666), at Clifton, 9.9 mi upstream from mouth.

DRAINAGE AREA.--2,766 mi^2, of which 2 mi^2 is noncontributing.

PERIOD OF RECORD.--October 1910 to March 1911, July 1911 to June 1912, September 1912, November 1912 to March 1913, May 1913 to July 1918, July 1927 to current year. Monthly discharge only for some periods, published in WSP 1313. Published as "San Francisco River at dam above Clifton" in 1911 and under both names in 1912.

REVISED RECORDS.--WSP 1049: 1911, 1913-15, 1917. WSP 1283: Drainage area. WSP 1313: 1927-30(M), 1932(M), 1934(M). WRD Ariz. 1972: 1917(M).

GAGE.--Water-stage recorder. Datum of gage is 3,436.16 ft above sea level. See WSP 1713 or 1733 for history of changes prior to Apr. 7, 1959. Apr. 7, 1959, to Mar. 23, 1961, at site 1,140 ft downstream at datum 5.37 ft lower. July 18, 1980 to July 28, 1983, supplementary water-stage recorder 0.4 mi upstream on right bank at same datum and June 15, 1981 to Sept. 30, 1983, crest-stage gages at site. Aug. 4, 1983 to Mar. 1, 1985, supplementary water-stage recorder on right bank at main gage site at same datum, Oct. 1, 1992 at main gage site, at datum 10.00 ft higher.

REMARKS.--Diversions for mining, municipal use, and for irrigation of about 2,700 acres above station.

AVERAGE DISCHARGE.--71 years, 226 ft^3/s, 163,700 acre-ft/yr; median of yearly mean discharges 130 ft^3/s, 94,200 acre-ft/yr.

STATION:--09432000 Gila River below Blue Creek, near Virden, NM

LOCATION.--Lat 32°38'53", long 108°50'43", in SE1/4SW1/4 sec. 18, T.19 S., R.19 W., Grant County, Hydrologic Unit 15040002, on left bank at head of canyon, 1.4 mi downstream from Blue Creek, 10 mi east of Virden, and 16 mi upstream from New Mexico-Arizona State line.

DRAINAGE AREA.--3,203 mi^2, excluding Animas River basin.

PERIOD OF RECORD.--May to November 1914, March to September 1915, July 1927 to current year. July 1927 to May 1931 monthly discharge only, published in WSP 1313, computed as sum of flow at Virden Bridge, 9 mi downstream, and in Sunset Canal. Published as "Gila River near Duncan, Ariz.," 1914-15 and as "Gila River at Fuller's Ranch, near Duncan, Ariz.," 1931-38.

REVISED RECORDS.--WSP 1283: Drainage area. WSP 1313: 1929, 1931-32(M).

GAGE.--Water-stage recorder. Elevation of gage is 3,875 ft above sea level, from river-profile map. May 11, 1914, to Sept. 30, 1915, at site 6 mi downstream, 1,000 ft upstream from intake of Sunset Canal. June 1 to July 7, 1931, nonrecording gage at present site and datum. Since April 18, 1980, supplementary gage on left bank 800 ft downstream at same datum. Since June 1980, crest-stage gages at supplementary gage site. Since Nov. 1990, water-stage recorder at supplementary gage.

REMARKS.--Records fair. Station is above all Duncan Valley diversions. Diversions for irrigation of about 6,200 acres above station.

AVERAGE DISCHARGE.--68 (water years 1928-95), 216 ft^3/s, 156,500 acre-ft/yr; median of yearly mean discharges, 150 ft^3/s, 109,000 acre-ft/yr.

FLOW DURATION

Flow duration curves represent the cumulative probability of exceeding a mean daily discharge for a given period of record at a gaging station. For this analysis the period in question follows the mid 1960's. The following flow duration curves come from analyzing the records of several gaging stations using the procedures outlined in the Demonstration Erosion Control, Design Manual (Watson, 1999) and the Reservoir Sedimentation Technical Guideline for Bureau of Reclamation (Strand, 1982). All of the curves are here, including the entire record, the period prior to the mid 1960's, and the period since the mid 1960's. Appendix C contains the tabular data for these curves.

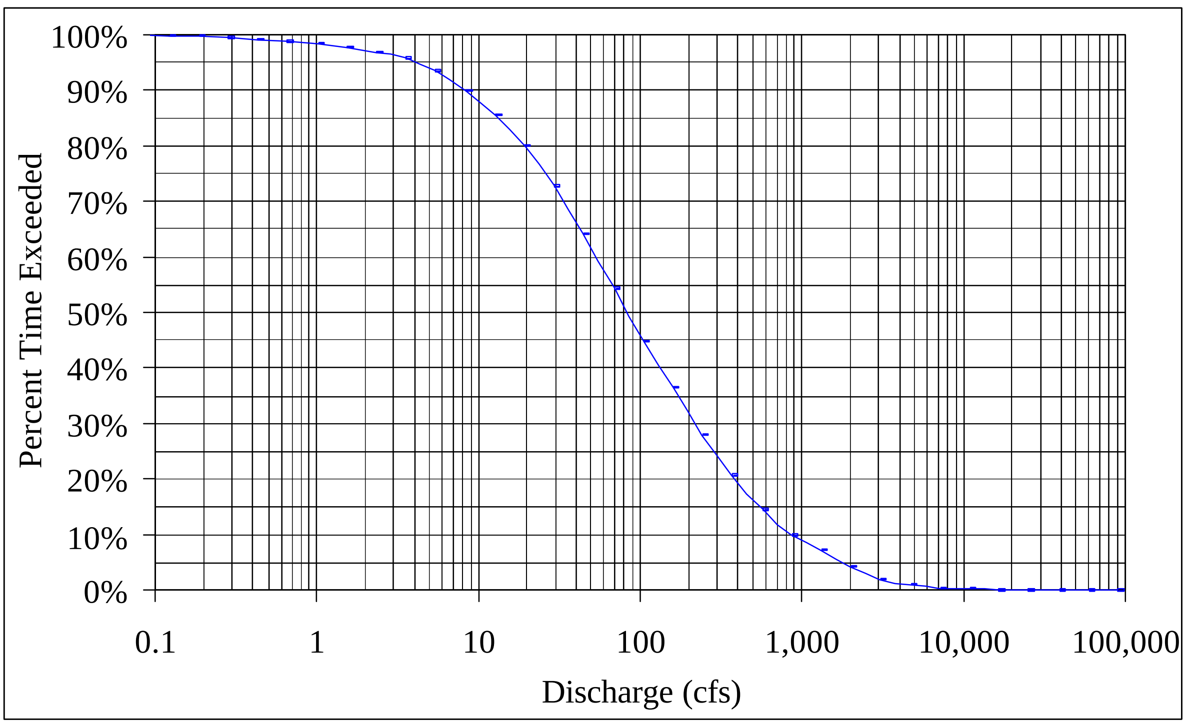


Figure 39. Discharge exceedance curve for Gila River at Calva, AZ. 1929-2000.

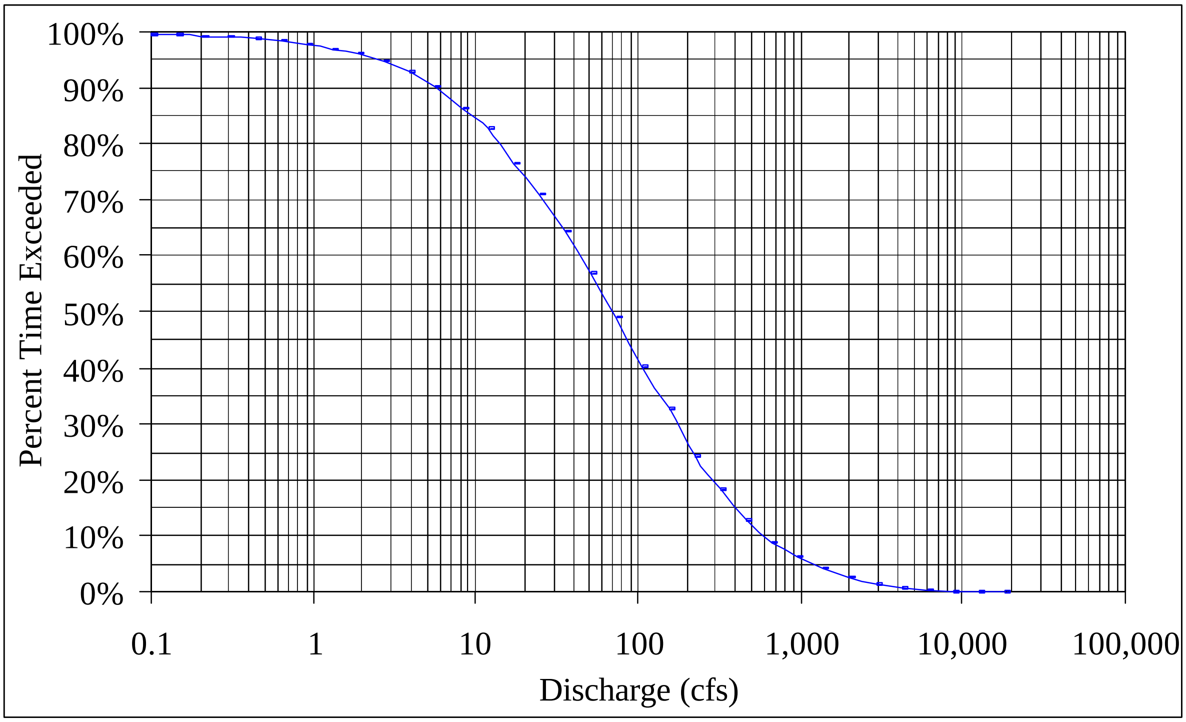


Figure 40. Discharge exceedance curve for Gila River at Calva, AZ. 1929-1964.

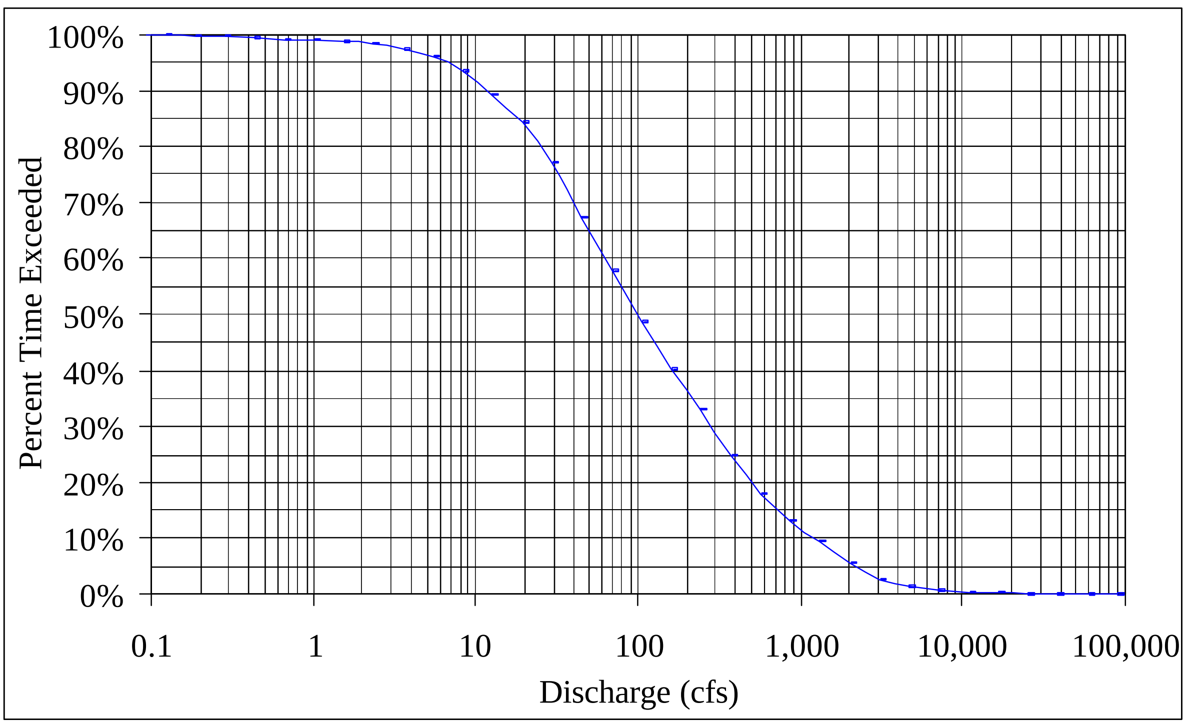


Figure 41. Discharge exceedance curve for Gila River at Calva, AZ. 1965-2000.

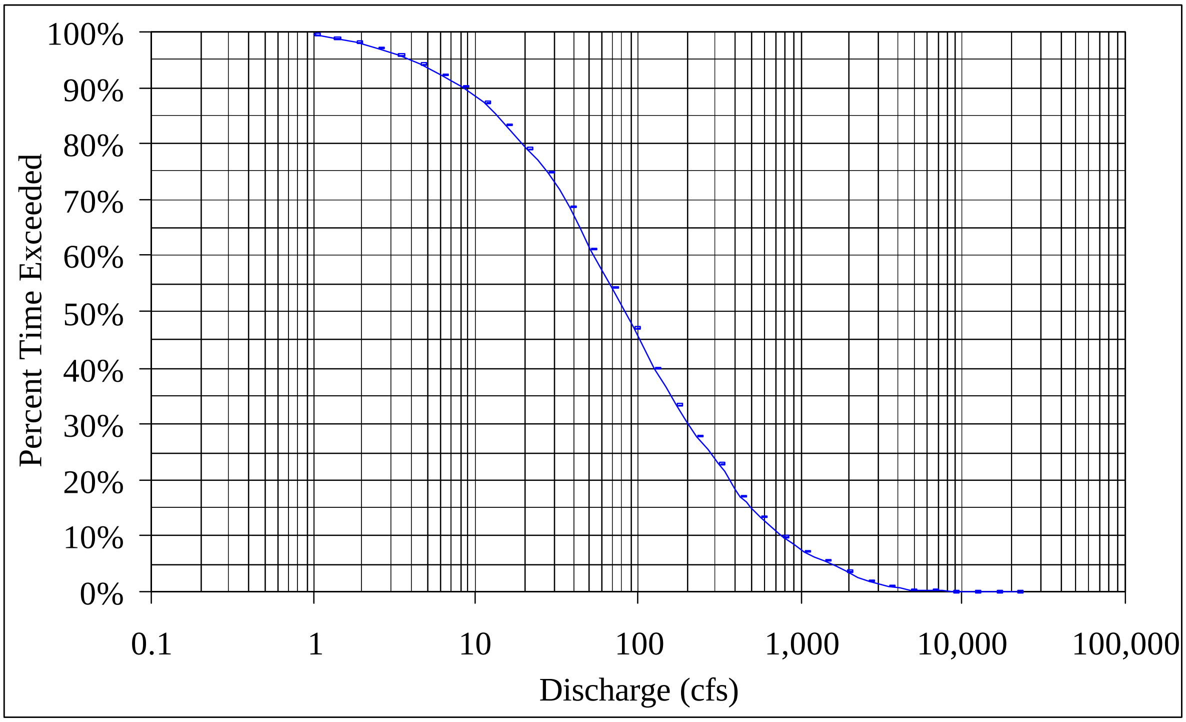


Figure 42. Discharge exceedance curve for Gila River at Safford, AZ. 1940-1965

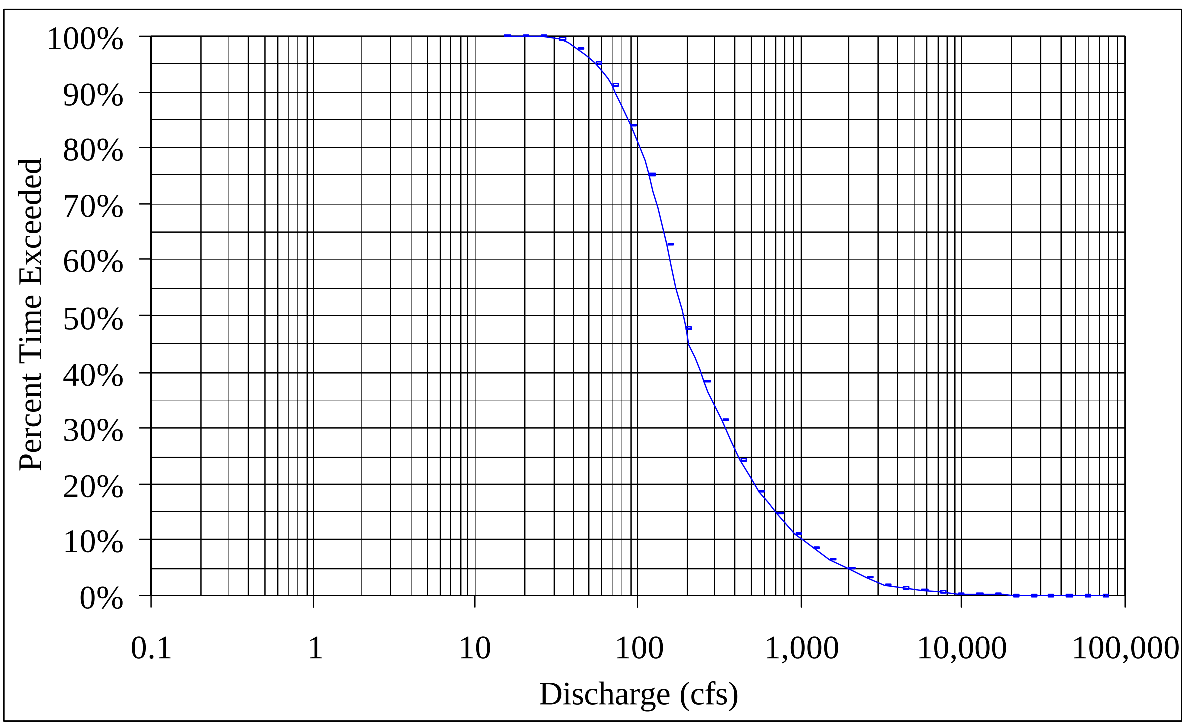


Figure 43. Discharge exceedance curve for Gila River near Solomon, AZ. 1914-1951

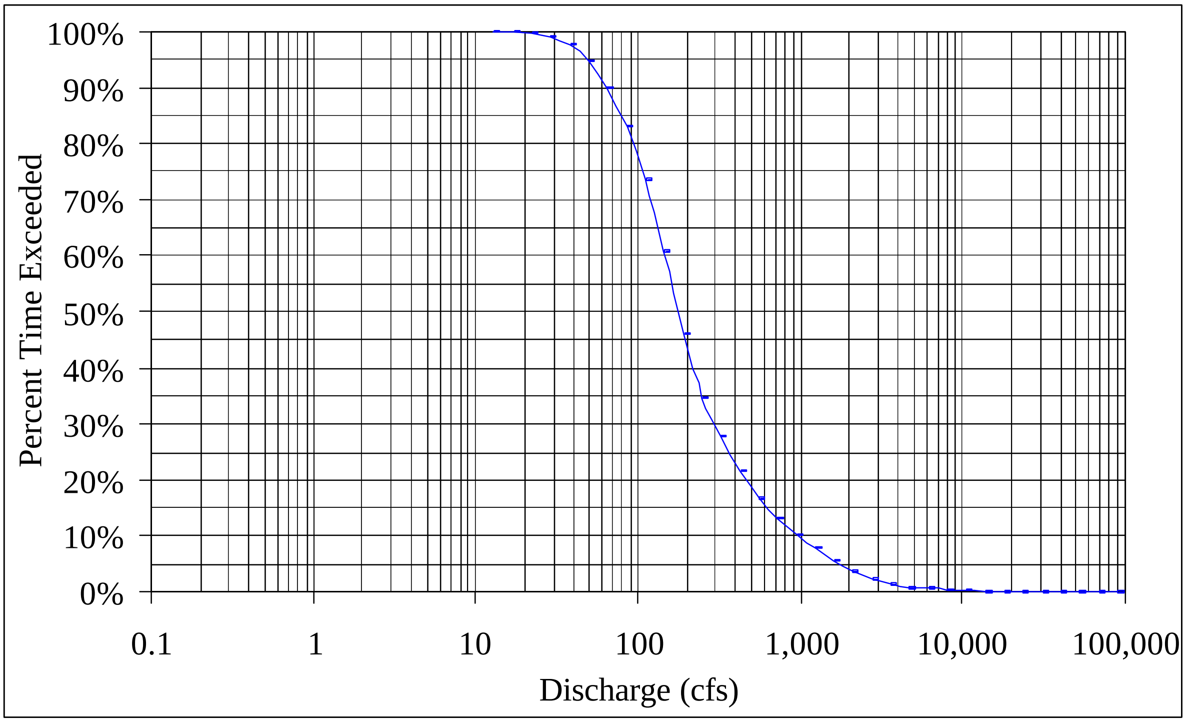


Figure 44. Discharge exceedance curve for Gila River at Head of Safford Valley, 1920-2000.

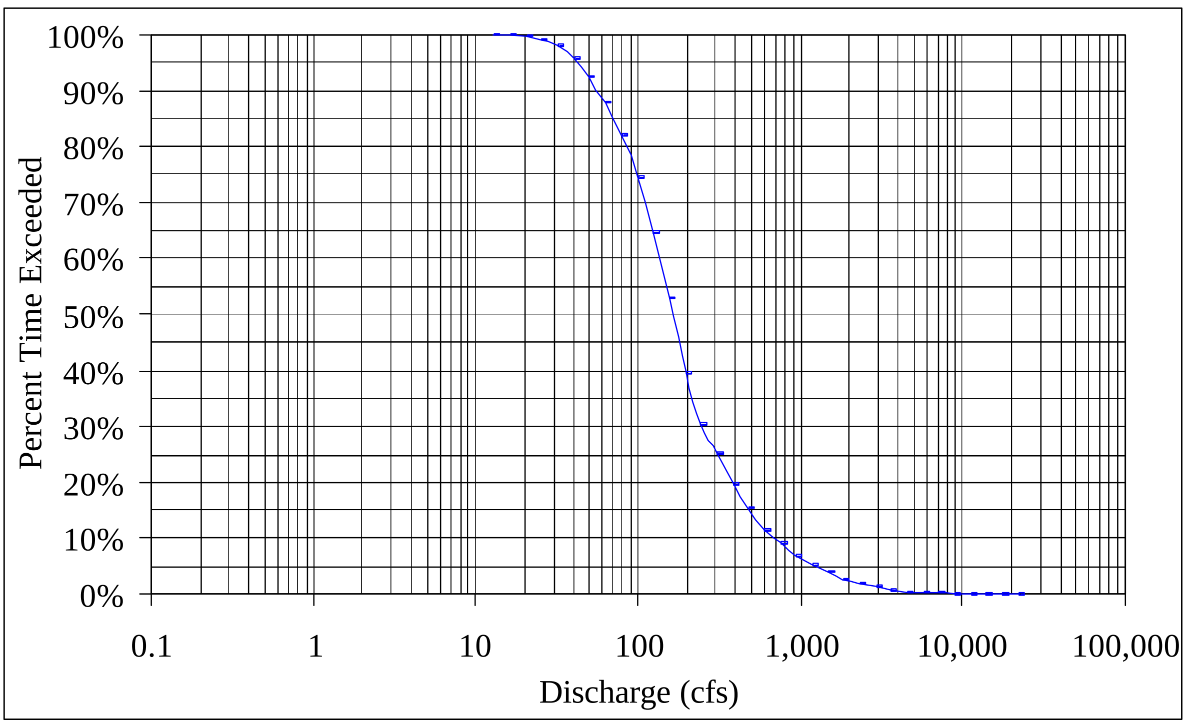


Figure 45. Discharge exceedance curve for Gila River at Head of Safford Valley, 1920-1964.

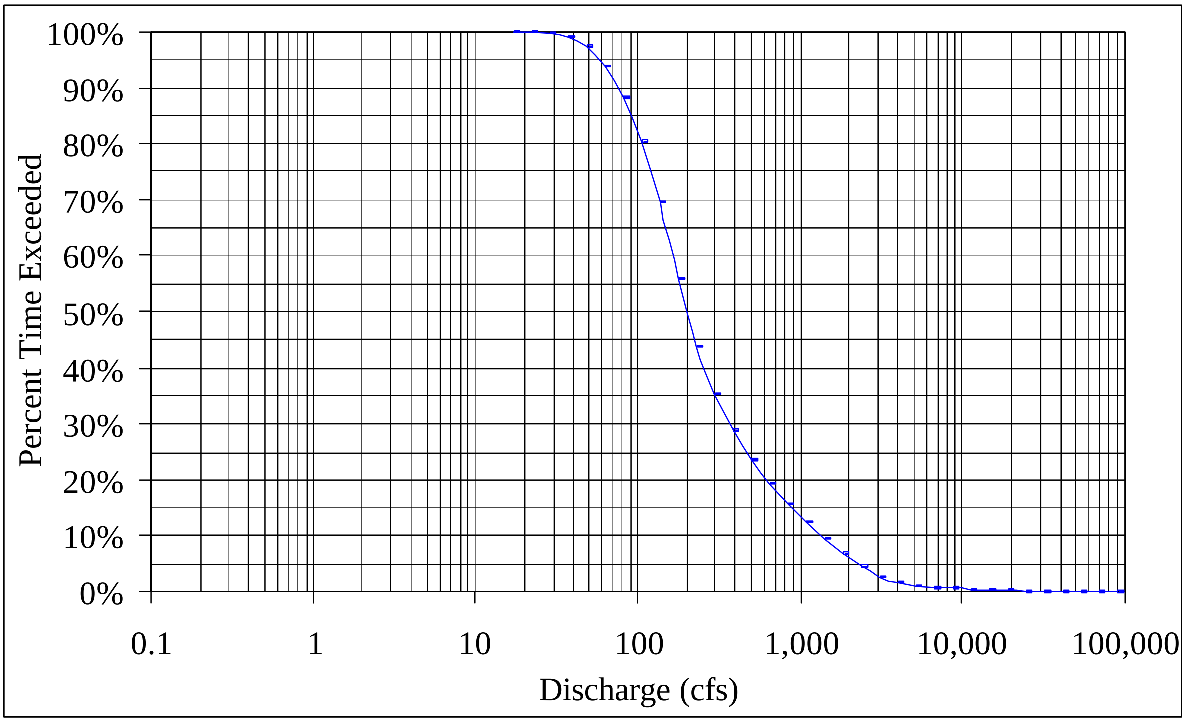


Figure 46. Discharge exceedance curve for Gila River at Head of Safford Valley, 1965-2000.

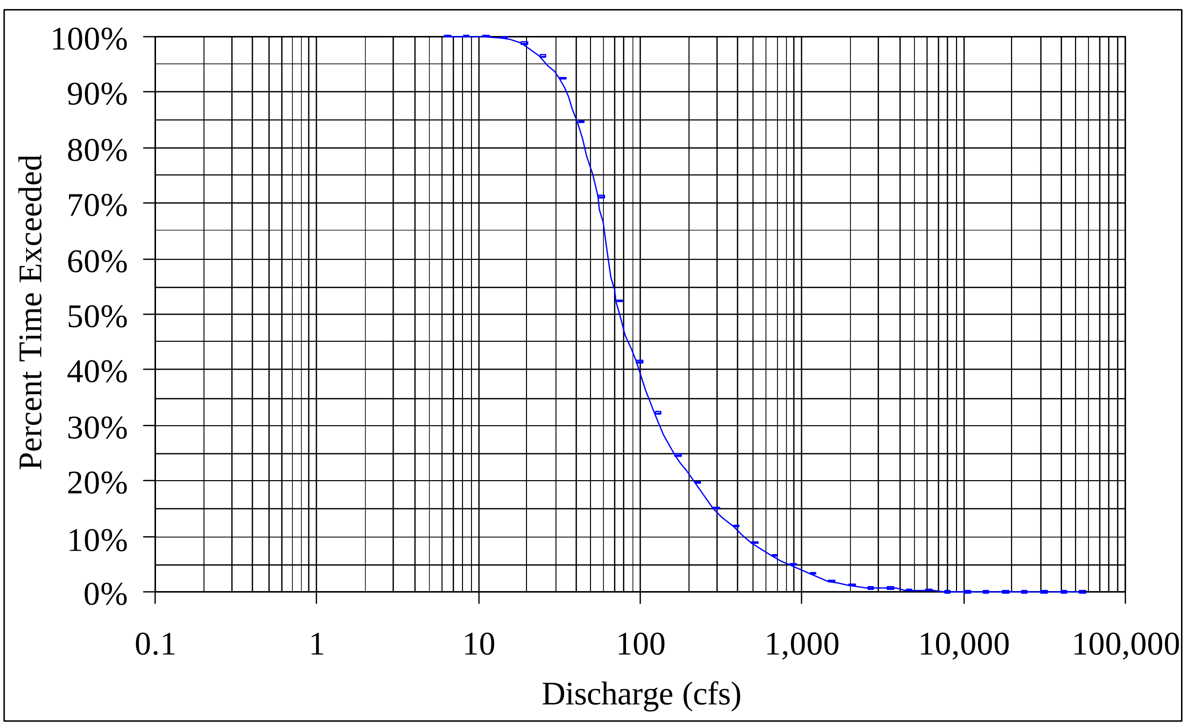


Figure 47. Discharge exceedance curve for San Francisco River at Clifton, AZ. 1911-2000.

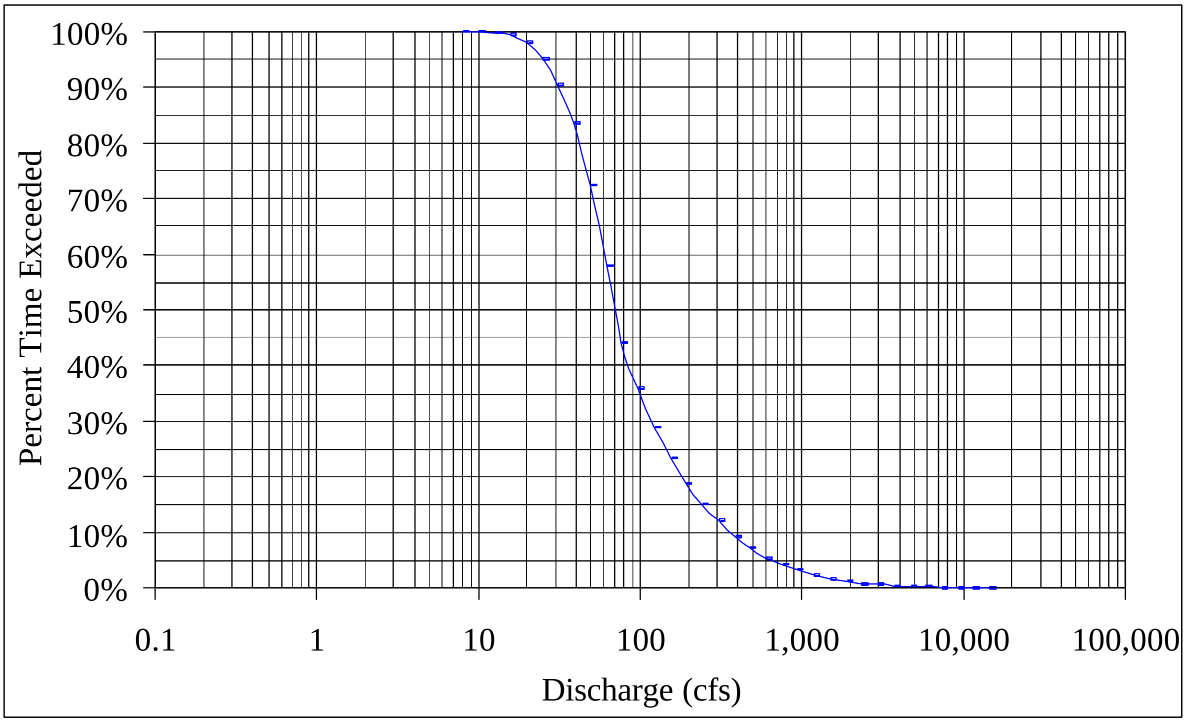


Figure 48. Discharge exceedance curve for San Francisco River at Clifton, AZ. 1911-1964.

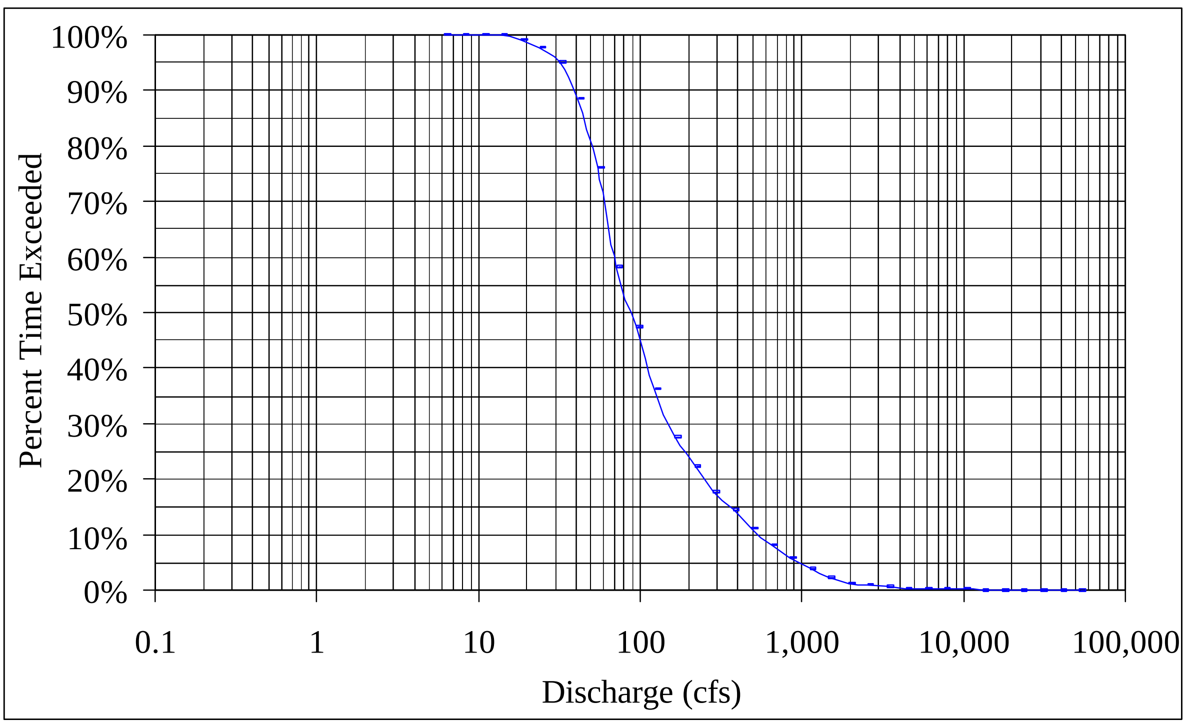


Figure 49. Discharge exceedance curve for San Francisco River at Clifton, AZ. 1965-1999.

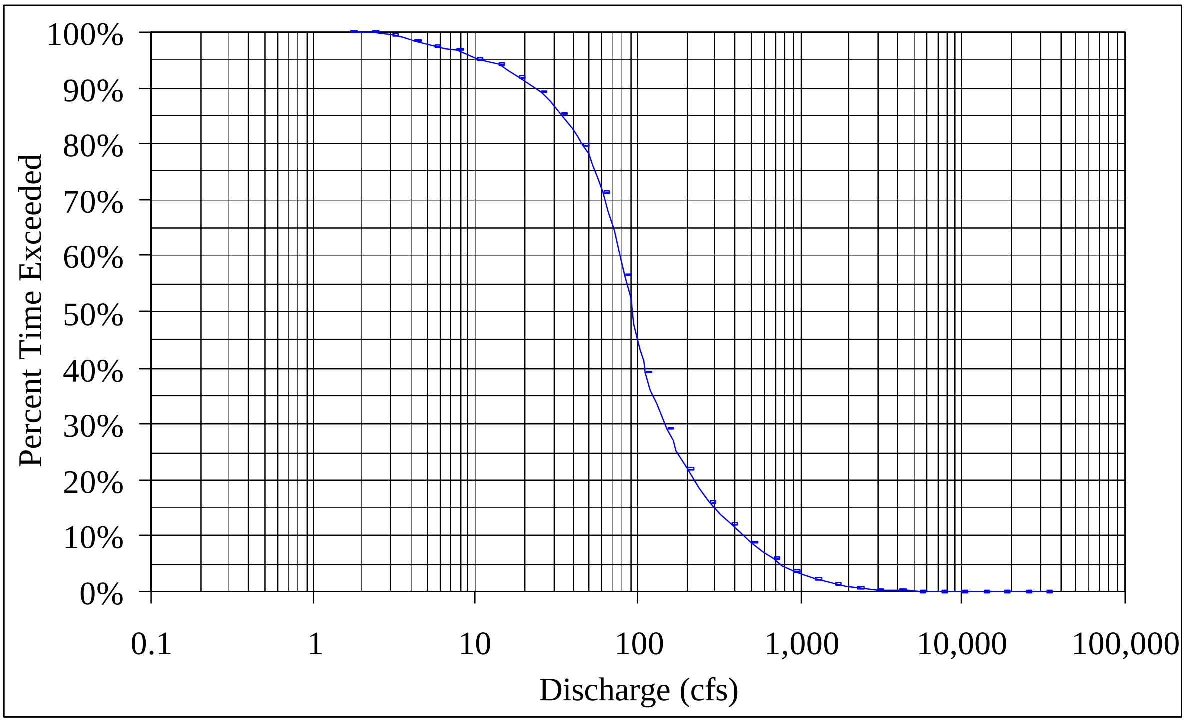


Figure 50. Discharge exceedance curve for Gila River below Blue Creek, near Virden, NM. 1927-2000.

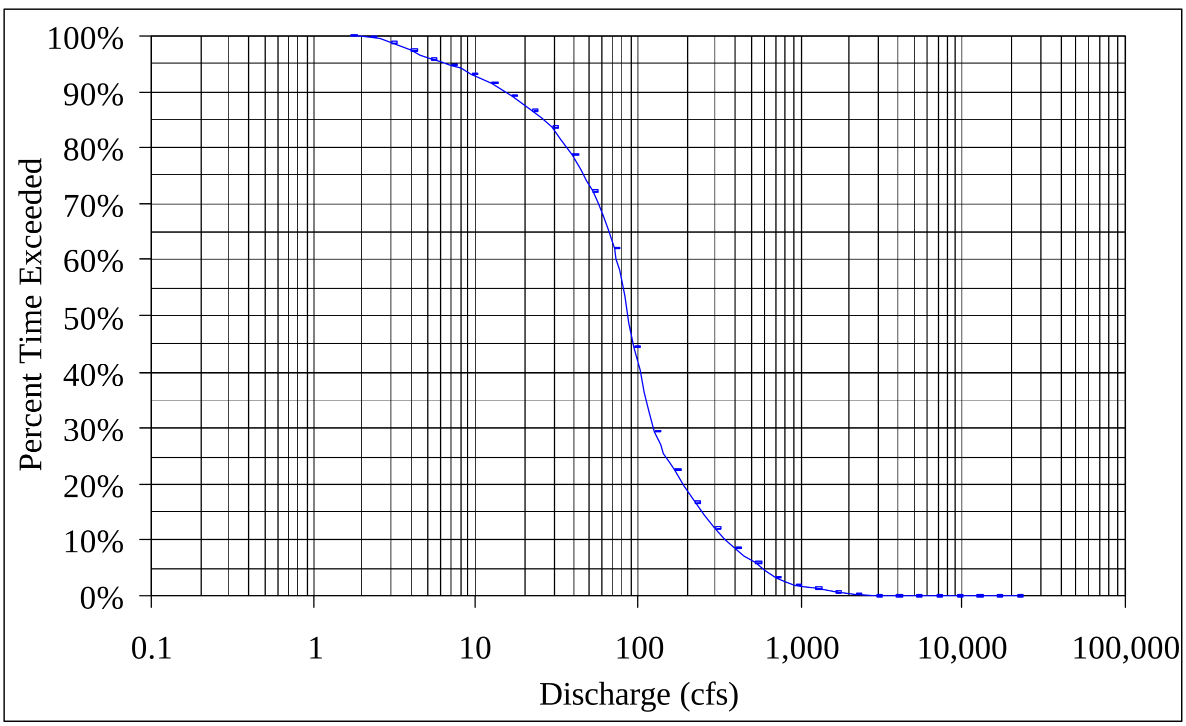


Figure 51. Discharge exceedance curve for Gila River below Blue Creek, near Virden, NM. 1927-1964.

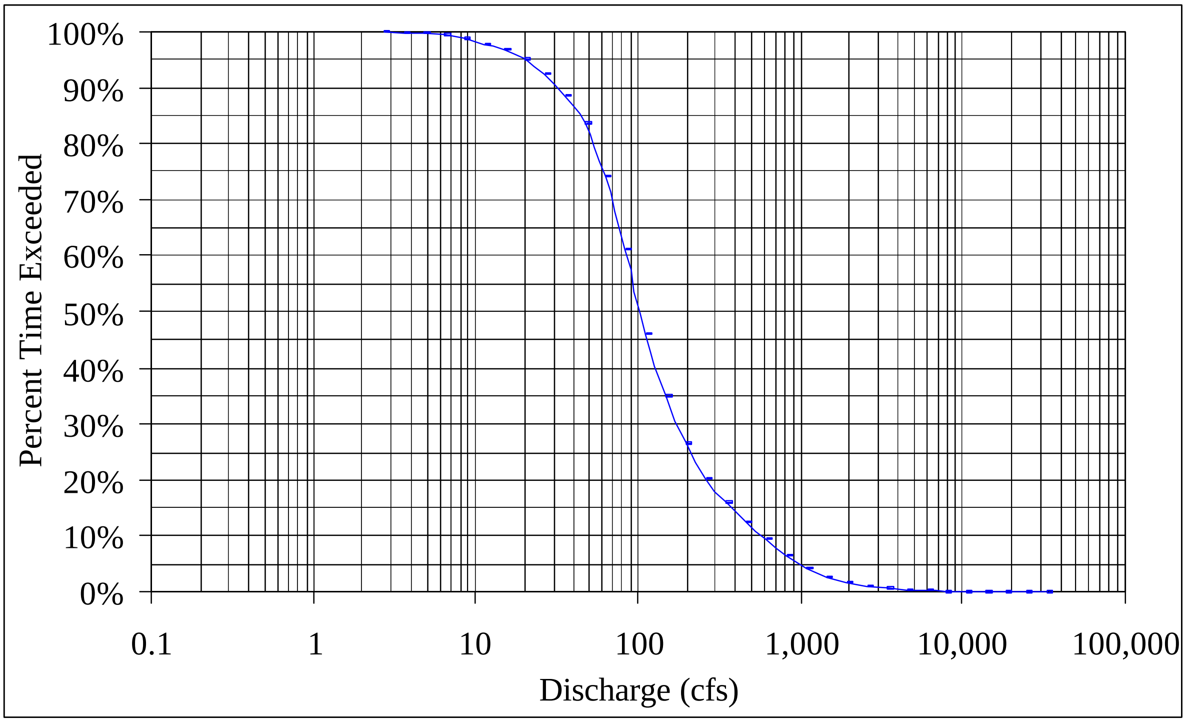


Figure 52. Discharge exceedance curve for Gila River below Blue Creek, near Virden, NM. 1965-2000.

SEDIMENT TRANSPORT

The Yang (Yang, 1973) sediment transport equations are used exclusively for the effective discharge calculations. Details on the calculation methods are available in Stream Channel Design for Sandbed Streams (Delcau, 1997).

EFFECTIVE DISCHARGE CALCULATIONS

This section presents the results of the effective discharge calculations. The procedure follows that specified in Reservoir Sedimentation – Technical Guideline for Bureau of Reclamation (Strand, 1982), pg. 12, Table 2.

LOWER REACH 1

Cross section 631.06 from the HEC-RAS model of Lower Reach 1 was selected to estimate the effective discharge. Figure 53 shows the graphical results of the tabulated calculations shown in Table 3. The effective discharge in Lower Reach 1 is roughly 1,191.6 m^3/s (42,082 ft^3/s) during the period of 1965 to 2000.

Figure 54 shows the graphical results of the tabulated calculations shown in Table 4. The effective discharge in Lower Reach 1 is roughly 94.58 m^3/s (3,340 ft^3/s) during the period of 1930 to 1965.

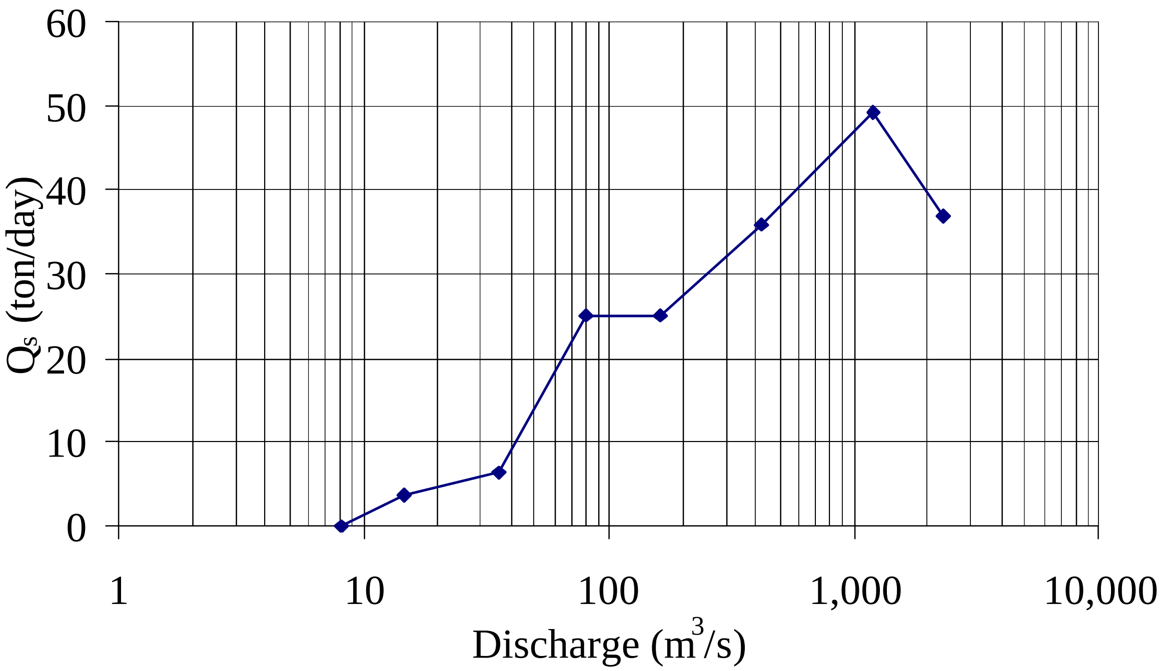


Figure 53. Gila River At Calva, AZ, USGS Gage # 09466500, 1965-2000, XS 631.06.

Table 3. Gila River At Calva, AZ, USGS Gage # 09466500, 1965-2000, XS 631.06.

1 Limits %	2 Interval %	3 Middle Ordinate	4 Q ft^3/s	Q m^3/s	5 Q_s tons/day	2 x 4 Q ft^3/s	2 x 5 Q_s tons/day
0.00-0.02	0.02	0.01	82,252.68	2,329.14	1850.2953	16.45	37.01
0.02 - 0.1	0.08	0.06	42,082.06	1,191.63	613.8718	33.67	49.11
0.1 - 0.5	0.4	0.3	14,907.88	422.14	89.6207	59.63	35.85
0.5 - 1.5	1	1	5,765.94	163.27	25.1359	57.66	25.14
1.5 - 5.0	3.5	3.25	2,867.35	81.19	7.2013	100.36	25.20
5.0 - 15	10	10	1,266.87	35.87	0.6397	126.69	6.40
15 - 25	10	20	513.91	14.55	0.3758	51.39	3.76
25 - 35	10	30	290.23	8.22	0.0000	29.02	0.00
35 - 45	10	40	163.16	4.62	0.0000	16.32	0.00
45 - 55	10	50	99.33	2.81	0.0000	9.93	0.00

1 Limits %	2 Interval %	3 Middle Ordinate	4 Q ft³/s	Q m³/s	5 Q_s tons/day	2 x 4 Q ft³/s	2 x 5 Q_s tons/day
55 - 65	10	60	62.93	1.78	0.0000	6.29	0.00
65 - 75	10	70	40.71	1.15	0.0000	4.07	0.00
75 - 85	10	80	25.52	0.72	0.0000	2.55	0.00
85 - 95	10	90	11.87	0.34	0.0000	1.19	0.00
95 - 96.5	3.5	96.75	4.53	0.13	0.0000	0.16	0.00
98.5 - 99.5	1	99	0.91	0.03	0.0000	0.01	0.00
99.5 - 99.9	0.4	99.7	0.27	0.01	0.0000	0.00	0.00
99.9 - 99.98	0.08	99.94	0.10	0.003	0.0000	0.00	0.00
99.98 - 100	0.02	99.99	0.08	0.002	0.0000	0.00	0.00
					Total =	515.39	182.46
					Q_{annual} =	373,373	AF/year
					$Q_{s\ annual}$ =	66,598	tons/year

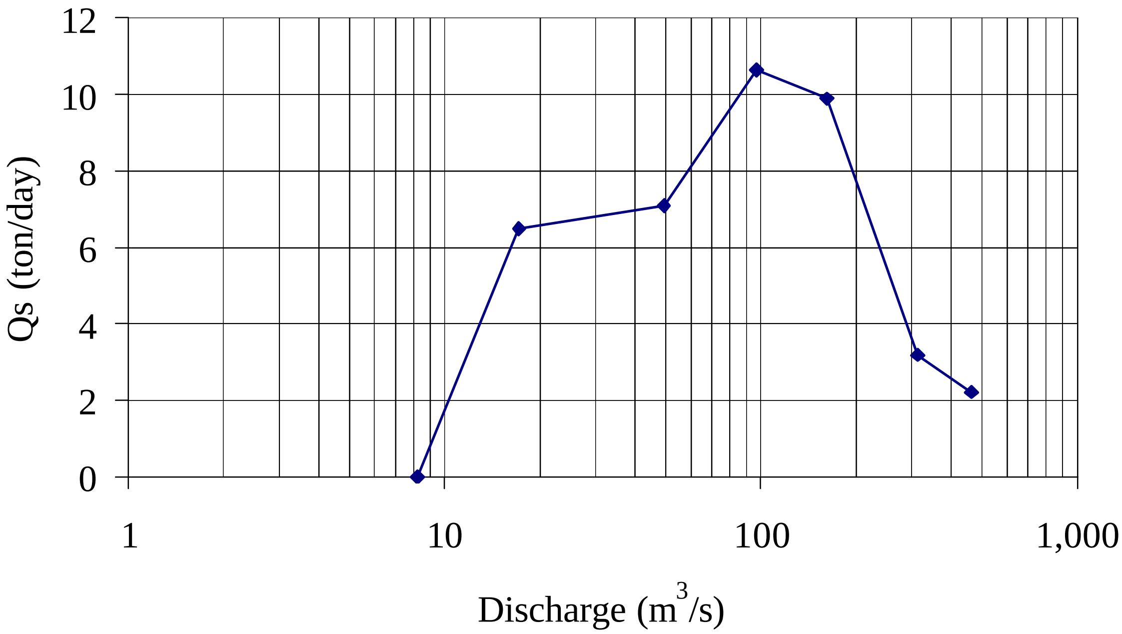


Figure 54. Gila River At Calva, AZ, USGS Gage # 09466500, 1930-1965, XS 631.06.

Table 4. Gila River At Calva, AZ, USGS Gage # 09466500, 1930-1965, XS 631.06.

1 Limits %	2 Interval %	3 Middle Ordinate	4 Q ft³/s	Q m³/s	5 Q_s tons/day	2 x 4 Q ft³/s	2 x 5 Q_s tons/day
0.00 - 0.02	0.02	0.01	16,476.83	466.57	112.1537	3.30	2.24
0.02 - 0.1	0.08	0.06	11,093.23	314.13	40.0424	8.87	3.20
0.1 - 0.5	0.4	0.3	5,687.60	161.06	24.7957	22.75	9.92
0.5 - 1.5	1	1	3,430.27	97.13	10.6553	34.30	10.66
1.5 - 5.0	3.5	3.25	1,745.22	49.42	2.0296	61.08	7.10
5.0 - 15	10	10	607.93	17.21	0.6462	60.79	6.46
15 - 25	10	20	289.66	8.20	0.0000	28.97	0.00
25 - 35	10	30	174.53	4.94	0.0000	17.45	0.00
35 - 45	10	40	108.41	3.07	0.0000	10.84	0.00

1 Limits %	2 Interval %	3 Middle Ordinate	4 Q ft³/s	Q m³/s	5 Q_s tons/day	2 x 4 Q ft³/s	2 x 5 Q_s tons/day
45 - 55	10	50	71.02	2.01	0.0000	7.10	0.00
55 - 65	10	60	44.43	1.26	0.0000	4.44	0.00
65 - 75	10	70	25.86	0.73	0.0000	2.59	0.00
75 - 85	10	80	14.06	0.40	0.0000	1.41	0.00
85 - 95	10	90	5.78	0.16	0.0000	0.58	0.00
95 - 96.5	3.5	96.75	1.37	0.04	0.0000	0.05	0.00
98.5 - 99.5	1	99	0.26	0.01	0.0000	0.00	0.00
99.5 - 99.9	0.4	99.7	0.05	0.0016	0.0000	0.00	0.00
99.9 - 99.98	0.08	99.94	0.01	0.0003	0.0000	0.00	0.00
99.98 - 100	0.02	99.99	0.00	0.0001	0.0000	0.00	0.00
					Total =	264.52	39.59
					Q_{annual} =	191,635	AF/year
					$Q_{s\ annual}$ =	14,449	tons/year

LOWER REACH 4

Cross section 17110.88 from the HEC-RAS model of Lower Reach 4 was selected to estimate the effective discharge. Figure 55 shows the graphical results of the tabulated calculations shown in Table 5. The effective discharge in Lower Reach 4 is roughly 426 m³/s (15,046 ft³/s) during the period of 1965 to 2000.

Figure 56 shows the graphical results of the tabulated calculations shown in Table 6. The effective discharge in Lower Reach 1 is roughly 47.5 m³/s (1,679 ft³/s) during the period of 1920 to 1965.

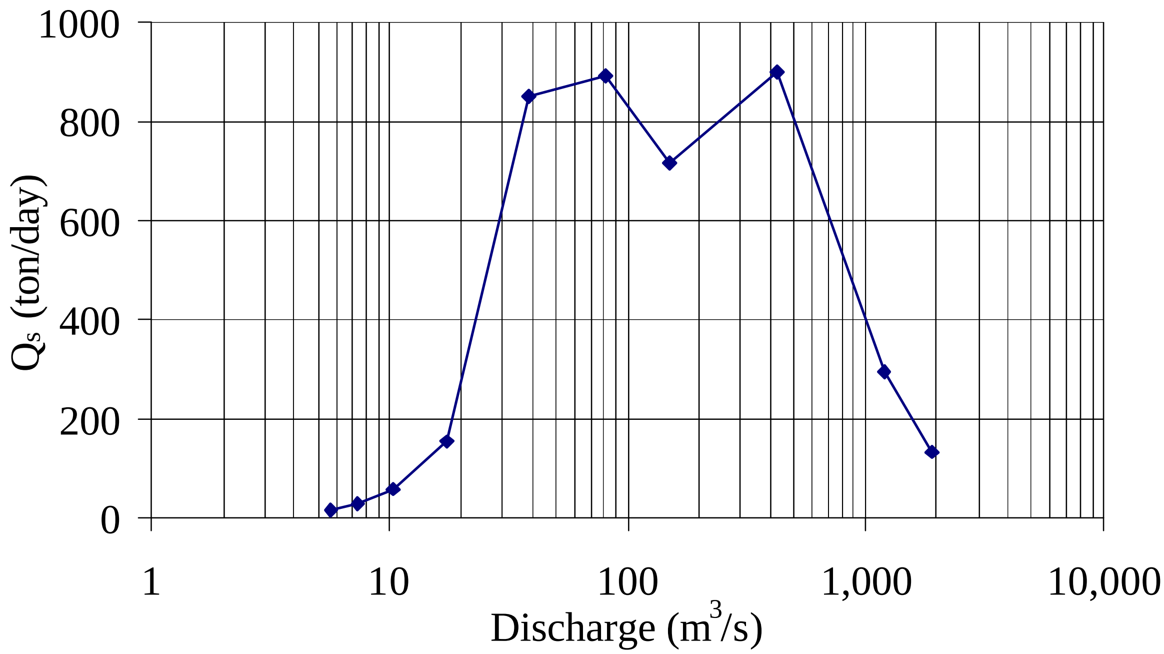


Figure 55. Gila River At Head Of Safford Valley, Near Solomon, AZ, USGS Gage # 09448500, 1965-2000, XS 17110.88.

Table 5. Gila River At Head Of Safford Valley, Near Solomon, AZ, USGS Gage #09448500, 1965-2000, XS 17110.88.

1 Limits %	2 Interval %	3 Middle Ordinate	4 Q ft^3/s	Q m^3/s	5 Q_s tons/day	2 x 4 Q ft^3/s	2 x 5 Q_s tons/day
0.00-0.02	0.02	0.01	67,932.73	1,923.64	6734.1177	13.59	134.68
0.02-0.1	0.08	0.06	42,286.92	1,197.43	3722.8172	33.83	297.83
0.1-0.5	0.4	0.3	15,045.98	426.05	2253.7201	60.18	901.49
0.5-1.5	1	1	5,336.17	151.10	715.1645	53.36	715.16
1.5-5.0	3.5	3.25	2,872.69	81.35	254.5001	100.54	890.75
5.0-15	10	10	1,366.60	38.70	85.1594	136.66	851.59
15-25	10	20	618.64	17.52	15.2676	61.86	152.68
25-35	10	30	366.40	10.38	5.6936	36.64	56.94
35-45	10	40	257.96	7.30	2.9410	25.80	29.41
45-55	10	50	201.25	5.70	1.7372	20.13	17.37
55-65	10	60	163.89	4.64	1.1597	16.39	11.60
65-75	10	70	134.66	3.81	0.7519	13.47	7.52
75-85	10	80	106.09	3.00	0.4319	10.61	4.32
85-95	10	90	74.75	2.12	0.1647	7.48	1.65
95-96.5	3.5	96.75	50.48	1.43	0.0166	1.77	0.06
98.5-99.5	1	99	37.05	1.05	0.0000	0.37	0.00
99.5-99.9	0.4	99.7	28.71	0.81	0.0000	0.11	0.00
99.9-99.98	0.08	99.94	23.10	0.65	0.0000	0.02	0.00
99.98-100	0.02	99.99	18.40	0.52	0.0000	0.00	0.00
					Total=	592.81	4073.04
					Q_{annual}=	429,460	AF/year
					$Q_{sannual}$=	1,486,660	tons/year

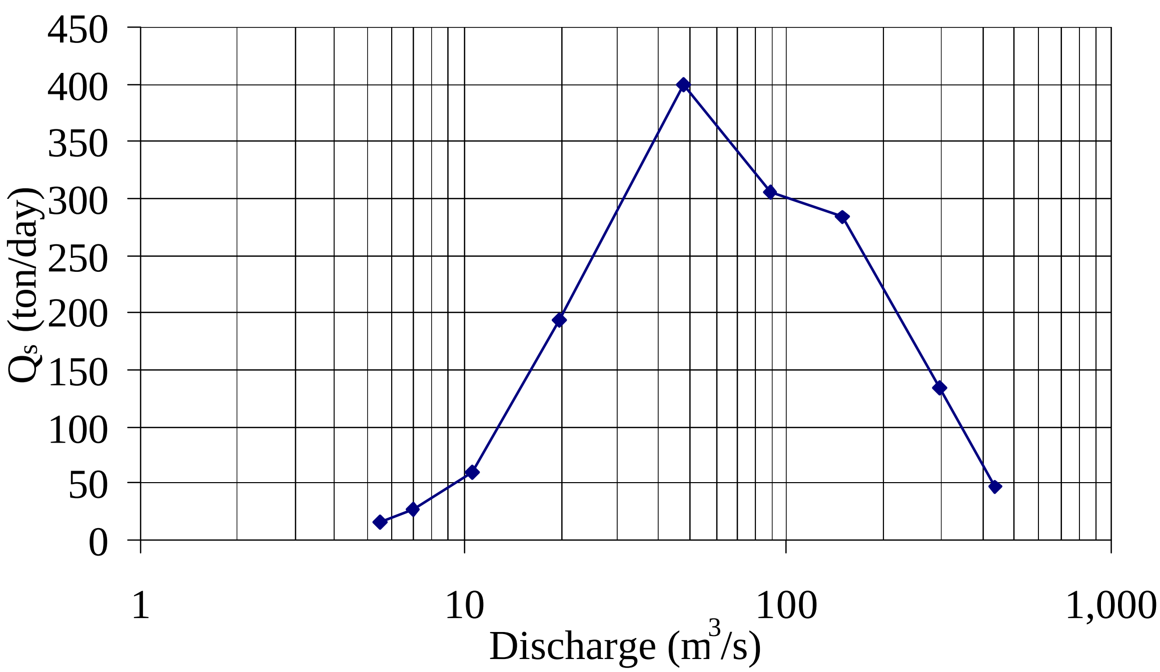


Figure 56. Gila River At Head Of Safford Valley, Near Solomon, AZ, USGS Gage # 09448500, 1920-1965, XS 17110.88.

Table 6. Gila River At Head Of Safford Valley, Near Solomon, AZ, USGS Gage #09448500, 1920-1965, XS 17110.88.

1 Limits %	2 Interval %	3 Middle Ordinate	4 Q ft^3/s	Q m^3/s	5 Q_s tons/day	2 x 4 Q ft^3/s	2 x 5 Q_s tons/day
0.00 - 0.02	0.02	0.01	15,616.48	442.21	2314.9791	3.12	46.30
0.02 - 0.1	0.08	0.06	10,451.85	295.96	1661.3147	8.36	132.91
0.1 - 0.5	0.4	0.3	5,240.37	148.39	711.3945	20.96	284.56
0.5 - 1.5	1	1	3,131.66	88.68	304.9383	31.32	304.94
1.5 - 5.0	3.5	3.25	1,678.90	47.54	114.3138	58.76	400.10
5.0 - 15	10	10	695.89	19.71	19.3864	69.59	193.86
15 - 25	10	20	377.97	10.70	5.9807	37.80	59.81
25 - 35	10	30	246.32	6.97	2.6220	24.63	26.22
35 - 45	10	40	192.98	5.46	1.6029	19.30	16.03
45 - 55	10	50	163.52	4.63	1.1572	16.35	11.57
55 - 65	10	60	136.12	3.85	0.7593	13.61	7.59
65 - 75	10	70	110.27	3.12	0.4802	11.03	4.80
75 - 85	10	80	84.29	2.39	0.2404	8.43	2.40
85 - 95	10	90	57.29	1.62	0.0415	5.73	0.41
95 - 96.5	3.5	96.75	36.33	1.03	0.0000	1.27	0.00
98.5 - 99.5	1	99	26.35	0.75	0.0000	0.26	0.00
99.5 - 99.9	0.4	99.7	20.43	0.58	0.0000	0.08	0.00
99.9 - 99.98	0.08	99.94	15.48	0.44	0.0000	0.01	0.00
99.98 - 100	0.02	99.99	13.16	0.37	0.0000	0.00	0.00
					Total =	330.62	1491.50
					Q_{annual} =	239,520	AF/year
					$Q_{s\ annual}$ =	544,399	tons/year

UPPER REACH

Cross section 24238.64 from the HEC-RAS model of the Upper Reach was selected to estimate the effective discharge. Figure 57 shows the graphical results of the tabulated calculations shown in Table 7. The effective discharge in the Upper Reach is roughly 152.47 m^3/s (5,384 ft^3/s) during the period of 1965 to 2000.

Figure 58 shows the graphical results of the tabulated calculations shown in Table 8. The effective discharge in the Upper Reach is roughly 20.5 m^3/s (725 ft^3/s) during the period of 1927 to 1964.

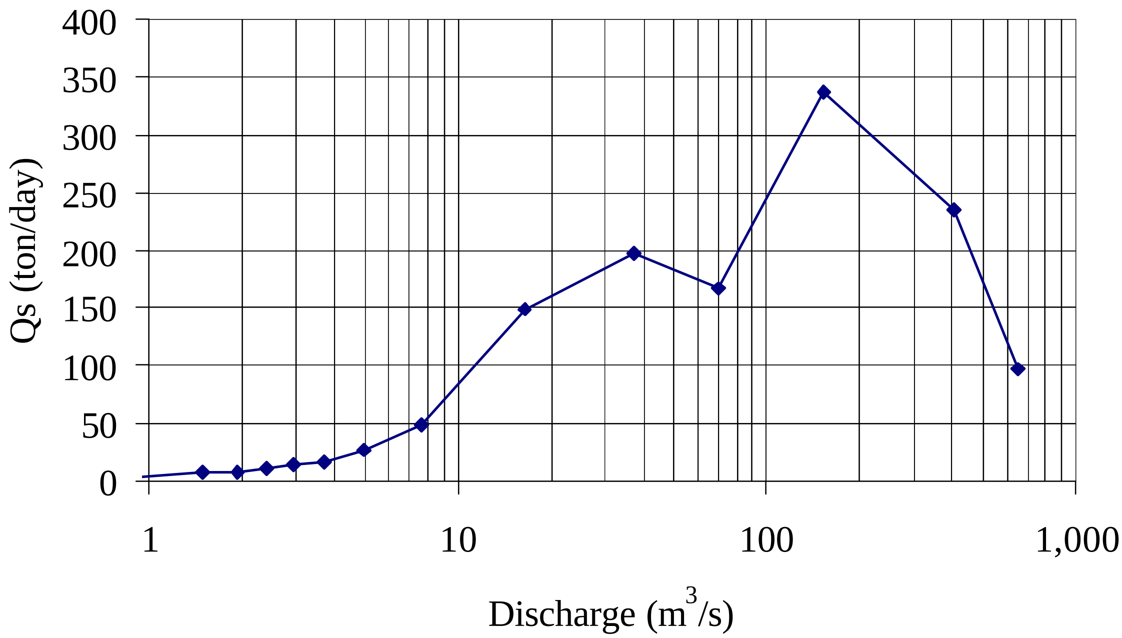


Figure 57. Gila River Below Blue Creek, Near Virden, NM, USGS Gage # 09432000, 1965-2000, XS 24238.64.

Table 7. Gila River Below Blue Creek, Near Virden, NM, USGS Gage # 09432000, 1965-2000, XS 24238.64.

1 Limits %	2 Interval %	3 Middle Ordinate	4 Q ft^3/s	Q m^3/s	5 Q_s tons/day	2 x 4 Q ft^3/s	2 x 5 Q_s tons/day
0.00-0.02	0.02	0.01	23034.46	652.26	4849.6050	4.61	96.99
0.02-0.1	0.08	0.06	14221.95	402.72	2935.7243	11.38	234.86
0.1-0.5	0.4	0.3	5384.36	152.47	840.9313	21.54	336.37
0.5-1.5	1	1	2470.03	69.94	167.0932	24.70	167.09
1.5-5.0	3.5	3.25	1309.41	37.08	56.5859	45.83	198.05
5.0-15	10	10	582.62	16.50	14.8565	58.26	148.57
15-25	10	20	267.34	7.57	4.8827	26.73	48.83
25-35	10	30	174.88	4.95	2.6453	17.49	26.45
35-45	10	40	130.31	3.69	1.5987	13.03	15.99
45-55	10	50	103.17	2.92	1.3462	10.32	13.46
55-65	10	60	84.64	2.40	1.0511	8.46	10.51
65-75	10	70	68.91	1.95	0.7983	6.89	7.98
75-85	10	80	52.94	1.50	0.6471	5.29	6.47
85-95	10	90	31.66	0.90	0.4207	3.17	4.21
95-96.5	3.5	96.75	15.13	0.43	0.1152	0.53	0.40
98.5-99.5	1	99	7.04	0.20	0.0094	0.07	0.01
99.5-99.9	0.4	99.7	4.29	0.12	0.0000	0.02	0.00
99.9-99.98	0.08	99.94	2.91	0.08	0.0000	0.00	0.00
99.98-100	0.02	99.99	1.17	0.03	0.0000	0.00	0.00
					Total=	258.32	1316.25
					Q_{annual}=	187,140	AF/year
					$Q_{sannual}$=	480,430	tons/year

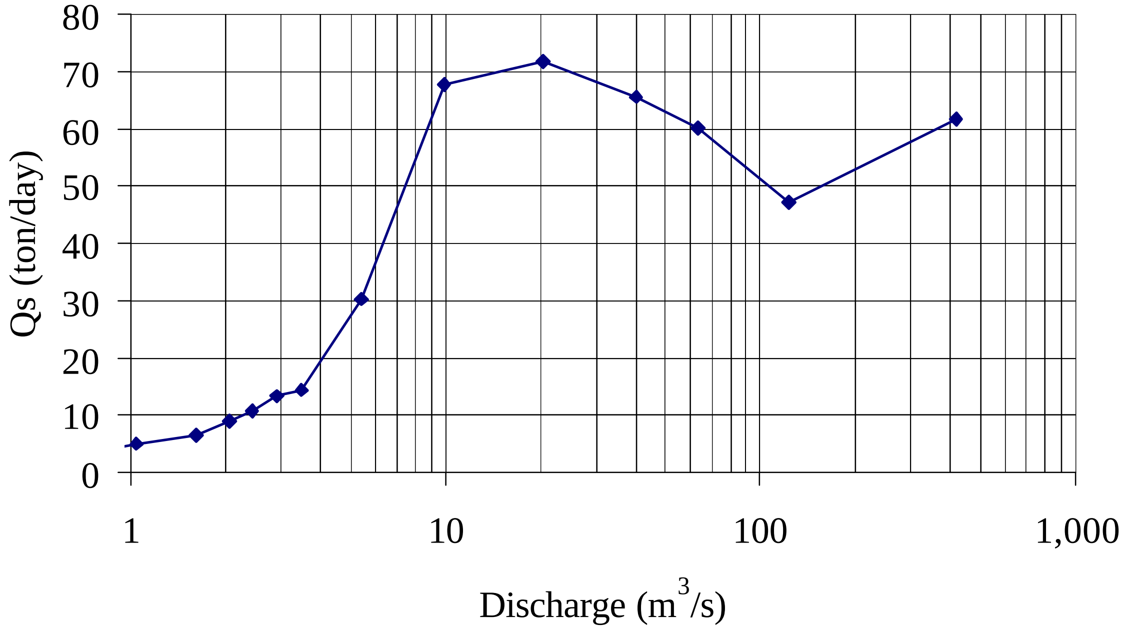


Figure 58. Gila River Below Blue Creek, Near Virden, NM, USGS Gage # 09432000, 1927-1964, XS 24238.64.

Table 8. Gila River Below Blue Creek, Near Virden, NM, USGS Gage # 09432000, 1927-1964, XS 24238.64.

1 Limits %	2 Interval %	3 Middle Ordinate	4 Q ft^3/s	Q m^3/s	5 Q_s tons/day	2 x 4 Q ft^3/s	2 x 5 Q_s tons/day
0.00 - 0.02	0.02	0.01	14830.16	419.94	3078.0348	2.97	61.56
0.02 - 0.1	0.08	0.06	4363.46	123.56	591.4365	3.49	47.31
0.1 - 0.5	0.4	0.3	2236.01	63.32	150.5934	8.94	60.24
0.5 - 1.5	1	1	1426.32	40.39	65.6738	14.26	65.67
1.5 - 5.0	3.5	3.25	725.38	20.54	20.4699	25.39	71.64
5.0 - 15	10	10	349.65	9.90	6.7727	34.96	67.73
15 - 25	10	20	190.80	5.40	3.0132	19.08	30.13
25 - 35	10	30	123.96	3.51	1.4475	12.40	14.48
35 - 45	10	40	103.33	2.93	1.3508	10.33	13.51
45 - 55	10	50	86.62	2.45	1.0667	8.66	10.67
55 - 65	10	60	73.25	2.07	0.8870	7.33	8.87
65 - 75	10	70	56.84	1.61	0.6662	5.68	6.66
75 - 85	10	80	37.22	1.05	0.4943	3.72	4.94
85 - 95	10	90	15.48	0.44	0.1257	1.55	1.26
95 - 96.5	3.5	96.75	4.49	0.13	0.0000	0.16	0.00
98.5 - 99.5	1	99	2.82	0.08	0.0000	0.03	0.00
99.5 - 99.9	0.4	99.7	2.26	0.06	0.0000	0.01	0.00
99.9 - 99.98	0.08	99.94	1.76	0.05	0.0000	0.00	0.00
99.98 - 100	0.02	99.99	0.58	0.02	0.0000	0.00	0.00
					Total =	158.96	464.67
					Q_{annual} =	115,162	AF/year
					$Q_{s\ annual}$ =	169,606	tons/year

SUMMARY OF HYDRAULIC, HYDROLOGIC, AND BED MATERIAL DATA

Table 9 summarizes the effective discharge calculations for each period of record at particular gaging stations, as well as listing the results of other calculations and comparisons. The table organizes much of the input necessary for RISAD and the stable channel analysis. The results from the Gila River at Calva, AZ, gage during the period of 1965 to 2000 will be used in the stable channel analysis in Lower Reach 1 and 2. The results from the Gila River at Head of Safford Valley Near Solomon, AZ, gage during the period of 1965 to 2000 will be used in the stable channel analysis in Lower Reach 3 and 4. The results from the Gila River Below Blue Creek Near Virden, NM, gage during the period 1965 to 2000 will be used in the stable channel analysis in the Upper Reach.

Table 9. Summary of periods of record and resulting hydrologic and sediment transport analysis.

Period	Calculated Mean AF/yr	USGS Mean AF/yr	Δ	Q_{eff} ft³/s	Ratio	Q_s t/d	Q_s PPM
GILA RIVER AT CALVA, AZ USGS Gage # 09466500							
1930-2000	284,410	277,456	2.5%				
1930-1964	191,635	176,205	8.8%	3,430		11	1.1
1965-2000	373,373	384,664	-2.9%	42,082	12.3	614	5.4
GILA RIVER AT SAFFORD, AZ USGS Gage # 09458500							
1940-1965	229,121	206,640	10.9%				
GILA RIVER NEAR SOLOMON, AZ USGS Gage # 09451000							
1914-1951	360,932	359,490	0.4%				
GILA RIVER AT HEAD OF SAFFORD VALLEY NEAR SOLOMON, AZ USGS Gage # 09448500							
1920-2000	325,435	342,418	-5.0%				
1920-1964	239,520	251,304	-4.7%	1,679		114	25.2
1965-2000	429,460	443,945	-3.3%	15,046	9.0	2254	55.5
SAN FRANCISCO RIVER AT CLIFTON, AZ USGS Gage # 09444500							
1911-1999	157,053	161,865	-3.0%				
1911-1964	131,472	130,034	1.1%				
1965-1999	184,421	195,516	-5.7%				
GILA RIVER BELOW BLUE CREEK NEAR VIRDEN, NM USGS Gage # 09432000							
1927-2000	150,728	154,683	-2.6%				
1927-1964	115,162	117,291	-1.8%	725		20	10.5
1965-2000	187,140	196,608	-4.8%	5,384	7.4	841	57.8

Table 10 summarizes the channel side slopes at each of the sections in the analysis. Cross section 631.06 will represent both Lower Reach 1 and 2.

Table 10. Summary of channel side slopes and seed widths for RISAD.

Reach	X-Section	Right Bank Z	Left Bank Z	Ratio	Top Width (ft)
Lower Reach 1 & 2	631.06	39	20	1.96	2073
Lower Reach 4 & 3	17110.88	23	44	1.86	1064
Upper Reach	24238.64	20	13	1.58	324

Cross section 17110.88 will represent both Lower Reach 3 and 4. Cross Section 24238.64 will represent the Upper Reach. In each case, the top-width, from the HEC-RAS model, of the main channel was selected as the "seed" width for the RISAD model. RISAD solves water continuity, roughness, and sediment transport continuity at a section, based upon the geometry of the section, i.e. the bank slopes, and the top width. It satisfies those three conditions simultaneously at various widths, based upon the “seed” width. It calculates at twenty intervals, beginning at one-tenth of the “seed” width, and proceeding up to twice the “seed” width. In each case, the exception being the Upper Reach, the Myer-Peter Muller equation was used for the sediment transport. In the Upper Reach Brownlie was used because the D_{50} was sand size.

STABLE CHANNEL ANALYSIS

This section presents the stable channel analysis. The analysis consists primarily of a chart plotting the slope of the energy grade line versus top width of the channel. The metric for stability is the relative proximity of the channel values to the RISAD developed curve. Points above the stable channel curve are in a zone that generally degrades. Points below the stable channel curve are in a zone that generally aggrades. Points in proximity to the stable channel curve, above and below, as well as dead-on, are in the zone of stability. It is best to take a collective look at the points from a reach. Outliers usually indicate either sections with bed-rock control or sections near diversion dams. The extremal hypothesis of stable channel analysis states that the channel will tend towards the minimum slope of the stable channel curve. Judgement regarding the trend of the river channel, both width and slope, comes from assessment of the relative position of the current channel conditions to the minimum slope on the stable channel curve.

LOWER REACHES 1 & 2

Figure 59 shows the input screen for the Stable Channel Design: Lower Reach 1. The results are also applied to Lower Reach 2.

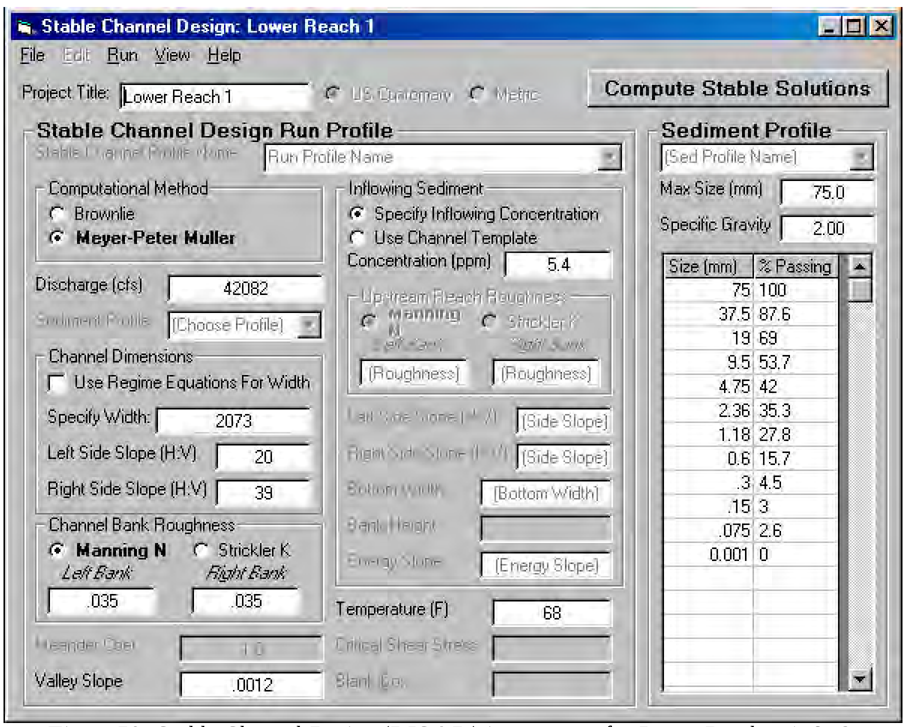


Figure 59. Stable Channel Design (RISAD) input screen for Lower Reaches 1 & 2.

Figure 60 presents the stable channel relationship produced by RISAD for Lower Reaches 1 & 2. Values for the Energy Grade Line (EGL) slope are at each HEC-RAS cross section in the respective reach, and are calculated by the HEC-RAS model.

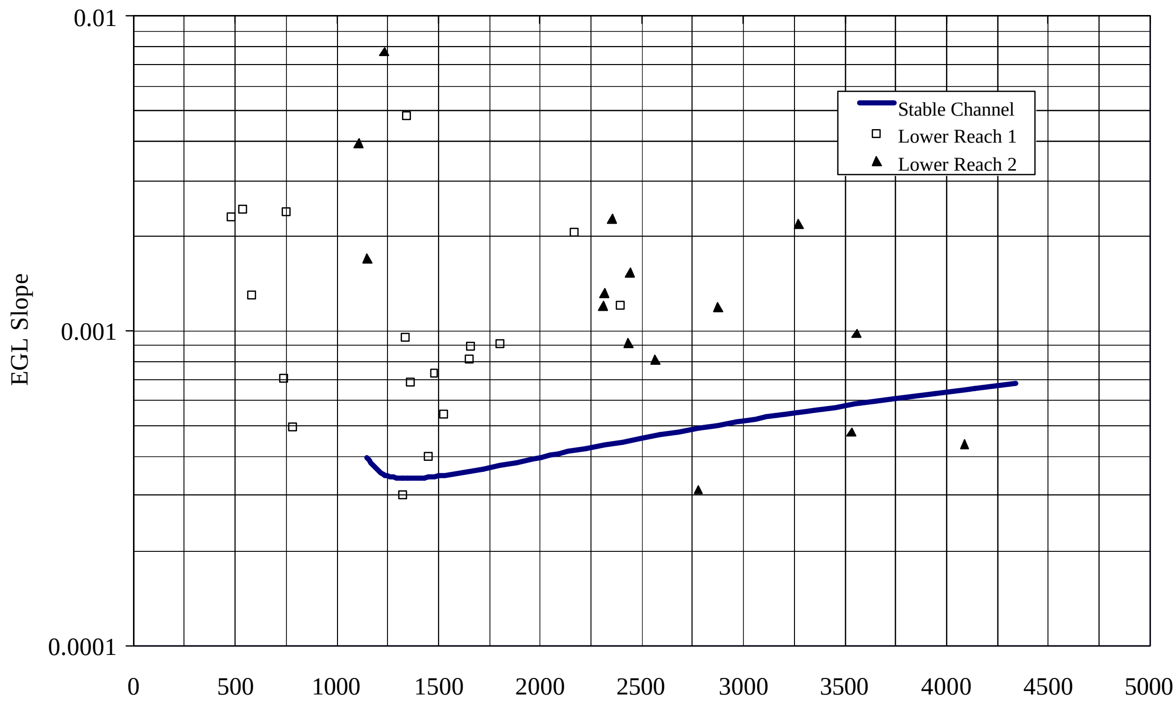


Figure 60. Stable channel analysis in Lower Reach 1 and 2.

Model results show that both reaches are relatively unstable. Some sections in Lower Reach 2 might be stable. The implications of the extremal hypothesis (trend towards the minimum slope on the stable channel curve) indicate that the channel is generally too steep, and many sections, especially in Lower Reach 2, are too wide. This parallels the conclusions of the Catalog of Historical Changes (Klawon, 2001), in that the channel in the upper Safford Valley is nearly at record width, over the period of 1935-1997, and may have been narrowing since 1997. The channel may reduce its slope in two ways: aggradation or increasing sinuosity. Local observation indicates that there may be local aggradation below Fort Thomas. The RISAD results do not indicate aggradation (points below the curve). The instability is probably due to increasing sinuosity, manifesting itself in bank instability and retreat.

LOWER REACHES 3 & 4

Figure 61 shows the input screen for the Stable Channel Design: Lower Reach 4. The results are also applied to Lower Reach 3.

Figure 62 presents the stable channel relationship produced by RISAD for Lower Reaches 3 & 4. Values for the Energy Grade Line (EGL) slope are at each HEC-RAS cross section in the respective reach, and are calculated by the HEC-RAS model.

Model results show that both reaches are relatively stable by virtue of the distribution of points about the stable channel curve. However, many points are a significant distance away from the curve and the minimum point on the curve. Observations from bridges in the valley reveal no obvious bed lowering. However, there has been significant lateral movement of the stream in several areas, due both to channel straightening projects and the river response to those and the hydrologic regime since the mid 1960’s.

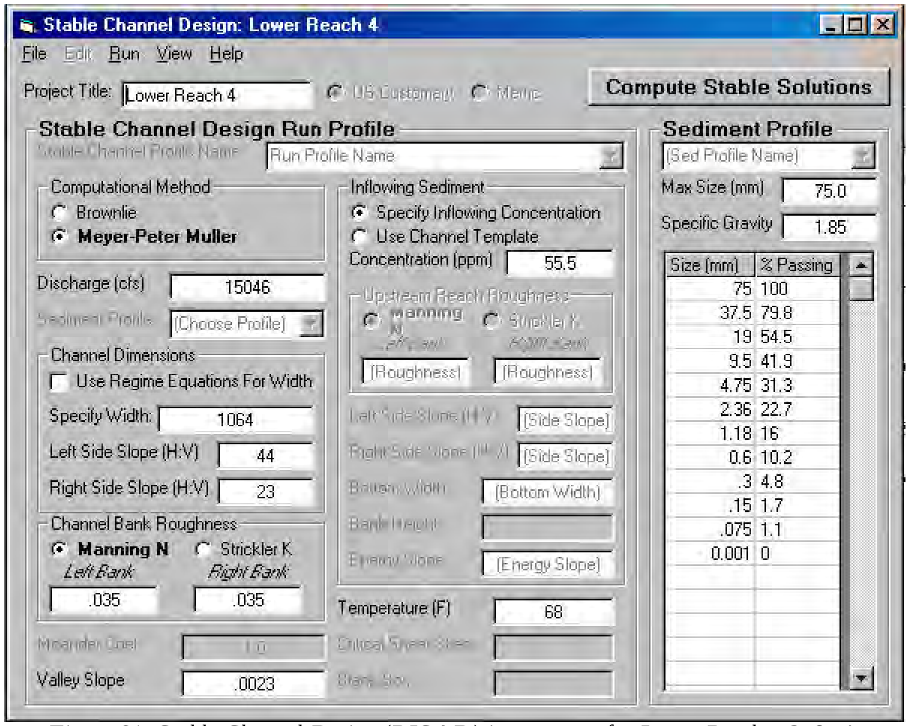


Figure 61. Stable Channel Design (RISAD) input screen for Lower Reaches 3 & 4.

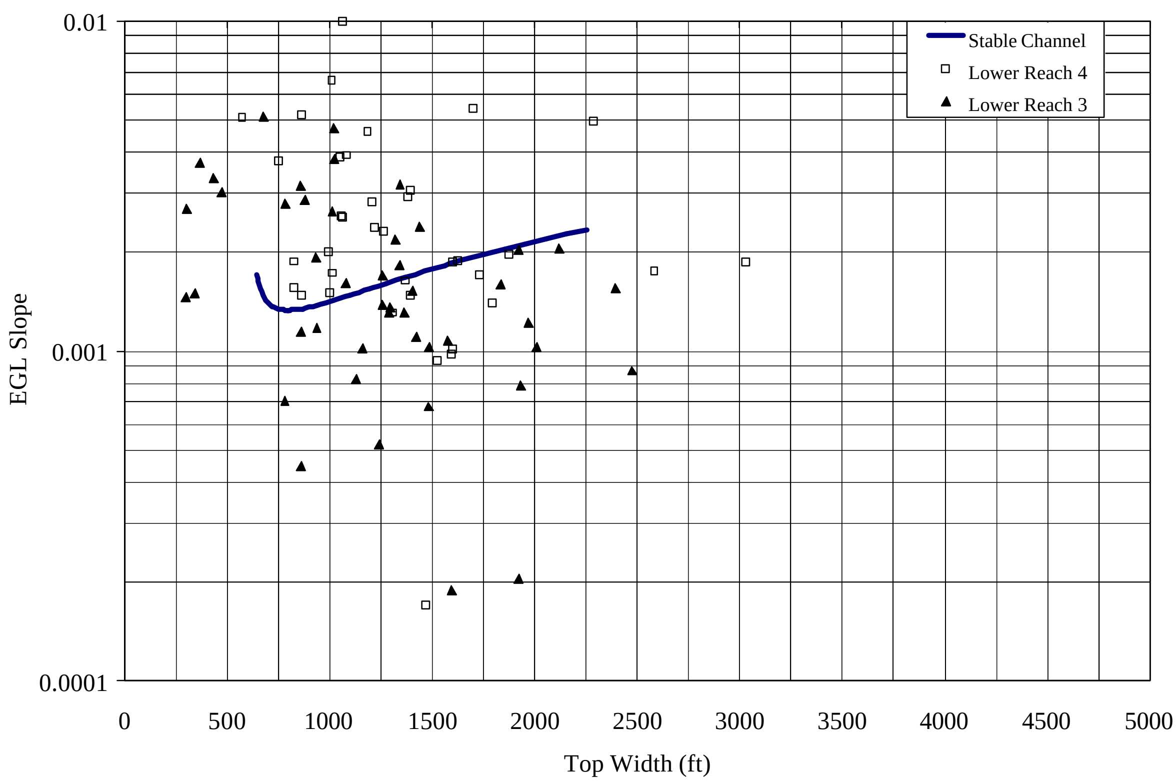


Figure 62. Stable channel analysis in Lower Reach 3 and 4.

UPPER REACH

Figure 63 shows the input screen for the Stable Channel Design: Upper Reach.

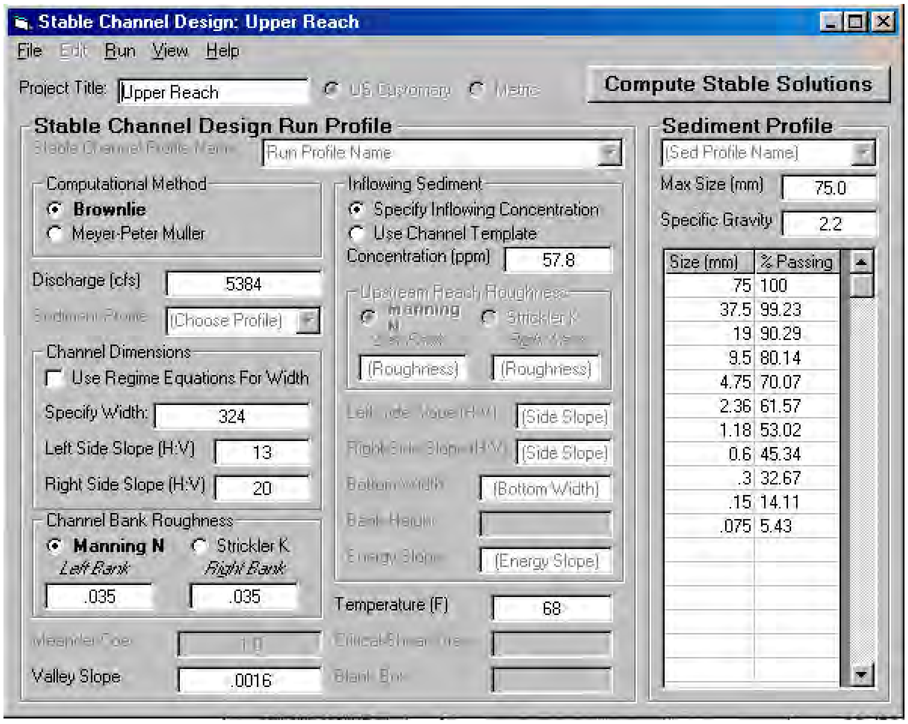


Figure 63. Stable Channel Design (RISAD) input screen for the Upper Reach.

Figure 64 presents the stable channel relationship produced by RISAD for the Upper Reach. Values for the Energy Grade Line (EGL) slope are at each HEC-RAS cross section in the reach, and are calculated by the HEC-RAS model.

Model results show that most of the sections in the Upper Reach are in the degradational range of the stable channel plot. Observations by Klawon (Klawon, personal communication, 2001) indicate recent aggradation that the channel is now cutting through. Implications of the extremal hypothesis are that the channel is indeed degrading, by lowering the bed and widening. Also, as the channel attempts to lower the slope, sinuosity will increase, resulting in bank instability and retreat. There are ample observations of that phenomenon in the Virden and Duncan areas.

There is evidence (Klawon, 2001) of bed rock controls in the lower portion of the Upper Reach. There also appear to be areas of hydraulic control that are not alluvial. The stable channel analysis does not apply to reaches in these areas, and likely produces outliers on the stable channel curve.

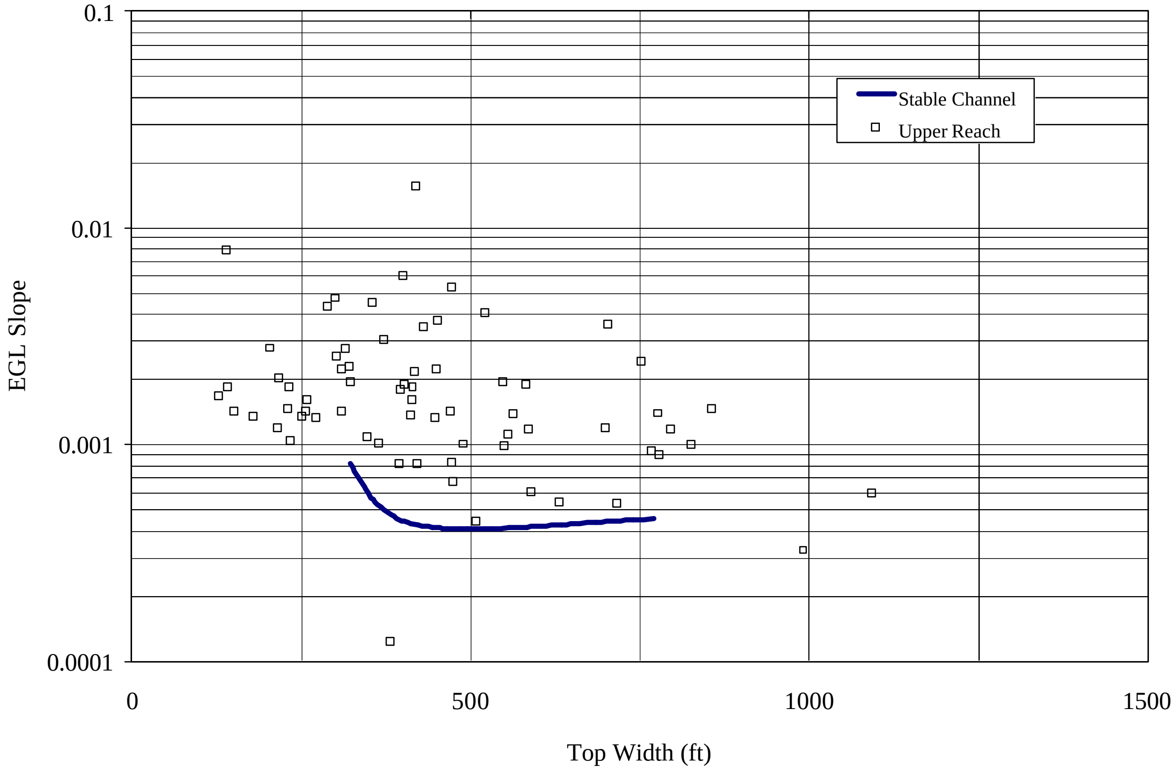


Figure 64. Stable channel analysis in the Upper Reach.

In general, since 1965 the study area is experiencing larger and more frequent floods compared to the 50 year preceding period. During the period from 1935 to 1965 the channel narrowed (Klawon, 2001). Since 1965 the channel is responding to the change in hydrology. The response includes widening, degrading in some reaches, aggrading in others, and increasing sinuosity. These are all normal geomorphic responses to an increase in the magnitude and frequency of floods in the channel forming flow range.

CONCLUSIONS

This analysis indicates that the results of the stable channel modeling are consistent with the geometry of the Gila River in the study area. The modeling indicates that the river is moderately unstable at the effective discharge in many sub-reaches, mostly in the area downstream of Safford and upstream of Sheldon. The modeling shows that the river is stable in a few sub-reaches, mostly between York and Sheldon, possibly due to bed-rock controls in the area. The instability is greatest with respect to the width and sinuosity of the stream. In general the channel has widened in response to an increase in the magnitude and frequency of floods since 1965. Without large floods in the future the channel will narrow and may locally aggrade, similar to the 1935-1965 period.

LOWER REACHES 1 & 2

Model results show that Lower Reach 1 and Lower Reach 2 are relatively unstable. Some sections in Lower Reach 2 might be stable. The channel in the Safford Valley is nearly the same as in 1935, the widest measured over the period of 1935-1997 (Klawon, 2001). Model results indicate that if the channel trends towards the minimum slope on the stable channel curve, Lower Reach 2 will experience the most channel narrowing. The process may include an increase in sinuosity causing widespread bank instability and retreat. Hypothetically, and separate from the stable channel analysis, a typical geomorphic response might include invasion of non-native vegetation, followed by bank encroachment and channel narrowing. The stable channel analysis indicates that Lower Reach 1 may to be overly steep. If the channel reduces its slope by increasing sinuosity, bank instability and retreat will result. However, local observations indicate that the channel may be aggrading in the reach below Fort Thomas. More modeling and geomorphic investigation is necessary to determine the channel trends in this area.

LOWER REACHES 3 & 4

Model results show that both Lower Reach 3 and Lower Reach 4 are relative stable by virtue of the distribution of points about the stable channel curve. There has been significant lateral movement of the stream in several areas, due both to channel straightening projects and the river response to those and the hydrologic regime since the mid 1960's. Lower Reach 3 may undergo the most channel narrowing following invasion by non-native vegetation and bank encroachment.

UPPER REACH

Model results show that most of the sections in the Upper Reach are in the degradational range of the stable channel plot. Geomorphic evidence indicates that the river is in a period of degradation following a period of aggradation. There are ample observations of that phenomenon in the Virden and Duncan areas. There are several bedrock areas and hydraulic controls that are not alluvial in nature, invalidating the stable channel analysis in those reaches.

REFERENCES

1. Andrews, E. D., 1980. "*Effective and bankfull discharge of streams in the Yampa basin, western Wyoming.*" Journal of Hydrology, 46, 311-330.

2. Chien, N., 1955. "*A Concept of the Regime Theory.*" Trans. Am. Soc. Civ. Engrs., No. 2884, 785-805.

3. Copeland, R.R., Biedenharn, D.S., Fischenich, J.C., 2000. "*Channel-Forming Discharge*." US Army Corps of Engineers. ERDC/CHL HETN-II-5, September 2000

4. Delcau, M.R., 1997. "*Stable Channel Design for Sand Bed Streams*." Thesis, in partial fulfillment of the requirements for the degree of Master of Science, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado. Summer, 1997.

5. Henderson, F.M., 1966. *"Open Channel Flow."* MacMillan Publishing Co., Inc., New York. p. 41.

6. Klawon, J.E., 2001. "*Upper Gila River Fluvial Geomorphology Study, Catalog Of Historical Changes, Arizona.*" Fluvial Hydraulics and Geomorphology Team, Technical Service Center, US Bureau of Reclamation, Denver, Colorado. June, 2001.

7. Lane, E.W., 1953. "*Design of Stable Channels.*" Trans. Am. Soc. Civ. Engrs., 120:1234-1260.

8. Mackin, J.H., 1948. "*Concept of the Graded River.*" Geol. Soc. Am. Bull., 59:463-511.

9. Murphy, P., Randle, T., et. al, 2001. "*Draft Technical Report, Platte River Sediment Transport and Riparian Vegetation Model.*" US Department of Interior, Bureau of Reclamation, Technical Service Center. River Hydraulics and Sedimentation Section, D-8540. Denver, Colorado.

10. Strand, R.I., Pemberton, E.L., 1982. "*Reservoir Sedimentation.*" Technical Guideline for Bureau of Reclamation, Sedimentation and River Hydraulics Section, Hydrology Branch, Division of Planning Technical Services, Engineering and Research Center, Denver, Colorado. October, 1982.

11. U.S. Geological Survey, 2001. "*Suspended-sediment database – daily values of suspended sediment and ancillary data:*" U.S. Geological Survey data available on the World Wide Web, accessed 10-10-01 at URL http://co.water.usgs.gov/sediment/

12. Watson, C.C., Biedenharn, D.S., Thorne, C.R., 1999. "*Demonstration Erosion Control, Design Manual.*" U.S. Army, Engineer Research and Development Center, Vicksburg, Mississippi. Funding for this document was provided by the U. S. Army, Corps of Engineers, Vicksburg District.

13. Wittler, R.J., Levish, D.R., 2001. "*Upper Gila River Fluvial Geomorphology Study, Field Data Collection Plan.* Fluvial Hydraulics and Geomorphology Team, Technical Service Center, US Bureau of Reclamation, Denver, Colorado. March, 2001.

14. Wolman, M.G., Miller, J.P., 1960. "*Magnitude and Frequency of Forces in Geomorphic Processes.*" Journal of Geology, 68, 54-74.

15. Yang, C.T. (1973), "*Incipient Motion and Sediment Transport*," Journal of the Hydraulics Division, ASCE, vol. 99, no. HY 10, Proceeding Paper 10 067, pp. 1679-1704.

APPENDIX A

HEC-RAS SECTION LOCATIONS

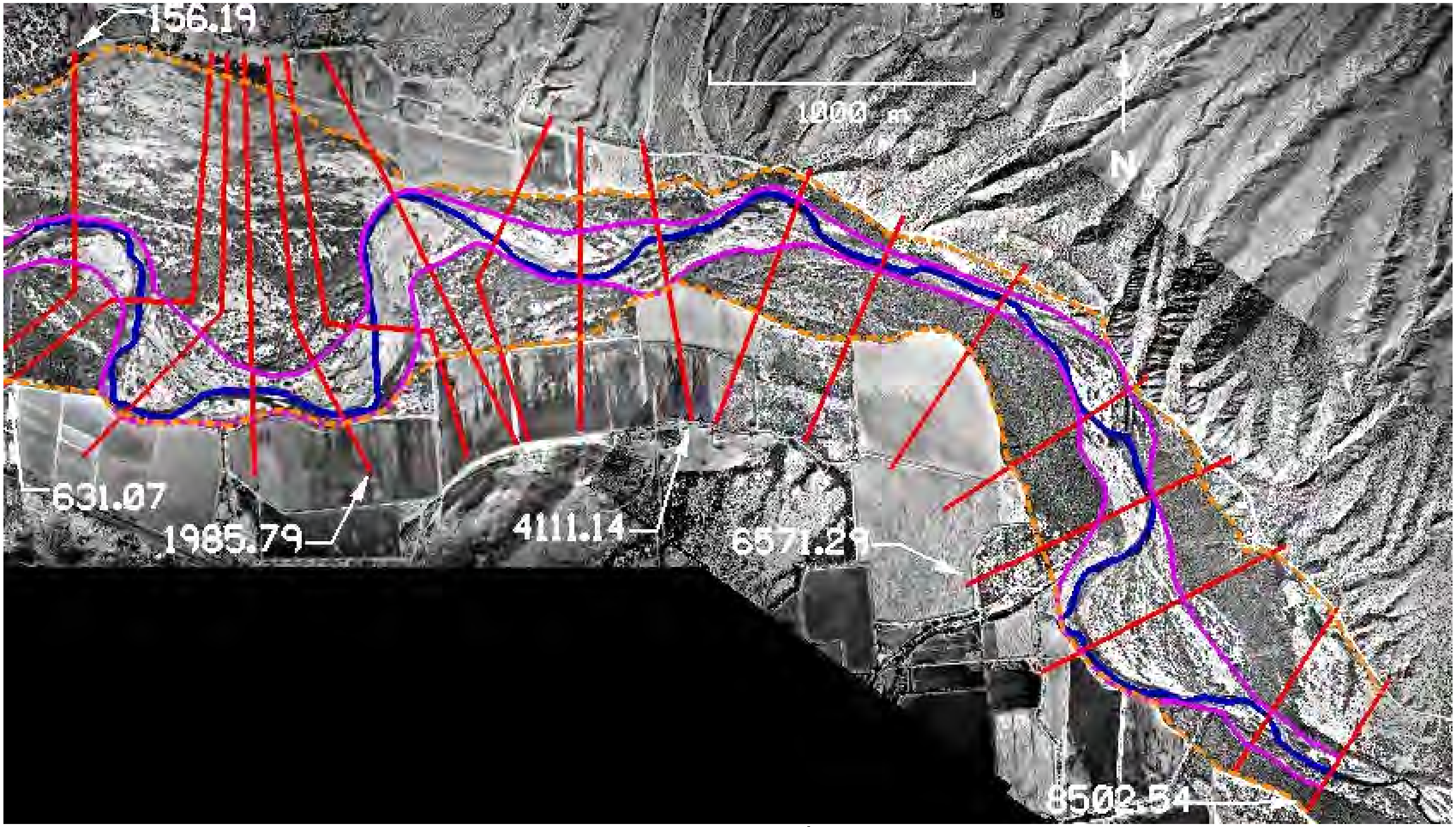


Figure 65. Lower Reach 1.

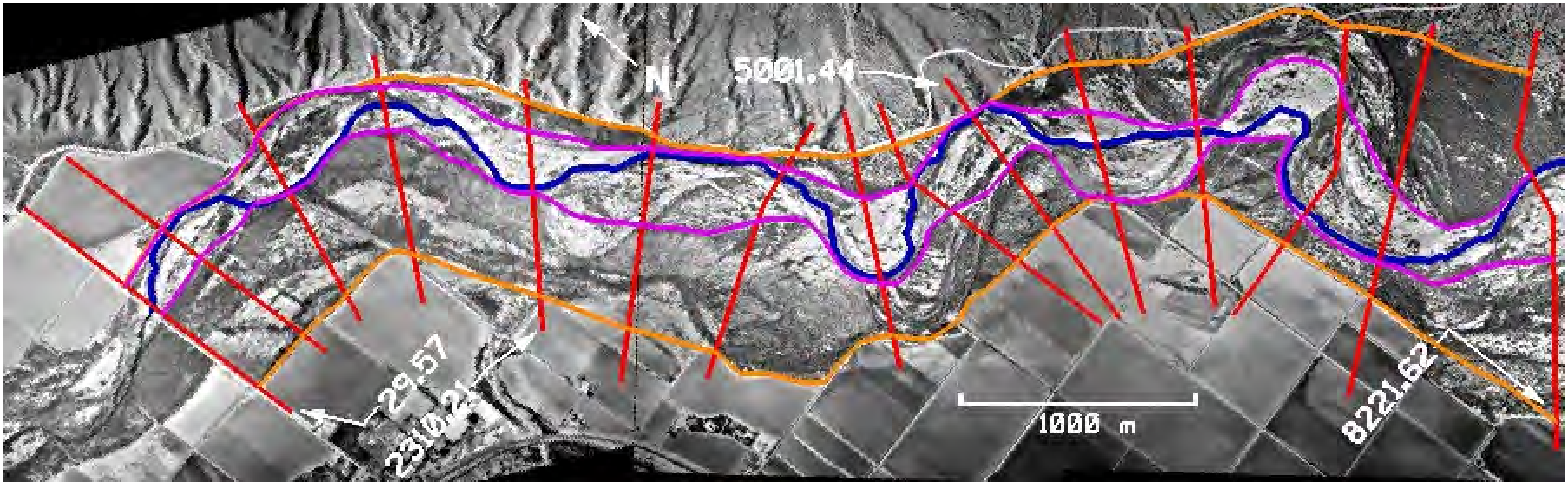


Figure 66. Lower Reach 2.

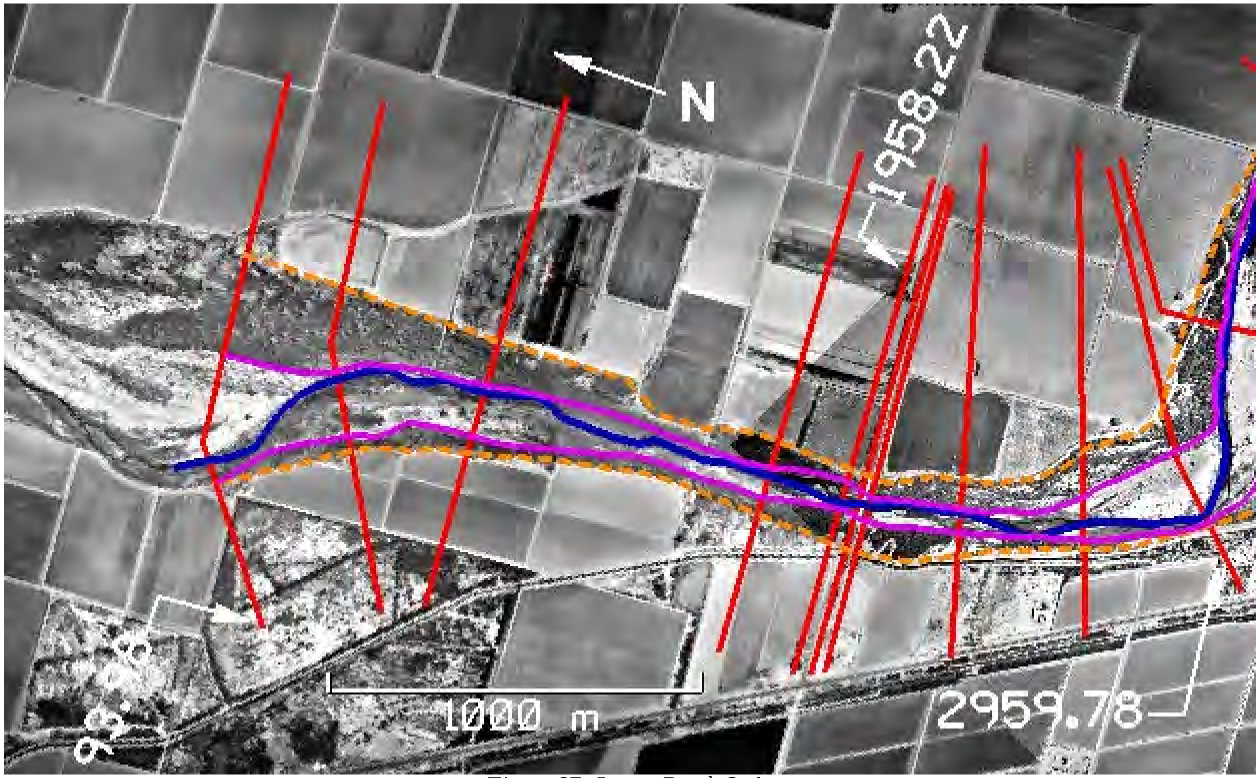


Figure 67. Lower Reach 3-A.

Figure 68. Lower Reach 3-B.

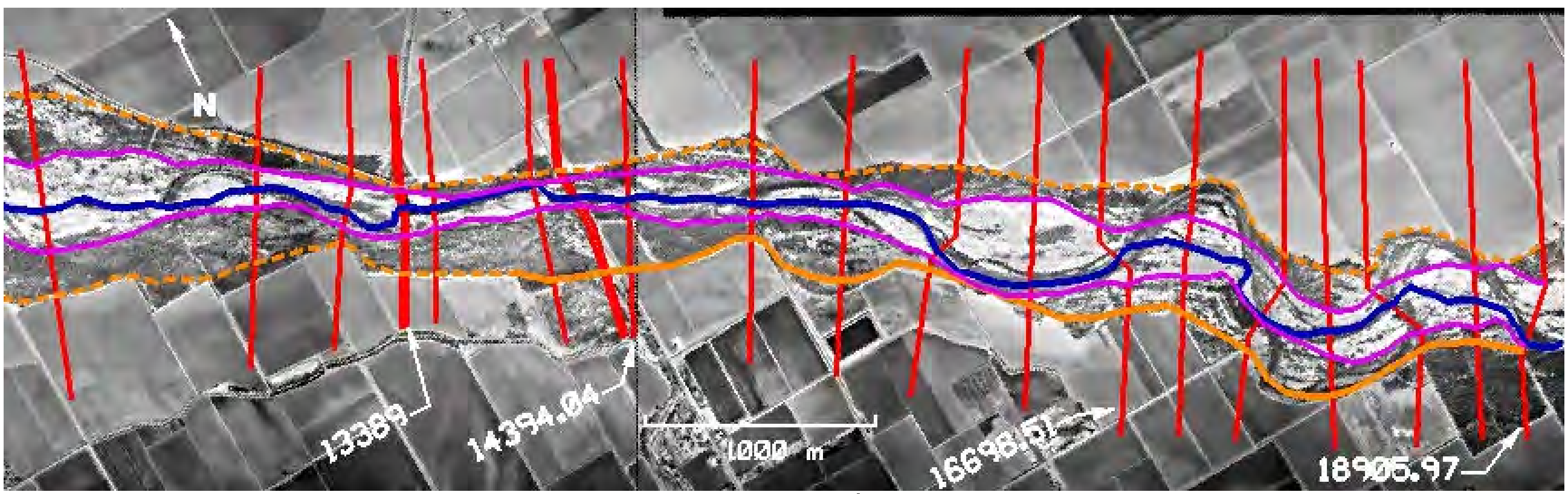


Figure 69. Lower Reach 3-C.

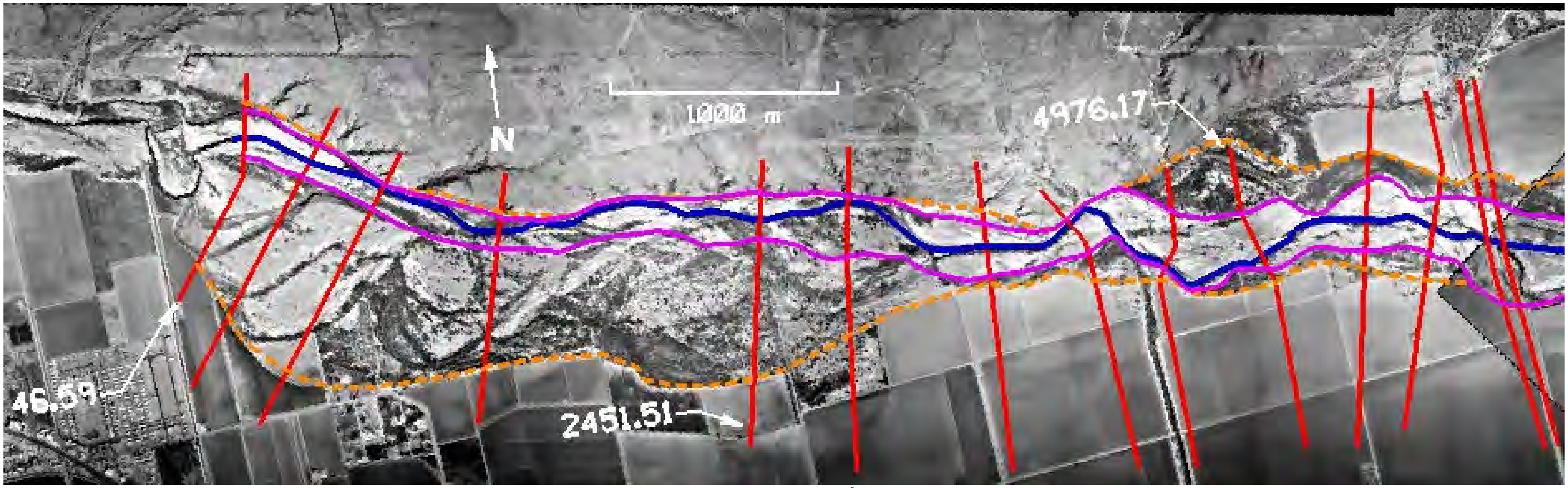


Figure 70. Lower Reach 4-A.

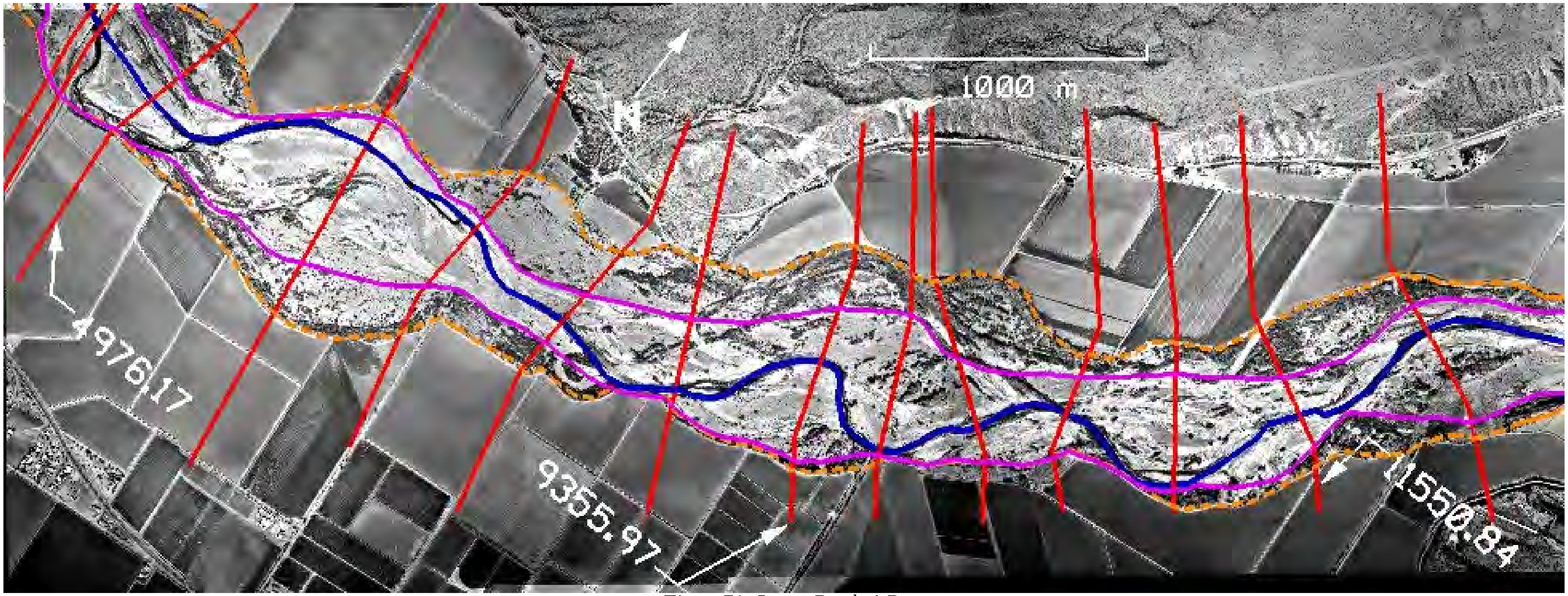


Figure 71. Lower Reach 4-B.

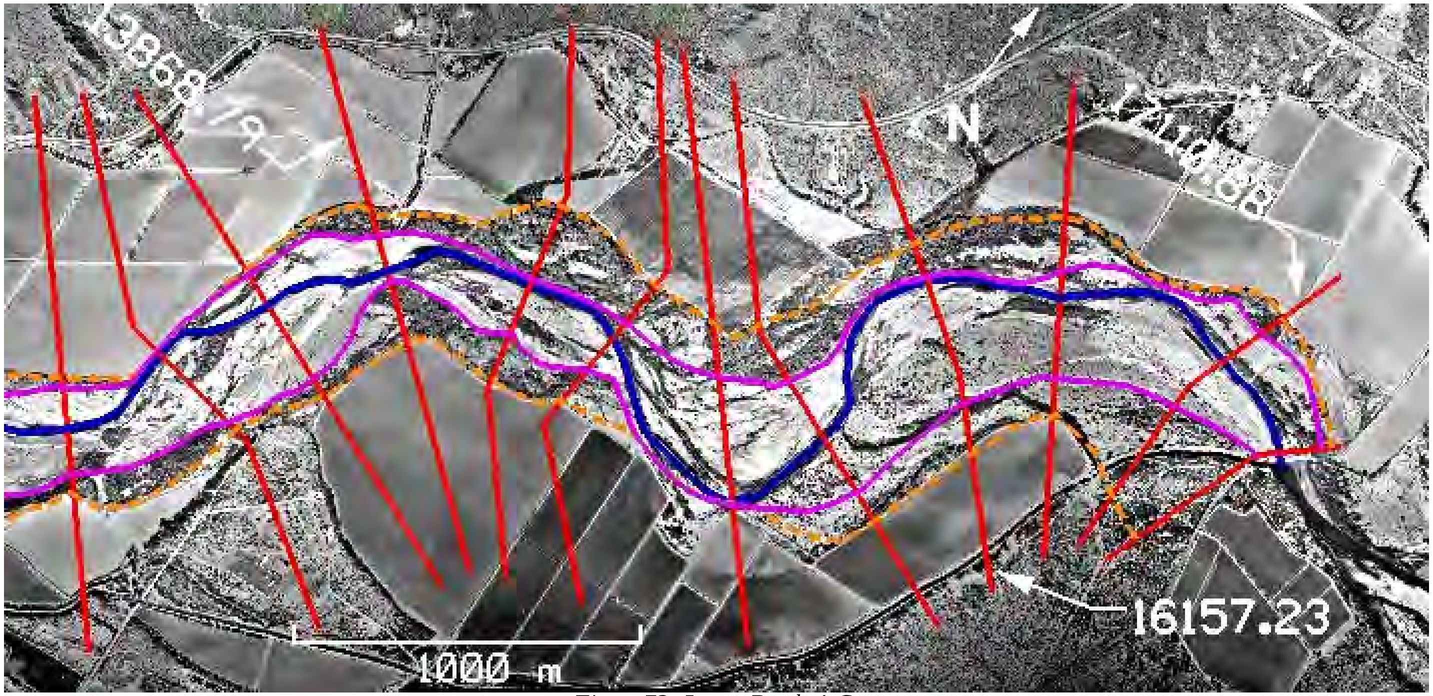


Figure 72. Lower Reach 4-C.

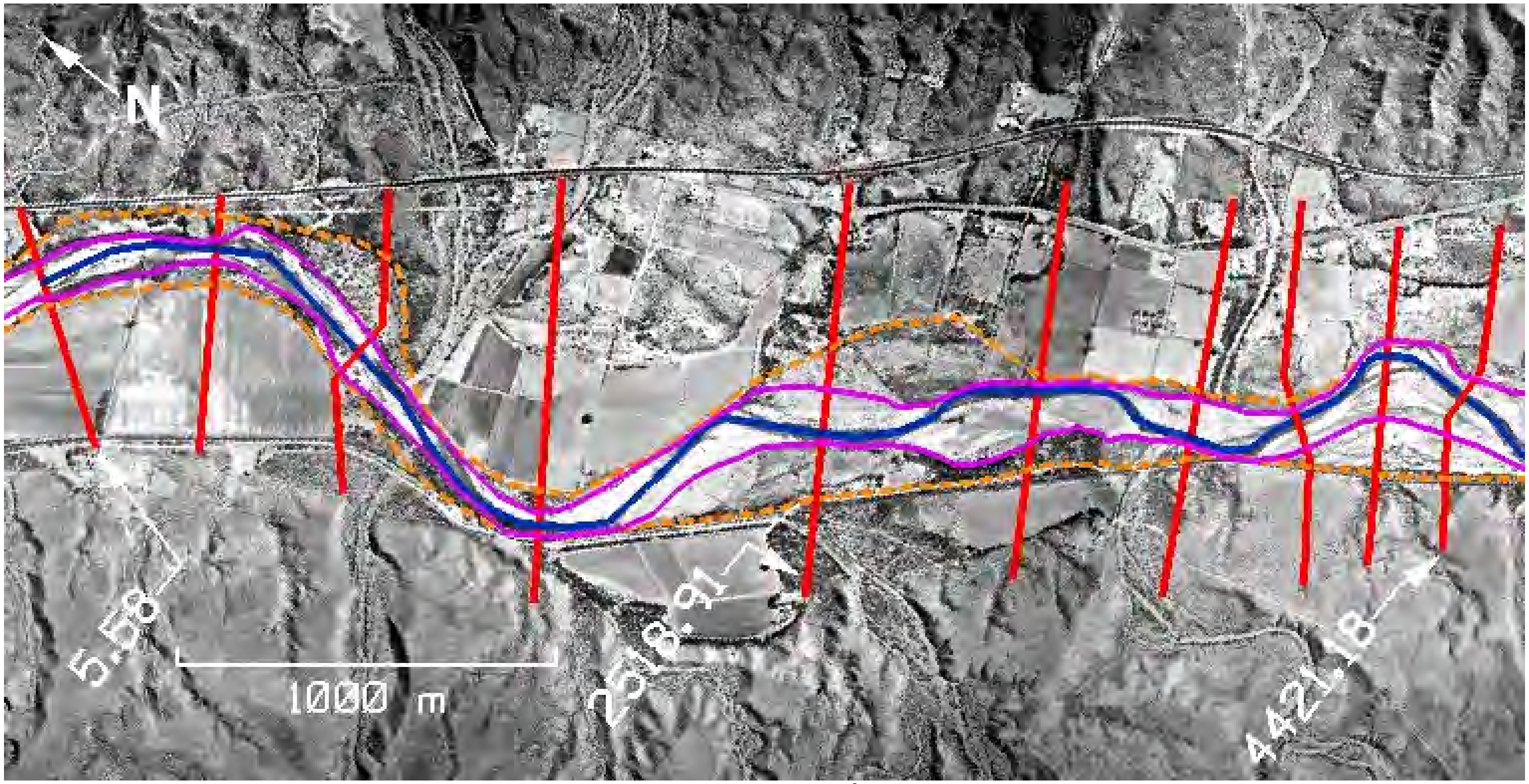


Figure 73. Upper Reach A.

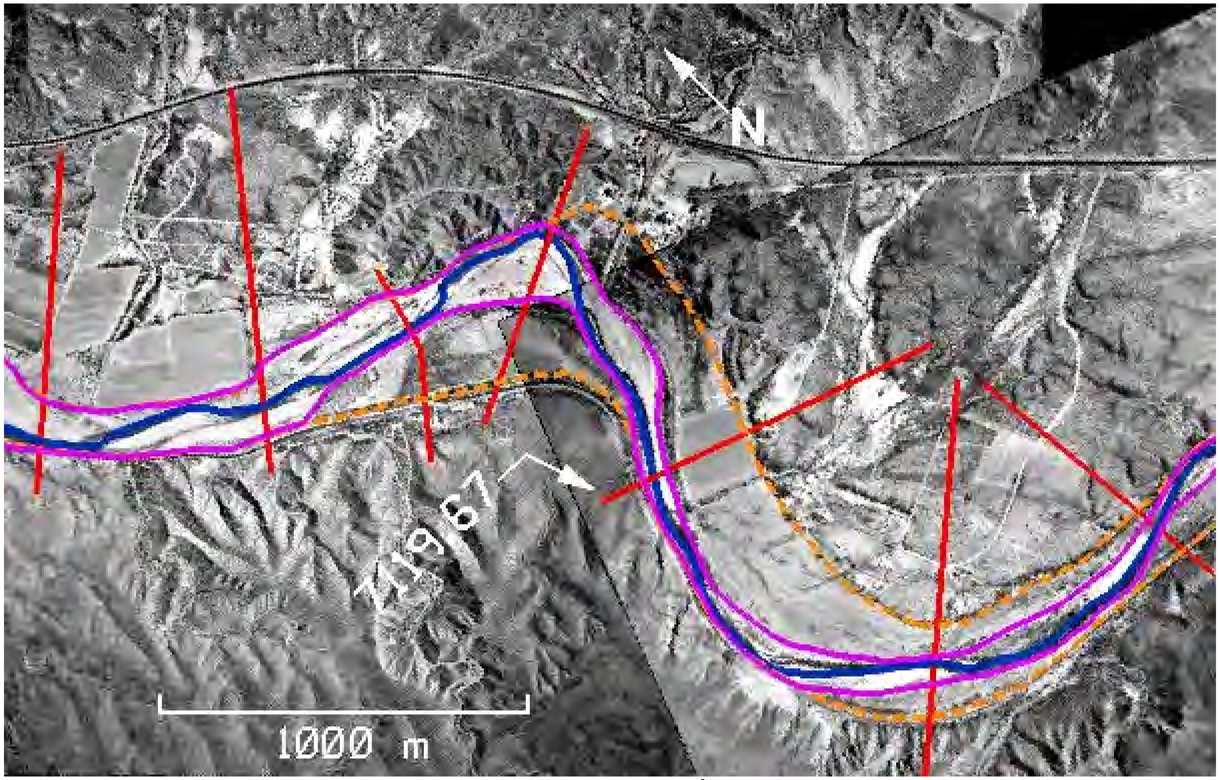


Figure 74. Upper Reach B.

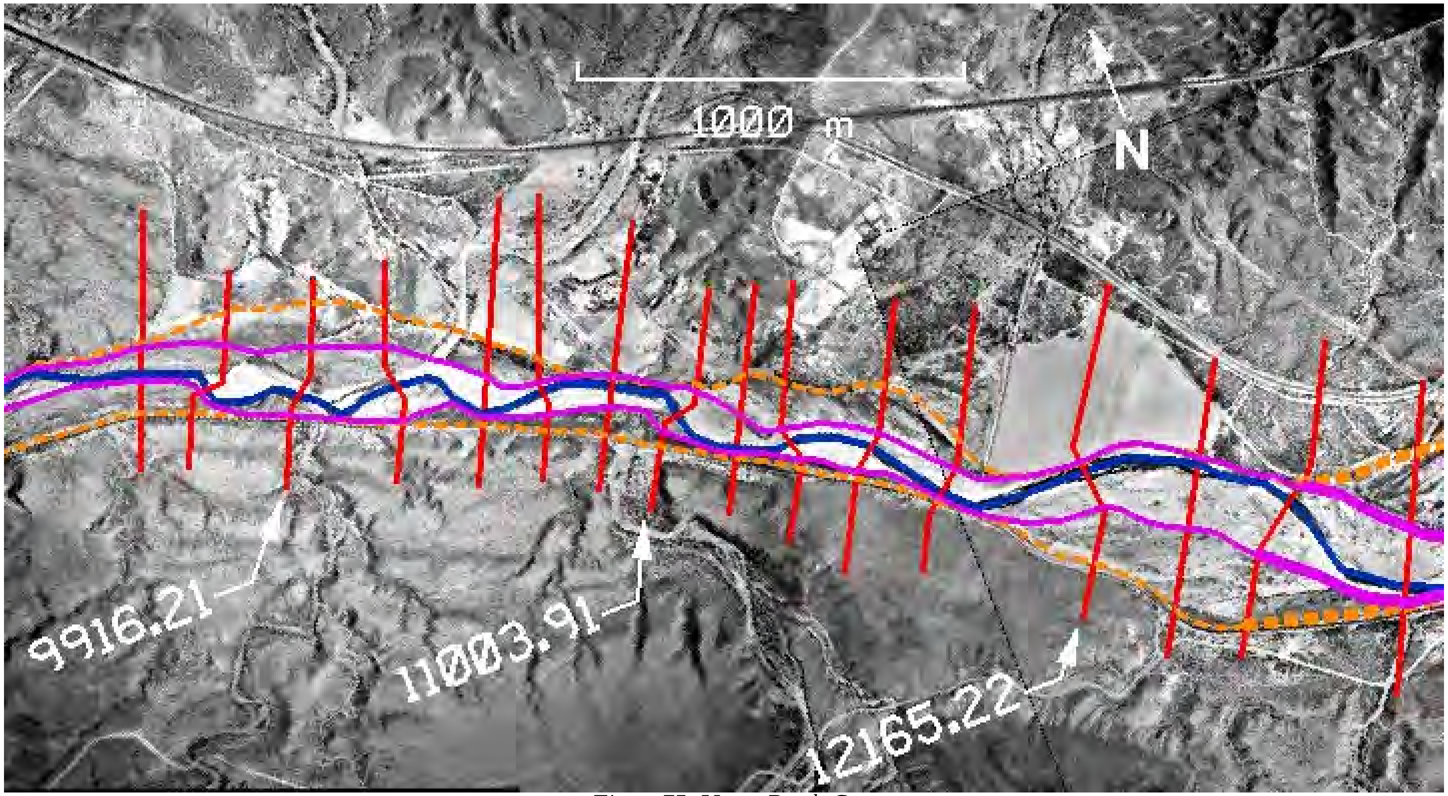


Figure 75. Upper Reach C.

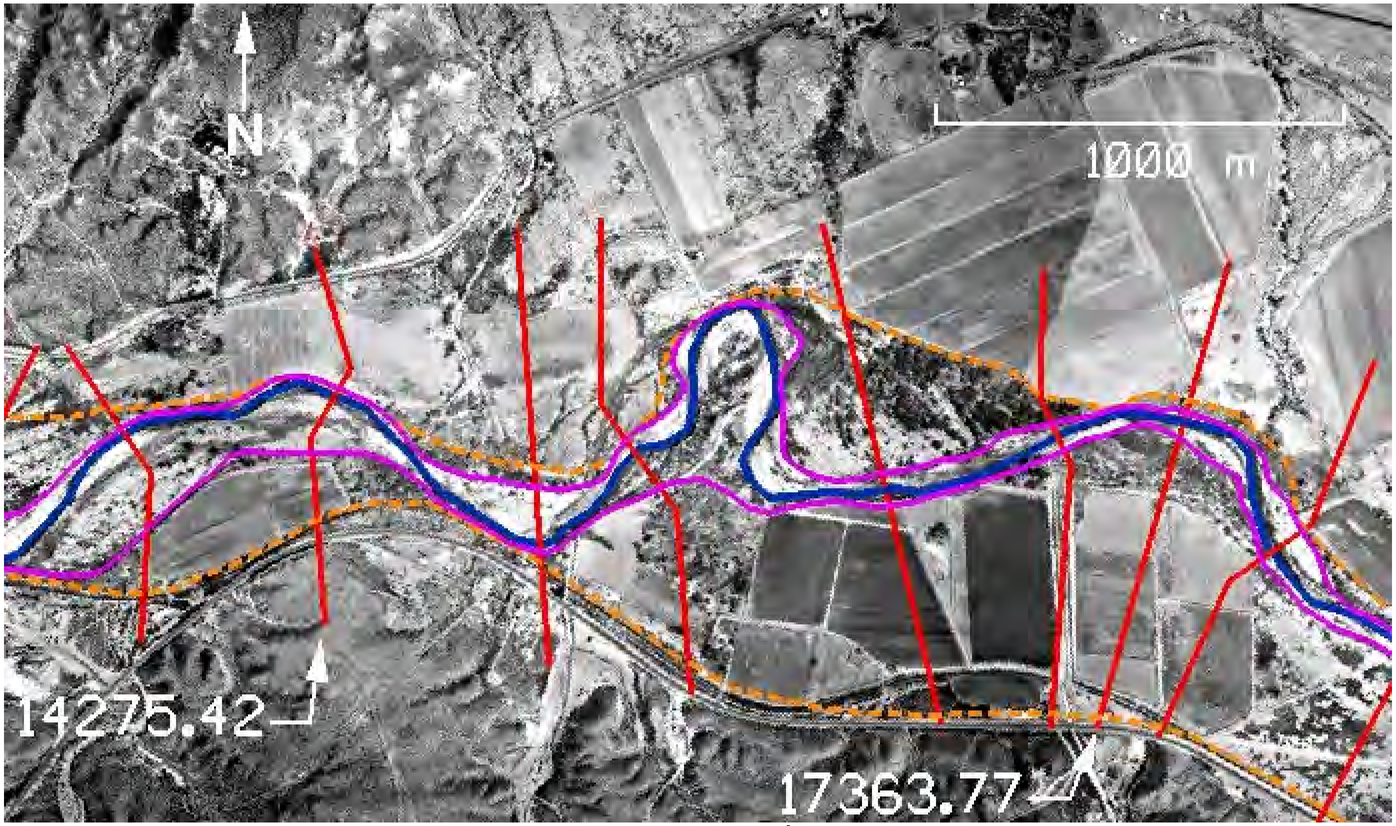


Figure 76. Upper Reach D.

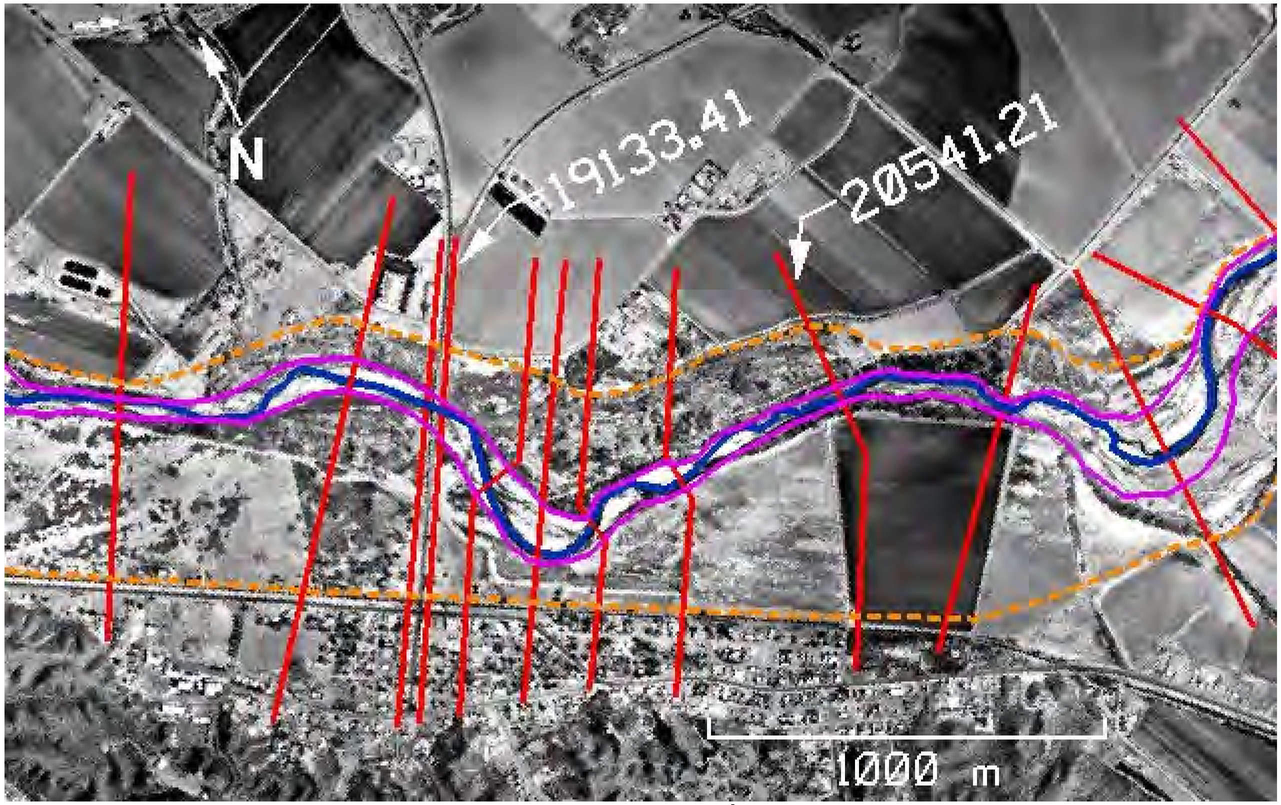


Figure 77. Upper Reach E.

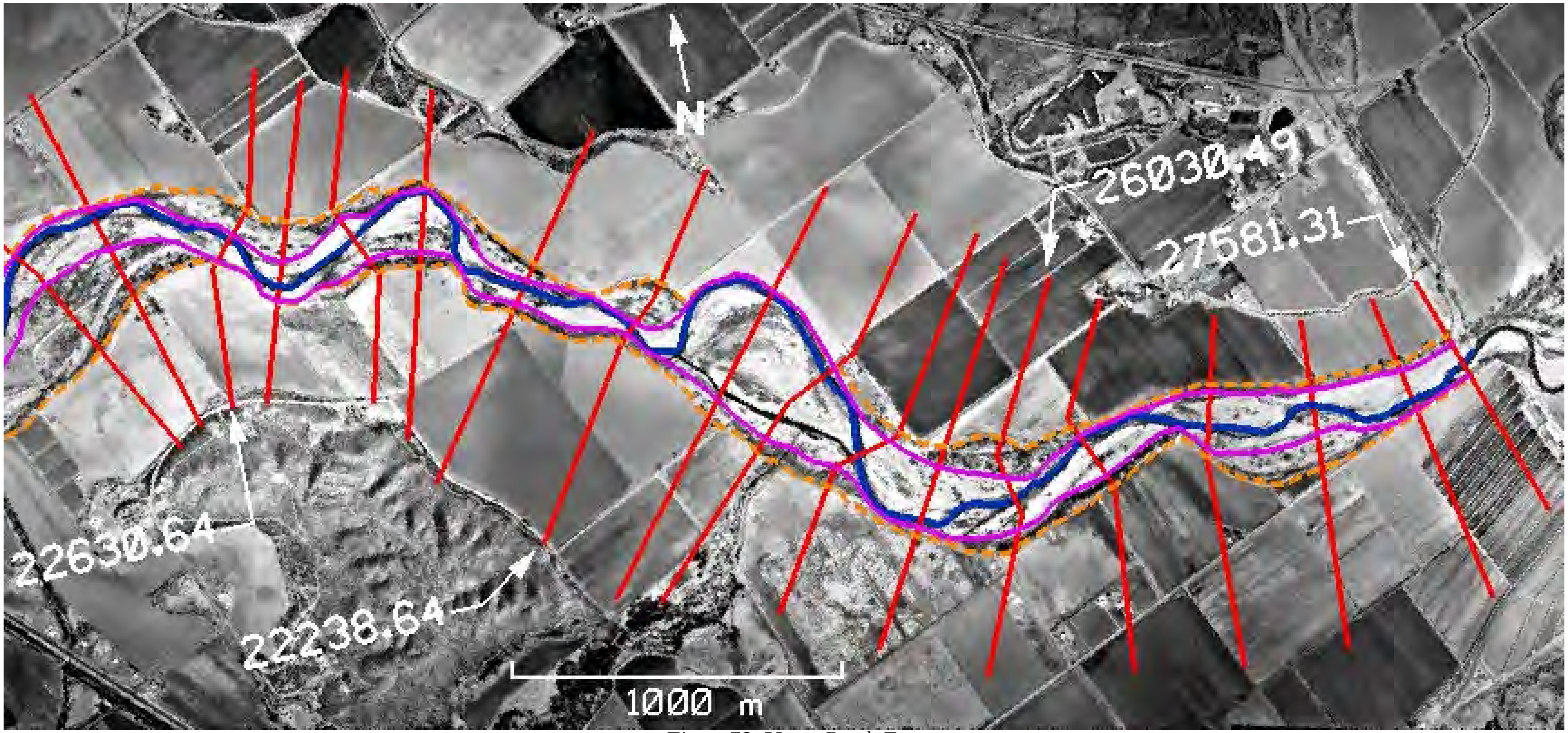


Figure 78. Upper Reach F.

APPENDIX B

SUMMARY OF BED MATERIAL SAMPLING LOCATIONS

Sample	Date	UTC	Description	Latitude	Longitude	Northing (m)	Easting (m)	State	Type	Depth	Location
1	12/13/00	2131	DS Valley Canal Diversion	N 32°41.339'	W 109°01.333'	3,618,347	685,421	NM	Grab	S - 6 in	REW
1A	12/13/00	2134	DS Valley Canal Diversion	do	do	do	do	NM	Grab	S - 3 in	Bar
2	12/13/00	2217	US Valley Canal Diversion	N 32°41.389'	W 109°00.216'	3,618,472	687,165	NM	Grab	S - 4 in	Bar
3	12/13/00	2321	DS Sunset Ditch Diversion	N 32°38.554'	W 108°55.348'	3,613,379	694,875	NM	Grab	S - 4 in	Bar
3A	12/13/00	2328	DS Sunset Ditch Diversion	do	do	do	do	NM	Grab	S - 4 in	REW
4	12/13/00	2350	US Sunset Ditch Diversion	N 32°38.430'	W 108°55.234'	3,613,154	695,058	NM	Grab	S - 5 in	
5	12/13/00	0026	DS Sunset Ditch Diversion	N 32°39.171'	W 108°55.826'	3,614,505	694,106	NM	Grab	S - 6 in	Bar
5A	12/13/00	0030	Right Bank Tributary Delta opposite Sample 5	do	do	do	do	NM	Photo		REW
6	12/14/00	1545	US Virden Bridge	N 32°39.292'	W 108°57.173'	3,614,688	691,996	NM	Grab	S - 6 in	Midbar
6A	12/14/00	1545	Left Bank Tributary Delta US of Virden Bridge	N 32°39.273'	W 108°57.294'	3,614,649	691,807	NM	Photo	S - 6 in	
6B	12/14/00	1545	do	do	do	do	do	NM	Photo	S - 6 in	
7	12/14/00	1558	DS Virden Bridge	N 32°39.364'	W 108°57.427'	3,614,813	691,596	NM	Grab	S - 6 in	Midbar
7A	12/14/00	1558	DS Virden Bridge	do	do	do	do	NM	Photo		Midbar
8	12/14/00	1630	US Model Canal Diversion	N 32°39.777'	W 108°58.437'	3,615,546	690,002	NM	Grab	S - 6 in	Midbar
8A	12/14/00	1625	Right Bank Tributary Delta US Model Canal Diversion	N 32°39.803'	W 108°58.459'	3,615,593	689,967	NM	Photo		REW
9	12/14/00	1700	DS Model Canal Diversion	N 32°40.088'	W 108°58.945'	3,616,106	689,197	NM	Grab	S - 6 in	REW Midbar
9A	12/14/00	1700	do	do	do	do	do	NM	Photo		do
9B	12/14/00	1706	do	N 32°40.095'	W 108°58.960'	3,616,118	689,174	NM	Photo		do
9C	12/14/00	1706	do	do	do	do	do	NM	Photo		do
10	12/14/00	1755	State Line	N 32°41.203'	W 109°02.898'	3,618,051	682,980	AZ	Grab	S - 6 in	LEW
10A	12/14/00	1751	do	N 32°41.214'	W 109°02.909'	3,618,071	682,963	AZ	Photo		REW
11	12/14/00	1819	Lunt Farm	N 32°41.816'	W 109°03.946'	3,619,153	681,322	AZ	Grab	S - 4 in	Midbar
12	12/14/00	1840	Deadman's Corner	N 32°42.966'	W 109°05.460'	3,621,236	678,918	AZ	Grab	S - 6 in	Midbar
13	12/14/00	1909	US Duncan Bridge	N 32°43.270'	W 109°06.082'	3,621,780	677,936	AZ	Grab	S - 6 in	REW
13A	12/14/00	1912	do	N 32°43.270'	W 109°06.082'	3,621,780	677,936	AZ	Grab	6 - 10 in	do
14	12/14/00	2040	Utilities Crossing	N 32°44.732'	W 109°07.967'	3,624,429	674,943	AZ	Grab	S - 7 in	LEW
15	12/14/00	2118	Little Sand Wash	N 32°45.944'	W 109°09.386'	3,626,630	672,688	AZ	Grab	S - 6 in	Midbar
15A	12/14/00	2122	do	N 32°45.961'	W 109°09.409'	3,626,661	672,652	AZ	Photo		do
16	12/14/00	2153	Sandia Wash Levee	N 32°47.049'	W 109°10.048'	3,628,654	671,619	AZ	Grab	S - 4 in	REW
17	12/14/00	2221	Sheldon	N 32°48.369'	W 109°10.576'	3,631,079	670,753	AZ	Grab	S - 6 in	Midbar
18	12/14/00	2239	Bridge DS of Sheldon	N 32°49.947'	W 109°10.759'	3,633,990	670,417	AZ	Grab	S - 6 in	REW
19	12/14/00	2300	Apache Grove	N 32°52.247'	W 109°11.908'	3,638,210	668,552	AZ	Grab	S - 6 in	LEW
20A	12/15/00	1533	Head of Safford Valley	N 32°52.524'	W 109°30.679'	3,638,265	639,271	AZ	Photo		REW
20B	12/15/00	1533	do	do	do	do	do	AZ	Photo		REW
21	12/15/00	1608	DS San Jose Diversion	N 32°51.764'	W 109°32.758'	3,636,816	636,049	AZ	Grab	S - 6 in	Midbar
22	12/15/00	1626	US San Jose Diversion	N 32°51.690'	W 109°32.576'	3,636,683	636,334	AZ	Grab	S - 6 in	Midbar

Sample	Date	UTC	Description	Latitude	Longitude	Northing (m)	Easting (m)	State	Type	Depth	Location
23	12/15/00	1701	Brandau Farm	N 32°51.553'	W 109°33.403'	3,636,412	635,048	AZ	Grab	S - 6 in	Midbar
24	12/15/00	1737	Runway	N 32°50.114'	W 109°35.122'	3,633,717	632,403	AZ	Grab	S - 6 in	REW
24A	12/15/00	1735	do	N 32°50.139'	W 109°35.186'	3,633,762	632,302	AZ	Photo		REW
24B	12/15/00	1735	do	do	do	do	do	AZ	Photo		REW
24C	12/15/00	1737	do	N 32°50.114'	W 109°35.122'	3,633,717	632,403	AZ	Photo		REW
25	12/15/00	1812	DS Solomon Bridge	N 32°49.658'	W 109°37.958'	3,632,816	627,989	AZ	Grab	S - 2 in	REW
25A	12/15/00	1812	do	do	do	do	do	AZ	Photo		REW
25B	12/15/00	1812	do	do	do	do	do	AZ	Photo		REW
26	12/15/00	1827	US Solomon Bridge	N 32°49.586'	W 109°37.767'	3,632,687	628,289	AZ	Grab	S - 3 in	REW
26A	12/15/00	1827	do	do	do	do	do	AZ	Photo		REW
27	12/15/00	2000	Geronimo Gage	N 33°05.525'	W 110°01.923'	3,661,721	590,332	AZ	Grab	S - 5 in	REW
28	12/15/00	2028	San Carlos Reservation	N 33°05.312'	W 110°03.094'	3,661,310	588,514	AZ	Grab	S - 6 in	Midbar
29	12/15/00	2100	Black Lane	N 33°04.568'	W 110°00.726'	3,659,970	592,210	AZ	Observation		
30	12/15/00	2131	Emery	N 33°04.018'	W 109°59.606'	3,658,970	593,962	AZ	Grab	S - 5 in	LEW
30A	12/15/00	2131	do	do	do	do	do	AZ	Photo		LEW
31	12/15/00	2215	US Ft. Thomas River Road (Low Water Crossing)	N 33°02.991'	W 109°57.953'	3,657,097	596,553	AZ	Grab	S - 5 in	LEW
32	12/15/00	2223	DS Ft. Thomas River Road (Low Water Crossing)	N 33°02.969'	W 109°58.024'	3,657,056	596,443	AZ	Grab	S - 5 in	LEW
32A	12/15/00	2223	do	do	do	do	do	AZ	Photo		LEW
32B	12/15/00	2223	do	do	do	do	do	AZ	Photo		LEW
33	12/15/00	2250	Forty Lane	N 33°01.178'	W 109°55.769'	3,653,781	599,986	AZ	Grab	S - 5 in	LEW
34	12/15/00	2331	DS Eden Bridge	N 32°57.923'	W 109°54.876'	3,647,781	601,438	AZ	Grab	S - 3 in	REW
35	12/15/00	2347	US Eden Bridge	N 32°57.608'	W 109°54.888'	3,647,199	601,425	AZ	Grab	S - 3 in	Midbar
36	12/16/00	1416	DS Thatcher Bridge	N 32°52.169'	W 109°46.016'	3,637,301	615,363	AZ	Grab	S - 4 in	REW
36A	12/16/00	1416	do	do	do	do	do	AZ	Photo		REW
36B	12/16/00	1416	do	do	do	do	do	AZ	Photo		REW
37	12/16/00	1420	US Thatcher Bridge	N 32°52.584'	W 109°45.962'	3,638,069	615,439	AZ	Grab	S - 5 in	Midbar
38	12/16/00	1515	DS Ft. Thomas Canal Diversion	N 32°56.728'	W 109°53.789'	3,645,591	603,154	AZ	Grab	S - 4 in	Midbar
38A	12/16/00	1515	do	N 32°56.728'	W 109°53.788'	3,645,591	603,156	AZ	Photo		Midbar
38B	12/16/00	1515	do	do	do	do	do	AZ	Photo		Midbar
39	12/16/00	1602	Glenbar	N 32°55.624'	W 109°51.399'	3,643,591	606,900	AZ	Grab	S - 4 in	Midbar
40	12/16/00	1641	DS Curtis Canal Diversion	N 32°55.092'	W 109°50.087'	3,642,630	608,956	AZ	Grab	S - 6 in	LEW of Island
40A	12/16/00	1641	do	do	do	do	do	AZ	Photo		do
40B	12/16/00	1641	do	do	do	do	do	AZ	Photo		do
41	12/16/00	1657	US Curtis Canal Diversion	N 32°55.034'	W 109°55.008'	3,642,441	601,287	AZ	Grab	S - 3 in	LEW
42	12/16/00	1730	DS Pima Bridge	N 32°54.924'	W 109°49.686'	3,642,326	609,584	AZ	Grab	S - 5 in	REW of Midbar
42A	12/16/00	1730	do	do	do	do	do	AZ	Photo		do

Sample	Date	UTC	Description	Latitude	Longitude	Northing (m)	Easting (m)	State	Type	Depth	Location
42B	12/16/00	1730	do	do	do	do	do	AZ	Photo		do
43	12/16/00	1742	US Pima Bridge	N 32°54.868'	W 109°49.574'	3,642,225	609,760	AZ	Grab	S - 6 in	REW
43A	12/16/00	1742	do	do	do	do	do	AZ	Photo		REW
44	12/16/00	1826	Holyoke	N 32°53.982'	W 109°48.105'	3,640,614	612,068	AZ	Grab	S - 4 in	REW-ROB
44A	12/16/00	1826	do	N 32°53.979'	W 109°48.110'	3,640,608	612,060	AZ	Photo		do
44B	12/16/00	1826	do	do	do	do	do	AZ	Photo		do
45	12/16/00	1945	US Safford Bridge	N 32°50.781'	W 109°42.917'	3,634,794	620,227	AZ	Grab	S - 5 in	LEW
45A	12/16/00	1945	do	do	do	do	do	AZ	Photo		LEW
45B	12/16/00	1945	do	do	do	do	do	AZ	Photo		LEW
46	12/16/00	1955	DS Safford Bridge	N 32°50.857'	W 109°43.046'	3,634,932	620,024	AZ	Grab	S - 3 in	LEW
47	12/16/00	2118	US Smithville Canal Diversion	N 32°51.574'	W 109°34.521'	3,636,427	633,304	AZ	Grab		Bed
48BB	12/16/00	2143	DS Smithville Canal Diversion	N 32°51.777'	W 109°44.686'	3,636,601	617,446	AZ	Grab	S - 4 in	LEW
48RJW	12/16/00	2143	do	do	do	do	do	AZ	Grab	S - 4 in	LEW
48A	12/16/00	2143	do	do	do	do	do	AZ	Photo		LEW
48B	12/16/00	2143	do	do	do	do	do	AZ	Photo		LEW
49	12/16/00	2308	US Graham Diversion Canal	N 32°50.446'	W 109°41.079'	3,634,210	623,102	AZ	Grab	S - 6 in	Midbar
49A	12/16/00	2308	do	do	do	do	do	AZ	Photo		
49B	12/16/00	2308	do	do	do	do	do	AZ	Photo		
49C	12/16/00	2308	do	do	do	do	do	AZ	Photo		
49D	12/16/00	2308	do	do	do	do	do	AZ	Photo		
49E	12/16/00	2308	do	do	do	do	do	AZ	Photo		
50	12/16/00	0000	DS Graham Diversion Canal	N 32°50.582'	W 109°41.491'	3,634,454	622,456	AZ	Grab		REW
50A	12/16/00	0000	do	do	do	do	do	AZ	Photo		REW
50B	12/16/00	0000	do	do	do	do	do	AZ	Photo		REW
50C	12/16/00	0000	Do	do	do	do	do	AZ	Photo		REW

Appendix C

FLOW DURATION TABULAR DATA

Table 11. Discharge Exceedance calculations for entire record of Gila River at Calva, AZ. 1929-2000.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	-1.0975	0.08	0	0.00%	100.00%
3	-0.9141	0.12	79	0.33%	99.67%
4	-0.7307	0.19	7	0.03%	99.64%
5	-0.5473	0.28	55	0.23%	99.42%
6	-0.3639	0.43	80	0.33%	99.09%
7	-0.1805	0.66	77	0.32%	98.77%
8	0.0029	1.01	72	0.30%	98.47%
9	0.1862	1.54	201	0.83%	97.64%
10	0.3696	2.34	215	0.89%	96.75%
11	0.5530	3.57	276	1.14%	95.61%
12	0.7364	5.45	556	2.30%	93.31%
13	0.9198	8.31	822	3.40%	89.91%
14	1.1032	12.68	1076	4.45%	85.46%
15	1.2865	19.34	1375	5.69%	79.77%
16	1.4699	29.51	1704	7.05%	72.72%
17	1.6533	45.01	2080	8.60%	64.12%
18	1.8367	68.66	2397	9.91%	54.20%
19	2.0201	104.73	2260	9.35%	44.86%
20	2.2035	159.76	2039	8.43%	36.42%
21	2.3869	243.70	2085	8.62%	27.80%
22	2.5702	371.74	1737	7.18%	20.61%
23	2.7536	567.06	1494	6.18%	14.44%
24	2.9370	864.99	1070	4.43%	10.01%
25	3.1204	1319.46	697	2.88%	7.13%
26	3.3038	2012.70	705	2.92%	4.21%
27	3.4872	3070.19	547	2.26%	1.95%
28	3.6705	4683.27	265	1.10%	0.85%
29	3.8539	7143.88	100	0.41%	0.44%
30	4.0373	10897.30	43	0.18%	0.26%
31	4.2207	16622.78	32	0.13%	0.13%
32	4.4041	25356.44	12	0.05%	0.08%
33	4.5875	38678.81	11	0.05%	0.03%
34	4.7709	59000.79	3	0.01%	0.02%
35	4.9542	90000.00	5	0.02%	0.00%
		TTL # of Q's =	**24177**	**100.00%**	

Table 12. Discharge Exceedance calculations for Gila River at Calva, AZ. 1929-1965.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	-1.0000	0.10	64	0.55%	99.45%
3	-0.8407	0.14	0	0.00%	99.45%
4	-0.6814	0.21	38	0.33%	99.13%
5	-0.5220	0.30	26	0.22%	98.90%
6	-0.3627	0.43	26	0.22%	98.68%
7	-0.2034	0.63	40	0.34%	98.34%
8	-0.0441	0.90	57	0.49%	97.85%
9	0.1153	1.30	121	1.04%	96.82%
10	0.2746	1.88	71	0.61%	96.21%
11	0.4339	2.72	175	1.50%	94.71%
12	0.5932	3.92	206	1.76%	92.95%
13	0.7526	5.66	322	2.76%	90.19%
14	0.9119	8.16	450	3.85%	86.34%
15	1.0712	11.78	433	3.71%	82.63%
16	1.2305	17.00	705	6.04%	76.59%
17	1.3899	24.54	677	5.80%	70.80%
18	1.5492	35.41	768	6.57%	64.22%
19	1.7085	51.11	859	7.35%	56.87%
20	1.8678	73.76	913	7.82%	49.05%
21	2.0271	106.45	1020	8.73%	40.32%
22	2.1865	153.63	904	7.74%	32.58%
23	2.3458	221.72	983	8.42%	24.17%
24	2.5051	319.98	704	6.03%	18.14%
25	2.6644	461.79	631	5.40%	12.74%
26	2.8238	666.45	448	3.84%	8.90%
27	2.9831	961.81	328	2.81%	6.10%
28	3.1424	1388.08	218	1.87%	4.23%
29	3.3017	2003.26	197	1.69%	2.54%
30	3.4611	2891.08	144	1.23%	1.31%
31	3.6204	4172.38	86	0.74%	0.57%
32	3.7797	6021.54	39	0.33%	0.24%
33	3.9390	8690.23	16	0.14%	0.10%
34	4.0984	12541.66	8	0.07%	0.03%
35	4.2577	18100.00	4	0.03%	0.00%
		TTL # of Q's =	**11681**	**100.00%**	

Table 13. Discharge Exceedance calculations for Gila River at Calva, AZ. 1965-2000.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	-1.0975	0.08	0	0.00%	100.00%
3	-0.9141	0.12	15	0.12%	99.88%
4	-0.7307	0.19	7	0.06%	99.82%
5	-0.5473	0.28	17	0.14%	99.69%
6	-0.3639	0.43	30	0.24%	99.45%
7	-0.1805	0.66	35	0.28%	99.17%
8	0.0029	1.01	29	0.23%	98.94%
9	0.1862	1.54	31	0.25%	98.69%
10	0.3696	2.34	54	0.43%	98.26%
11	0.5530	3.57	95	0.76%	97.50%
12	0.7364	5.45	183	1.46%	96.03%
13	0.9198	8.31	338	2.70%	93.33%
14	1.1032	12.68	511	4.09%	89.24%
15	1.2865	19.34	604	4.83%	84.40%
16	1.4699	29.51	905	7.24%	77.16%
17	1.6533	45.01	1238	9.91%	67.25%
18	1.8367	68.66	1196	9.57%	57.68%
19	2.0201	104.73	1129	9.03%	48.65%
20	2.2035	159.76	1043	8.35%	40.30%
21	2.3869	243.70	930	7.44%	32.86%
22	2.5702	371.74	983	7.87%	24.99%
23	2.7536	567.06	857	6.86%	18.13%
24	2.9370	864.99	645	5.16%	12.97%
25	3.1204	1319.46	420	3.36%	9.61%
26	3.3038	2012.70	491	3.93%	5.68%
27	3.4872	3070.19	376	3.01%	2.67%
28	3.6705	4683.27	180	1.44%	1.23%
29	3.8539	7143.88	66	0.53%	0.70%
30	4.0373	10897.30	33	0.26%	0.44%
31	4.2207	16622.78	25	0.20%	0.24%
32	4.4041	25356.44	11	0.09%	0.15%
33	4.5875	38678.81	11	0.09%	0.06%
34	4.7709	59000.79	3	0.02%	0.04%
35	4.9542	90000.00	5	0.04%	0.00%
		TTL # of Q's =	**12496**	**100.00%**	

Table 14. Discharge Exceedance calculations for entire record of Gila River near Safford, AZ. 1940-1965.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	0.0000	1.00	35	0.63%	99.37%
3	0.1315	1.35	40	0.71%	98.66%
4	0.2629	1.83	34	0.61%	98.05%
5	0.3944	2.48	62	1.11%	96.94%
6	0.5259	3.36	68	1.22%	95.73%
7	0.6573	4.54	81	1.45%	94.28%
8	0.7888	6.15	119	2.13%	92.15%
9	0.9203	8.32	110	1.97%	90.19%
10	1.0517	11.27	158	2.82%	87.36%
11	1.1832	15.25	219	3.91%	83.45%
12	1.3147	20.64	241	4.31%	79.14%
13	1.4462	27.94	248	4.43%	74.71%
14	1.5776	37.81	334	5.97%	68.74%
15	1.7091	51.18	434	7.76%	60.98%
16	1.8406	69.27	374	6.68%	54.30%
17	1.9720	93.76	403	7.20%	47.10%
18	2.1035	126.91	396	7.08%	40.02%
19	2.2350	171.78	379	6.77%	33.24%
20	2.3664	232.50	307	5.49%	27.76%
21	2.4979	314.70	280	5.00%	22.75%
22	2.6294	425.96	314	5.61%	17.14%
23	2.7608	576.55	216	3.86%	13.28%
24	2.8923	780.38	203	3.63%	9.65%
25	3.0238	1056.26	143	2.56%	7.10%
26	3.1552	1429.69	94	1.68%	5.42%
27	3.2867	1935.13	103	1.84%	3.57%
28	3.4182	2619.26	85	1.52%	2.06%
29	3.5496	3545.24	59	1.05%	1.00%
30	3.6811	4798.60	31	0.55%	0.45%
31	3.8126	6495.06	6	0.11%	0.34%
32	3.9441	8791.26	11	0.20%	0.14%
33	4.0755	11899.25	5	0.09%	0.05%
34	4.2070	16106.02	1	0.02%	0.04%
35	4.3385	21800.00	2	0.04%	0.00%
		TTL # of Q's =	**5595**	**100.00%**	

Table 15. Discharge Exceedance calculations for entire record of Gila River near Solomon, AZ. 1914-1951.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	1.1761	15.00	1	0.01%	99.99%
3	1.2879	19.41	7	0.06%	99.93%
4	1.3998	25.11	7	0.06%	99.86%
5	1.5116	32.48	58	0.54%	99.32%
6	1.6235	42.02	173	1.61%	97.72%
7	1.7353	54.36	293	2.72%	95.00%
8	1.8471	70.33	418	3.88%	91.12%
9	1.9590	90.99	778	7.22%	83.90%
10	2.0708	117.71	957	8.88%	75.02%
11	2.1827	152.29	1331	12.35%	62.66%
12	2.2945	197.02	1620	15.03%	47.63%
13	2.4064	254.89	1000	9.28%	38.35%
14	2.5182	329.76	761	7.06%	31.29%
15	2.6300	426.62	758	7.03%	24.25%
16	2.7419	551.92	590	5.48%	18.77%
17	2.8537	714.04	433	4.02%	14.76%
18	2.9656	923.77	387	3.59%	11.16%
19	3.0774	1195.10	303	2.81%	8.35%
20	3.1892	1546.14	204	1.89%	6.46%
21	3.3011	2000.27	172	1.60%	4.86%
22	3.4129	2587.81	176	1.63%	3.23%
23	3.5248	3347.91	137	1.27%	1.96%
24	3.6366	4331.27	79	0.73%	1.23%
25	3.7485	5603.48	40	0.37%	0.85%
26	3.8603	7249.36	36	0.33%	0.52%
27	3.9721	9378.68	18	0.17%	0.35%
28	4.0840	12133.43	13	0.12%	0.23%
29	4.1958	15697.33	7	0.06%	0.17%
30	4.3077	20308.03	5	0.05%	0.12%
31	4.4195	26273.00	8	0.07%	0.05%
32	4.5314	33990.05	1	0.01%	0.04%
33	4.6432	43973.78	1	0.01%	0.03%
34	4.7550	56889.98	2	0.02%	0.01%
35	4.8669	73600.00	1	0.01%	0.00%
		TTL # of Q's =	**10775**	**100.00%**	

Table 16. Discharge Exceedance calculations for Gila River at Head of Safford Valley, near Solomon, AZ. 1920-2000.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	1.1139	13.00	1	0.00%	100.00%
3	1.2303	16.99	11	0.04%	99.96%
4	1.3467	22.22	63	0.22%	99.73%
5	1.4631	29.04	194	0.69%	99.05%
6	1.5794	37.97	372	1.32%	97.73%
7	1.6958	49.64	808	2.86%	94.88%
8	1.8122	64.89	1422	5.03%	89.85%
9	1.9286	84.83	1944	6.87%	82.97%
10	2.0449	110.90	2654	9.39%	73.59%
11	2.1613	144.98	3596	12.72%	60.87%
12	2.2777	189.53	4164	14.73%	46.15%
13	2.3940	247.77	3216	11.37%	34.77%
14	2.5104	323.90	1973	6.98%	27.80%
15	2.6268	423.44	1733	6.13%	21.67%
16	2.7432	553.56	1395	4.93%	16.73%
17	2.8595	723.66	1008	3.56%	13.17%
18	2.9759	946.03	826	2.92%	10.25%
19	3.0923	1236.74	703	2.49%	7.76%
20	3.2087	1616.78	643	2.27%	5.49%
21	3.3250	2113.61	527	1.86%	3.62%
22	3.4414	2763.10	411	1.45%	2.17%
23	3.5578	3612.19	260	0.92%	1.25%
24	3.6741	4722.18	143	0.51%	0.75%
25	3.7905	6173.27	71	0.25%	0.50%
26	3.9069	8070.27	47	0.17%	0.33%
27	4.0233	10550.20	27	0.10%	0.23%
28	4.1396	13792.20	21	0.07%	0.16%
29	4.2560	18030.44	18	0.06%	0.10%
30	4.3724	23571.05	5	0.02%	0.08%
31	4.4888	30814.26	9	0.03%	0.05%
32	4.6051	40283.24	5	0.02%	0.03%
33	4.7215	52661.97	4	0.01%	0.01%
34	4.8379	68844.59	3	0.01%	0.00%
35	4.9542	90000.00	1	0.00%	0.00%
		TTL # of Q's =	**28278**	**100.00%**	

Table 17. Discharge Exceedance calculations for Gila River at Head of Safford Valley, near Solomon, AZ. 1920-1964.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	1.1139	13.00	1	0.01%	99.99%
3	1.2118	16.28	11	0.07%	99.92%
4	1.3096	20.40	34	0.22%	99.70%
5	1.4074	25.55	85	0.55%	99.15%
6	1.5053	32.01	193	1.25%	97.91%
7	1.6031	40.10	336	2.17%	95.74%
8	1.7009	50.23	494	3.19%	92.55%
9	1.7988	62.92	710	4.58%	87.97%
10	1.8966	78.81	916	5.91%	82.06%
11	1.9944	98.73	1159	7.48%	74.58%
12	2.0923	123.67	1532	9.89%	64.69%
13	2.1901	154.92	1824	11.77%	52.92%
14	2.2879	194.06	2058	13.28%	39.63%
15	2.3858	243.09	1450	9.36%	30.28%
16	2.4836	304.51	815	5.26%	25.02%
17	2.5814	381.45	814	5.25%	19.76%
18	2.6793	477.82	685	4.42%	15.34%
19	2.7771	598.55	583	3.76%	11.58%
20	2.8749	749.78	380	2.45%	9.13%
21	2.9728	939.21	328	2.12%	7.01%
22	3.0706	1176.52	251	1.62%	5.39%
23	3.1684	1473.77	240	1.55%	3.84%
24	3.2663	1846.13	166	1.07%	2.77%
25	3.3641	2312.57	144	0.93%	1.84%
26	3.4619	2896.87	106	0.68%	1.16%
27	3.5598	3628.78	75	0.48%	0.67%
28	3.6576	4545.63	43	0.28%	0.39%
29	3.7554	5694.12	24	0.15%	0.24%
30	3.8533	7132.79	9	0.06%	0.18%
31	3.9511	8934.94	14	0.09%	0.09%
32	4.0489	11192.43	7	0.05%	0.05%
33	4.1468	14020.30	5	0.03%	0.01%
34	4.2446	17562.65	1	0.01%	0.01%
35	4.3424	22000.00	1	0.01%	0.00%
		TTL # of Q's =	**15494**	**100.00%**	

Table 18. Discharge Exceedance calculations for Gila River at Head of Safford Valley, near Solomon, AZ. 1965-2000.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	1.2304	17.00	1	0.01%	99.99%
3	1.3433	22.04	1	0.01%	99.98%
4	1.4561	28.58	35	0.27%	99.71%
5	1.5690	37.07	91	0.71%	99.00%
6	1.6818	48.06	206	1.61%	97.39%
7	1.7947	62.32	480	3.75%	93.63%
8	1.9075	80.82	691	5.41%	88.23%
9	2.0203	104.80	994	7.78%	80.45%
10	2.1332	135.89	1391	10.88%	69.57%
11	2.2460	176.21	1762	13.78%	55.79%
12	2.3589	228.49	1545	12.09%	43.70%
13	2.4717	296.29	1089	8.52%	35.18%
14	2.5846	384.20	831	6.50%	28.68%
15	2.6974	498.19	671	5.25%	23.44%
16	2.8102	646.01	539	4.22%	19.22%
17	2.9231	837.69	439	3.43%	15.79%
18	3.0359	1086.24	416	3.25%	12.53%
19	3.1488	1408.53	372	2.91%	9.62%
20	3.2616	1826.46	343	2.68%	6.94%
21	3.3745	2368.38	300	2.35%	4.59%
22	3.4873	3071.10	239	1.87%	2.72%
23	3.6001	3982.32	142	1.11%	1.61%
24	3.7130	5163.90	74	0.58%	1.03%
25	3.8258	6696.07	37	0.29%	0.74%
26	3.9387	8682.85	30	0.23%	0.51%
27	4.0515	11259.13	10	0.08%	0.43%
28	4.1643	14599.80	15	0.12%	0.31%
29	4.2772	18931.68	16	0.13%	0.19%
30	4.3900	24548.86	5	0.04%	0.15%
31	4.5029	31832.71	7	0.05%	0.09%
32	4.6157	41277.73	4	0.03%	0.06%
33	4.7286	53525.17	4	0.03%	0.03%
34	4.8414	69406.52	3	0.02%	0.01%
35	4.9542	90000.00	1	0.01%	0.00%
		TTL # of Q's =	**12784**	**100.00%**	

Table 19. Discharge Exceedance calculations for entire record of San Francisco River at Clifton, AZ. 1911-1999.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	0.7853	6.10	1	0.00%	100.00%
3	0.9045	8.03	6	0.02%	99.98%
4	1.0237	10.56	22	0.08%	99.90%
5	1.1428	13.89	50	0.18%	99.72%
6	1.2620	18.28	270	0.96%	98.77%
7	1.3811	24.05	695	2.46%	96.31%
8	1.5003	31.64	1083	3.83%	92.48%
9	1.6195	41.64	2221	7.86%	84.62%
10	1.7386	54.78	3839	13.58%	71.04%
11	1.8578	72.08	5312	18.79%	52.25%
12	1.9769	94.83	3009	10.64%	41.60%
13	2.0961	124.77	2639	9.34%	32.27%
14	2.2153	164.16	2146	7.59%	24.67%
15	2.3344	215.99	1431	5.06%	19.61%
16	2.4536	284.18	1242	4.39%	15.22%
17	2.5728	373.90	994	3.52%	11.70%
18	2.6919	491.95	798	2.82%	8.88%
19	2.8111	647.26	684	2.42%	6.46%
20	2.9302	851.61	474	1.68%	4.78%
21	3.0494	1120.48	465	1.64%	3.14%
22	3.1686	1474.23	342	1.21%	1.93%
23	3.2877	1939.67	176	0.62%	1.31%
24	3.4069	2552.06	163	0.58%	0.73%
25	3.5261	3357.78	66	0.23%	0.50%
26	3.6452	4417.88	45	0.16%	0.34%
27	3.7644	5812.67	30	0.11%	0.23%
28	3.8835	7647.82	26	0.09%	0.14%
29	4.0027	10062.35	12	0.04%	0.10%
30	4.1219	13239.19	10	0.04%	0.06%
31	4.2410	17419.00	7	0.02%	0.04%
32	4.3602	22918.44	6	0.02%	0.01%
33	4.4793	30154.13	0	0.00%	0.01%
34	4.5985	39674.24	2	0.01%	0.01%
35	4.7177	52200.00	2	0.01%	0.00%
		TTL # of Q's =	**28268**	**100.00%**	

Table 20. Discharge Exceedance calculations for San Francisco River at Clifton, AZ. 1911-1964.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	0.9031	8.00	4	0.03%	99.97%
3	1.0019	10.04	18	0.12%	99.85%
4	1.1007	12.61	20	0.13%	99.72%
5	1.1996	15.83	56	0.37%	99.35%
6	1.2984	19.88	195	1.29%	98.06%
7	1.3972	24.96	453	3.00%	95.07%
8	1.4960	31.34	711	4.70%	90.36%
9	1.5949	39.34	1024	6.77%	83.59%
10	1.6937	49.40	1720	11.38%	72.21%
11	1.7925	62.02	2181	14.43%	57.79%
12	1.8914	77.87	2074	13.72%	44.07%
13	1.9902	97.76	1261	8.34%	35.73%
14	2.0890	122.74	1019	6.74%	28.99%
15	2.1878	154.11	846	5.60%	23.39%
16	2.2867	193.49	681	4.50%	18.89%
17	2.3855	242.93	548	3.62%	15.27%
18	2.4843	305.01	489	3.23%	12.03%
19	2.5831	382.94	438	2.90%	9.13%
20	2.6820	480.80	304	2.01%	7.12%
21	2.7808	603.65	258	1.71%	5.42%
22	2.8796	757.90	168	1.11%	4.31%
23	2.9784	951.57	169	1.12%	3.19%
24	3.0773	1194.72	129	0.85%	2.33%
25	3.1761	1500.00	105	0.69%	1.64%
26	3.2749	1883.29	57	0.38%	1.26%
27	3.3737	2364.52	84	0.56%	0.71%
28	3.4726	2968.72	31	0.21%	0.50%
29	3.5714	3727.31	17	0.11%	0.39%
30	3.6702	4679.74	23	0.15%	0.24%
31	3.7690	5875.55	11	0.07%	0.17%
32	3.8679	7376.91	16	0.11%	0.06%
33	3.9667	9261.91	3	0.02%	0.04%
34	4.0655	11628.58	2	0.01%	0.03%
35	4.1644	14600.00	4	0.03%	0.00%
		TTL # of Q's =	**15119**	**100.00%**	

Table 21. Discharge Exceedance calculations for San Francisco River at Clifton, AZ. 1965-1999.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	0.7853	6.10	1	0.01%	99.99%
3	0.9045	8.03	2	0.02%	99.98%
4	1.0237	10.56	4	0.03%	99.95%
5	1.1428	13.89	10	0.08%	99.87%
6	1.2620	18.28	100	0.76%	99.11%
7	1.3811	24.05	181	1.38%	97.73%
8	1.5003	31.64	372	2.83%	94.90%
9	1.6195	41.64	823	6.26%	88.65%
10	1.7386	54.78	1670	12.70%	75.94%
11	1.8578	72.08	2346	17.84%	58.10%
12	1.9769	94.83	1419	10.79%	47.31%
13	2.0961	124.77	1449	11.02%	36.29%
14	2.2153	164.16	1132	8.61%	27.68%
15	2.3344	215.99	699	5.32%	22.37%
16	2.4536	284.18	589	4.48%	17.89%
17	2.5728	373.90	462	3.51%	14.37%
18	2.6919	491.95	428	3.26%	11.12%
19	2.8111	647.26	391	2.97%	8.15%
20	2.9302	851.61	280	2.13%	6.02%
21	3.0494	1120.48	288	2.19%	3.83%
22	3.1686	1474.23	212	1.61%	2.21%
23	3.2877	1939.67	107	0.81%	1.40%
24	3.4069	2552.06	74	0.56%	0.84%
25	3.5261	3357.78	37	0.28%	0.56%
26	3.6452	4417.88	19	0.14%	0.41%
27	3.7644	5812.67	14	0.11%	0.30%
28	3.8835	7647.82	10	0.08%	0.23%
29	4.0027	10062.35	7	0.05%	0.17%
30	4.1219	13239.19	8	0.06%	0.11%
31	4.2410	17419.00	5	0.04%	0.08%
32	4.3602	22918.44	6	0.05%	0.03%
33	4.4793	30154.13	0	0.00%	0.03%
34	4.5985	39674.24	2	0.02%	0.02%
35	4.7177	52200.00	2	0.02%	0.00%
		TTL # of Q's =	**13149**	**100.00%**	

Table 22. Discharge Exceedance calculations for entire record, Gila River Below Blue Creek, Near Virden, NM, 1927-2000.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	0	0	0.00%	100.00%
2	0.2304	1.70	4	0.02%	99.98%
3	0.3604	2.29	37	0.14%	99.85%
4	0.4904	3.09	133	0.50%	99.35%
5	0.6204	4.17	238	0.89%	98.45%
6	0.7504	5.63	254	0.95%	97.50%
7	0.8804	7.59	238	0.89%	96.60%
8	1.0103	10.24	380	1.43%	95.17%
9	1.1403	13.81	322	1.21%	93.96%
10	1.2703	18.63	535	2.01%	91.95%
11	1.4003	25.14	754	2.83%	89.12%
12	1.5303	33.90	997	3.75%	85.37%
13	1.6602	45.73	1479	5.56%	79.81%
14	1.7902	61.69	2299	8.64%	71.17%
15	1.9202	83.22	3915	14.72%	56.45%
16	2.0502	112.25	4550	17.10%	39.35%
17	2.1802	151.41	2753	10.35%	29.00%
18	2.3101	204.24	1920	7.22%	21.78%
19	2.4401	275.50	1516	5.70%	16.08%
20	2.5701	371.63	1091	4.10%	11.98%
21	2.7001	501.29	869	3.27%	8.72%
22	2.8301	676.20	737	2.77%	5.95%
23	2.9601	912.12	585	2.20%	3.75%
24	3.0900	1230.37	371	1.39%	2.35%
25	3.2200	1659.65	270	1.01%	1.34%
26	3.3500	2238.71	170	0.64%	0.70%
27	3.4800	3019.80	74	0.28%	0.42%
28	3.6100	4073.42	41	0.15%	0.27%
29	3.7399	5494.66	32	0.12%	0.15%
30	3.8699	7411.77	11	0.04%	0.11%
31	3.9999	9997.77	10	0.04%	0.07%
32	4.1299	13486.04	9	0.03%	0.03%
33	4.2599	18191.38	5	0.02%	0.02%
34	4.3898	24538.43	3	0.01%	0.00%
35	4.5198	33100.00	1	0.00%	0.00%
		TTL # of Q's =	**26603**	**100.00%**	

Table 23. Discharge Exceedance calculations for Gila River Below Blue Creek, Near Virden, NM, 1927-1964.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	-	0	0.00%	100.00%
2	0.2304	1.70	4	0.03%	99.97%
3	0.3549	2.26	37	0.27%	99.70%
4	0.4793	3.02	129	0.95%	98.75%
5	0.6037	4.02	205	1.51%	97.24%
6	0.7281	5.35	188	1.38%	95.86%
7	0.8526	7.12	166	1.22%	94.64%
8	0.9770	9.48	193	1.42%	93.22%
9	1.1014	12.63	249	1.83%	91.39%
10	1.2258	16.82	279	2.05%	89.34%
11	1.3503	22.40	356	2.62%	86.73%
12	1.4747	29.83	436	3.20%	83.52%
13	1.5991	39.73	642	4.72%	78.81%
14	1.7235	52.91	888	6.53%	72.28%
15	1.8480	70.46	1387	10.19%	62.09%
16	1.9724	93.84	2379	17.48%	44.60%
17	2.0968	124.97	2054	15.10%	29.51%
18	2.2212	166.43	952	7.00%	22.51%
19	2.3457	221.65	774	5.69%	16.82%
20	2.4701	295.18	658	4.84%	11.99%
21	2.5945	393.11	486	3.57%	8.41%
22	2.7189	523.53	355	2.61%	5.81%
23	2.8434	697.21	325	2.39%	3.42%
24	2.9678	928.52	187	1.37%	2.04%
25	3.0922	1,236.56	104	0.76%	1.28%
26	3.2166	1,646.79	82	0.60%	0.68%
27	3.3411	2,193.12	50	0.37%	0.31%
28	3.4655	2,920.71	20	0.15%	0.16%
29	3.5899	3,889.67	12	0.09%	0.07%
30	3.7143	5,180.08	5	0.04%	0.04%
31	3.8388	6,898.61	2	0.01%	0.02%
32	3.9632	9,187.26	0	0.00%	0.02%
33	4.0876	12,235.19	1	0.01%	0.01%
34	4.2120	16,294.28	1	0.01%	0.01%
35	4.3365	21,700.00	1	0.01%	0.00%
		TTL # of Q's =	**13607**	**100.00%**	

Table 24. Discharge Exceedance calculations for Gila River Below Blue Creek, Near Virden, NM, 1965-2000.

Bin Number	Log Bins	Discharges	No. of Occur	% Frequency	% Time Exceeded
1	0	-	0	0.00%	100.00%
2	0.4314	3	3	0.02%	99.98%
3	0.5553	4	20	0.15%	99.82%
4	0.6791	5	27	0.21%	99.62%
5	0.8030	6	55	0.42%	99.19%
6	0.9269	8	76	0.58%	98.61%
7	1.0508	11	116	0.89%	97.71%
8	1.1747	15	118	0.91%	96.81%
9	1.2986	20	201	1.55%	95.26%
10	1.4225	26	379	2.92%	92.34%
11	1.5464	35	511	3.93%	88.41%
12	1.6703	47	607	4.67%	83.74%
13	1.7942	62	1225	9.43%	74.32%
14	1.9181	83	1732	13.33%	60.99%
15	2.0420	110	1917	14.75%	46.24%
16	2.1659	147	1462	11.25%	34.99%
17	2.2898	195	1105	8.50%	26.49%
18	2.4136	259	789	6.07%	20.41%
19	2.5375	345	566	4.36%	16.06%
20	2.6614	459	454	3.49%	12.57%
21	2.7853	610	407	3.13%	9.43%
22	2.9092	811	372	2.86%	6.57%
23	3.0331	1,079	305	2.35%	4.22%
24	3.1570	1,436	196	1.51%	2.72%
25	3.2809	1,909	151	1.16%	1.55%
26	3.4048	2,540	81	0.62%	0.93%
27	3.5287	3,378	39	0.30%	0.63%
28	3.6526	4,493	31	0.24%	0.39%
29	3.7765	5,977	20	0.15%	0.24%
30	3.9004	7,950	11	0.08%	0.15%
31	4.0243	10,574	8	0.06%	0.09%
32	4.1481	14,065	4	0.03%	0.06%
33	4.2720	18,709	6	0.05%	0.02%
34	4.3959	24,885	1	0.01%	0.01%
35	4.5198	33,100	1	0.01%	0.00%
		TTL # of Q's =	**12996**	**100.00%**	