NAVIGABILITY ALONG THE NATURAL CHANNEL OF THE VERDE RIVER, AZ

Detailed analysis from Sullivan Lake to the USGS gage near Clarkdale.
and
General analysis from Clarkdale gage to mouth.

An assessment based on history, Federal GLO surveys, hydrology, hydraulics and morphology

By

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October 4, 2014

FORWARD

As a fourth generation resident of the Verde Valley, with a great grandmother and several ancestors resting in the Valley View Cemetery at Clarkdale, Arizona, I've experienced first hand the changing Verde River. When I was born in Phoenix, the population of Arizona was about 1 million – a small fraction of the present population. Since settlers first discovered the Verde River watershed in the middle of the 19^{th} century, the population of the area has also increased at an impressive rate. Many of the early settlers were miners, ranchers and farmers. My grandparents and great grandmother arrived in Jerome in 1914 where my grandfather (W. J. Flood), a graduate of the school on mines at Reno NV, was a mining engineer and member of the Arizona 4^{th} legislature with M. A. Perkins and others.

My personal experience and memories of the Verde River Watershed include my time as a child living in Prescott during WW2 when my father was an army officer stationed in Iceland for 6 years. My mother would take us on picnics to various lakes in the Prescott area including Sullivan Lake at the head of the Verde River. I have childhood memories of swimming in Sullivan Lake when the water was clear and always flowing over the dam. My brothers and I were not allowed to swim near the dam.

It's easy to think of my early experiences as the "good old days" and conjure up impressions of how pristine and natural the area was before tens of thousands of humans discovered the beautiful area. As I've matured and learned about hydrology as a professional river engineer for the past 53 years, however, I've grown to realize that humans impacted the flow in the Verde River long before I was born and even before my grandfather was born. For example, I've observed the base flow at the USGS streamflow gage near Paulden, a gage site I personally selected as a young USGS engineer, steadily decrease. I've also come to realize that when the train dropped us off for a picnic and swim in the Verde River Canyon in the late 1940s, that the flow in the river was significantly less than the natural base flow before settlers arrived in the 1850s. The early accounts of the area by military explorations of Whipple, Ives and Sitgreaves are fascinating. I'm aware of the grist mills on Granite Creek and at Del Rio Springs and accounts by ranch women and Sharlot M. Hall of the early living conditions.

Thanks in part to John Wesley Powell I've learned that to understand river conditions, one needs to focus beyond the river on the total watershed. I now realize that before my education, personal impressions of the natural Verde River were incorrect because humans within the watershed had significantly impacted the base flow long before my great grandmother arrived in the area. When human impacts are understood and applied with the proper hydrologic context, we can begin to see what the natural Verde River once was.

Win Hjalmarson
2014

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EXECUTIVE SUMMARY

This Report is an assessment of the navigability of the natural channel of the Verde River with emphasis on the Upper Verde River that uses hydrologic and hydraulic methods that project hydrologic information into the past. Although the overall assessment is for the entire river, the detailed assessment focuses on the 36.6 mile reach of the Verde River from the dam at Sullivan Lake to the USGS stream gage near Clarkdale, Arizona (hereinafter "Upper Verde River").

The purpose is to determine if the Verde River was susceptible to navigation at the time of Arizona statehood (February 14, 1912) in its ordinary and natural condition. This report is being prepared for proceedings before the Arizona Navigable Stream Adjudication Commission (ANSAC).

For purposes of this assessment, I have used the following test for determining navigability

> We hold that, to prove navigability of an Arizona watercourse under the federal standard for title purposes, one must merely demonstrate the following: On February 14,1912, the watercourse, in its natural and ordinary condition, either was used or was susceptible to being used for travel or trade in any customary mode used on water. *See The Daniel Ball,* 77 U.S. (10 Wall.) at 563, 19 L.Ed. 999.
>
> Also, physical evidence is presented on two issues: (1) navigability or non-navigability of the Verde River in its "ordinary and natural condition" at the State of Arizona's admission to the United States on February 14, 1912, consistent with the Arizona Court of Appeals decision in State v. Arizona Navigable Stream Adjudication Comm'n, 224 Ariz. 230, 229 P.3d 242 (App. 2010); and (2) segmentation of the Gila River consistent with the United States Supreme Court's decision in PPL Montana, LLC v. Montana, 556 U.S. ___, 132 S.Ct. 1215 (2012).

The detailed assessment of the Upper Verde River used a systematic three-step procedure to first determine the natural condition of the Upper Verde River, and then evaluate its susceptibility to navigation in that condition. This approach is necessary because at the time of statehood the base runoff was impacted by many upstream diversions for irrigation, storage, livestock and mining. Diversions for irrigation, livestock and mining to a small degree along the Verde River and to a much greater degree along headwater tributary streams and mountain front springs reduced the amount of downstream water. Human activities that greatly altered the flow long before statehood challenged this evaluation of the navigability.

First, the natural hydrology of the headwater area including tributary streams was defined using three independent hydrologic techniques. These techniques all use published information of the USBR, USGS, USFS, Salt River Project, local historic newspapers and Federal Land Surveys. Second, channel geometry, morphology and hydraulics were calculated using both flow characteristics from step 1 and also published information. Information of the USFS, Sierra Club, Arizona Geological Survey and USGS was especially useful for defining present hydraulic conditions and estimating the natural channel conditions. Finally, navigability was estimated using two independent methods of federal agencies based on information from steps 1 and 2.

Important hydrologic characteristics of the upper area are:

- The Verde River drained about 2170 square miles at the upper end of the study reach (the Upper Verde River) and about 3,503 square miles at the lower end. The watershed was hydrologically diverse because of the diversity of climate, geology and topography. The mountainous areas that surround the headwaters of the watershed typically received more than 20 inches of precipitation per year. The valley areas typically received about 12 inches of precipitation per year. Precipitation fell during two distinct periods--late summer and midwinter. Snow accumulated in the higher mountains and typically melted and ran off in the spring. Some of the runoff for navigation was from the rainfall and snowmelt in the mountainous areas.

- When rain fell onto the land in the Upper Verde River watershed it started moving according to basic principles of hydrology. A portion of the precipitation seeped into the ground to replenish ground water. Some of the water flowed downhill on the land surface as direct runoff and appeared in surface streams that were unaffected by artificial diversions, storage, or other works of man in or on the stream channels. In the Upper Verde River watershed, most of the runoff from storms reached the river channel directly on the land surface via overland flow, flow in rills, creeks and streams. Direct runoff was seasonal because the storms were seasonal and provided runoff for navigation for part of each year.

- The portion of the water that replenished the ground water was very important for the susceptibility of the Upper Verde River to navigation. Under natural conditions the water that replenished the ground water was temporarily stored, and later discharged to the headwater tributary streams at springs and seeps in the watershed. This base runoff was released from storage during dry periods. Perennial base runoff was maintained by ground-water discharge to the Upper Verde River and tributary streams. Several of the springs were fed from huge reservoirs of stored groundwater that have been recharged for many years. This stored groundwater is known as carryover storage and is important for annual water budgeting. Base flow is comprised of ground-water discharge from mountain front springs and seeps and Quaternary aquifers and basin fill and also deeper aquifers.

Important hydraulic characteristics of the Upper Verde River area under natural conditions at statehood were:

- The natural flow in the Upper Verde River was perennial with a median annual flow of 60 cfs and 116 cfs, respectively, at the upper and lower ends of the study reach. The corresponding average widths of flow were about 35 and 50 ft.,respectively. The measured depths of flow averaged at least 2.9 ft. There were numerous pools where depths were greater than 2.9 ft.

- The cross-sectional geometry (size and shape) of the low-water channel appears to have remained unchanged even with the human depletion of base flow. The series of pools (deep water areas) and riffles (shallow water areas typically dominated by cobbles and small boulders) are relatively stable throughout the Upper Verde River.

Important navigability characteristics of the upper area were:

- Using the high standard associated with optimum boating conditions defined by the Fish and Wildlife Service of the Dept. of the Interior, the 3.3 miles above the Campbell Ranch area that includes much of the Big Chino Springs area was not considered navigable.

- The depth and current (velocity) of the Upper Verde River flow were important: too little depth and too much velocity limited navigability. Except during large floods, the flow depth was sufficiently great and flow velocity was sufficiently small for small watercraft to navigate along the Upper Verde River.

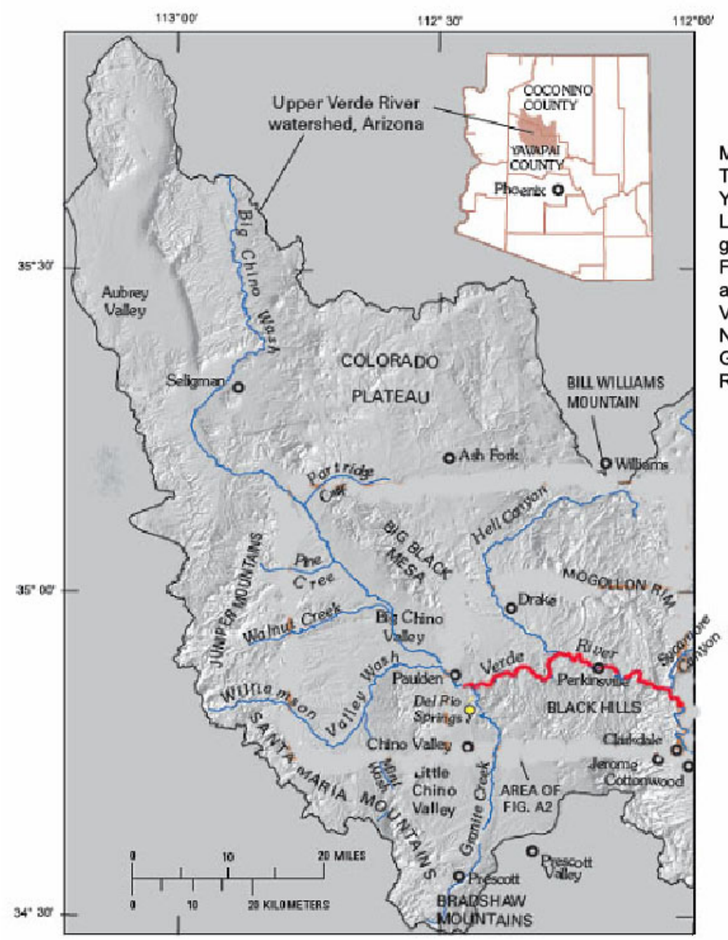
- There are numerous pools where depths were greater than 2.9 ft. and there were occasional small-steep riffles where portage might be required. Two Federal methods show the upper Verde River along the 33.3 mile reach was navigable.

For the remaining reach of the Verde River, a total drainage area of 6,188 square miles, from the end of the upper reach to the mouth at the Salt River (mile 36.6 to mile 230) a similar but less detailed procedure using the same high standard was used for the assessment. The technique used published USGS, Arizona GS, Oregon Department of State Lands and USBR reports. Focus was on the hydrology, channel geometry and high use of boating along the entire river for the past several years. The navigability assessment was partially based on similarities between the Verde River and the John Day River in Oregon that has been found navigable.

Based on all the hydrologic and hydraulic information, data and analysis contained in this report, it is the author's opinion that the natural channel of the Verde River, from river mile 3.3 in the Stewart Ranch area to the mouth at the Salt River was susceptible to navigation at the time of statehood (February 14, 1912) in its natural condition. During ordinary years the river was susceptible to navigation more than 95% of the time.

INTRODUCTION

This report and analysis were undertaken to assess the navigability of the Verde River in its natural condition, at the time of Arizona statehood for presentation to ANSAC. This analysis is based on (1) my knowledge and expertise concerning hydrology, hydraulics and fluvial processes, in general, and the application of this knowledge to the Upper Verde River in central and northern Arizona, in particular, (2) the documents of prior ANSAC studies, (3) published reports by the U. S. Geological Survey and other State and Federal agencies, and (4) federal definitions of navigable and natural flow. The assessment is in two parts—the 36.6 mile reach of the Upper Verde River from Sullivan Lake to the USGS gage near Clarkdale shown in Figure 1 and the 193.4 mile reach from the Clarkdale gage to the mouth at the Salt River. The 2-part assessment is because different methods were used for the two reaches and does not imply the Verde River should be segmented. The analysis for the 193.4 mile reach is given in Appendix G and the more detailed analysis for the Upper Verde River follows.



Modified from: Wirt, L., 2005, The Verde River headwaters, Yavapai Count, Arizona in Wirt, Laurie, DeWitt, Ed, and Langenheim, V.E., eds., Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-Central Arizona: U.S Geological Survey Open-File Report 2004-1411, 33 p.

Study reach from Sullivan Lake to USGS Clarkdale gage--36.6 miles long.

Figure 1. Upper Verde River watershed.

The test for determining navigability used in this analysis is from *Defenders of Wildlife v. Hull*, 199 Ariz. 411,426, 18 P.3d 722 (App. 2001):

> We hold that, to prove navigability of an Arizona watercourse under the federal standard for title purposes, one must merely demonstrate the following: On February 14,1912, the watercourse, in its natural and ordinary condition, either was used or was susceptible to being used for travel or trade in any customary mode used on water. *See The Daniel Ball*, 77 U.S. (10 Wall.) at 563, 19 L.Ed. 999.

Also, physical evidence is presented on two issues: (1) navigability or non-navigability of the Verde River in its “ordinary and natural condition” on the date that the State of Arizona was admitted to the United States,February 14, 1912, consistent with the Arizona Court of Appeals decision in *State v. Arizona Navigable Stream Adjudication Comm’n,* 224 Ariz. 230, 229 P.3d 242 (App. 2010); and (2) segmentation of the Gila River consistent with the United States Supreme Court’s decision in *PPL Montana, LLC v. Montana*, 556 U.S. ___, 132 S.Ct. 1215 (2012).

This river engineering report evaluates the ability of the natural channel of the Verde River to accommodate navigation. The necessary studies are channel widths, velocities, stability and depths at various seasons and locations. The question “*was the natural river channel susceptible to travel?”* is answered.

General approach

The ability to navigate a river depends upon many factors such as the amount of flow in the river channel, the width and depth of flow in the channel, the type of vessel and the purpose of the travel. Obviously, there must be a minimum depth of water in the channel because even the draft of a canoe will be a few inches. There are other factors of an economic and commercial nature that may be less obvious. These non-hydraulic factors, while important to the actual presence of navigation, are not included in this assessment of navigability.

To make a reliable evaluation of navigability under the federal test, the anthropogenic impacts, such as the many diversions along the tributary headwater streams, and to a lesser degree along the Upper Verde River, for irrigation by settlers, should be adjusted for because the diversion of flow affected the navigability. Two reports were presented to the previous ANSAC hearings on the Verde River. These reports were prepared by Jon Fuller and the Arizona Geological Survey and describe the hydrologic and geomorphologic characteristics of the Verde River before and at the time of Statehood and compare those characteristics to those of the present day. These two reports document important information regarding the history of the Verde River, especially the long history of human impacts and associated changes of hydrology of the watershed.

In this evaluation of the navigability of the Upper Verde River, the greatest challenge is the fact that by 1912, the hydrology of the watershed had been so altered by human activities (see Appendices A, C-F, for example) that it is difficult to assess its condition in its "natural and ordinary" state. The evidence shows that the natural river had a substantial natural base flow. The reason that the natural flow did not find its way into the river channel is human interference through diversions, storage, and groundwater pumping. Yet, as the Arizona Court of Appeals made clear, the Commission must evaluate the river as though those activities did not occur. When such adjustments are made, it is apparent that several tributary streams that are presently ephemeral were sufficiently perennial or intermittent to support a finding that the upper Verde River was susceptible to navigation by small watercraft and, therefore, was capable of being used as a highway for commerce. In other words, the base runoff of the Upper Verde River was considerably more than the present base flow.

The study was performed as outlined in the following diagram. I first examined background information that included historic accounts of water use in the watershed and hydrology of the watershed. Then I used a three-step procedure to determine what we know about the navigability of the Upper Verde River for the natural condition of flow.

Step. 1: **Estimate the amount and temporal distribution of natural flow for the Upper Verde River**

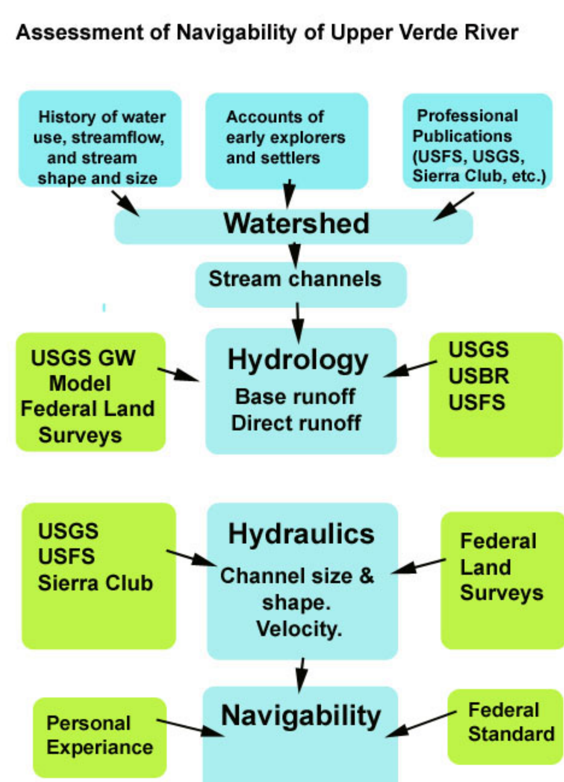
The natural hydrology for the Upper Verde River is based largely on published reports by the U. S. Bureau of Reclamation, U. S. Geological Survey and Federal Land Surveys.

Step 2: Estimate the natural hydraulic characteristics of the river channel that are related to navigation.

The natural size and shape of the Upper Verde River channel are based on published and unpublished channel geometry relations (cross sections of the river) along the upper river. Current meter measurements and surveyed cross sections were furnished by the Federal Land Surveys, U. S. Geological Survey, U. S. Forest Service and the Sierra Club.

Step 3: Determine whether in its natural condition the Upper Verde River was susceptible to navigation upstream of the USGS gage near Clarkdale, AZ (09504000).

Navigability along the Upper Verde River is evaluated after the natural hydrology, hydraulics morphology of the channel



determined in steps 1 and 2, are used to estimate the size and shape of the natural river. Two relatively simple methods developed by the U.S. Department of the Interior were used.

Published information and standard civil engineering and engineering hydrologic and hydraulic methods were used to accomplish the three basic steps. Also, a considerable amount of time was devoted to examining plats and field notes of original Federal Land Surveys throughout the upper watershed.

This report presents the results of a quantitative estimate of the navigability of the Upper Verde River based largely on USGS, USBR and USFS reports and published USGS stream gage records. Several USGS reports and a USFS report on the flow characteristics and morphology of the Upper Verde River, that use relatively recent channel geometry were used to estimate natural channel geometry. Unpublished current meter measurements and surveyed channel cross sections furnished by the USGS, Sierra Club and the USFS are much appreciated. With personal experience this information formed the basis of this assessment of the navigability of the Upper Verde River and the following reported analysis.

Note

As noted above, the assessment for the entire 230 mile river is given in two parts. The first part is the following detailed assessment of the upper 36.6 mile reach from the dam at Sullivan Lake to the USGS stream gage near Clarkdale, AZ. The second part is in Appendix G and is a less detailed assessment for the remaining reach of the Verde River, a total drainage area of 6,188 square miles, from the end of the upper reach to the mouth at the Salt River (mile 36.6 to mile 230). Obviously, the assessment for the second part of the river is influenced by runoff and sediment yield of the upper watershed.

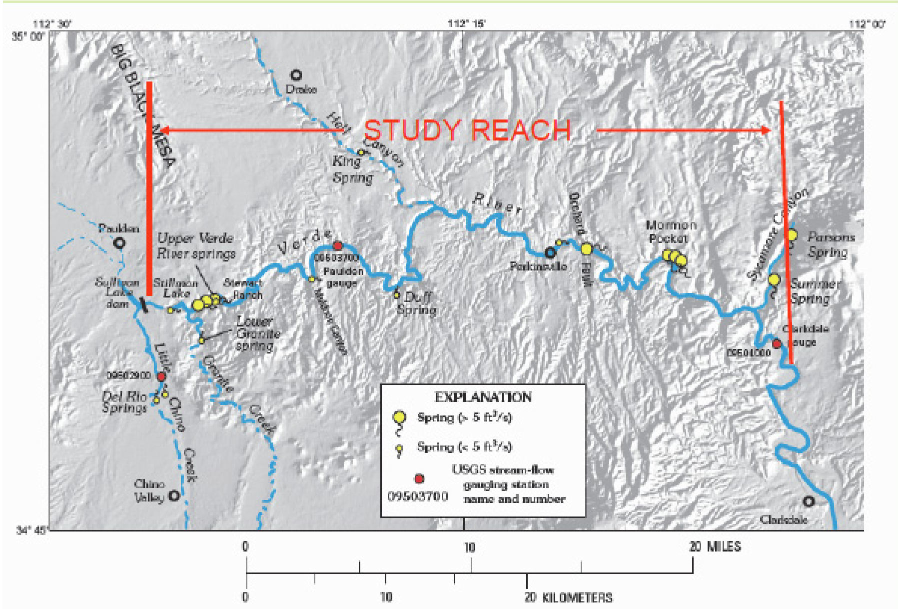
DESCRIPTION OF UPPER WATERSHED

The upper Verde River watershed drains the northwestern Transition Zone and southwestern Colorado Plateau geologic provinces. Proterozoic igneous rocks largely define the basin geometry and boundaries of the Big and Little Chino basin-fill aquifers (Item 6 Appendix A). Big and Little Chino Valleys contain gently sloping reservoirs of ground water that drain toward large springs near their basin outlets. The ground-water flow direction of basin-fill aquifers is from the basin margins and tributaries toward the basin center and then down the major axes of the valleys. Spring flow in the river canyon emerges from Paleozoic carbonate rocks downstream from the confluence of the Big and Little Chino basin-fill aquifers (Wirt, F.N., DeWitt, Ed, and Langenheim, V.E., 2005, Hydrogeologic Framework, *in* Wirt, Laurie, DeWitt, Ed, and Langenheim, V.E., eds., Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-Central Arizona: U.S. Geological Survey Open-File Report 2004-1411-D, 27 p.).

The Verde River drained about 2170 square miles at the upper end of the study reach at Sullivan Lake dam and about 3,503 square miles at the lower end at the USGS stream gage near Clarkdale, AZ. The watershed was (is) hydrologically diverse because of the diversity of climate, geology and topography. The mountainous areas that surround the headwaters of the watershed typically received more than 20 inches of precipitation per year. The valley areas typically received about 12 inches of precipitation per year. Precipitation fell during two distinct periods--late summer and midwinter. Snow accumulated in the higher mountains and typically melted and ran off in the spring. Much of the runoff for navigation was from the rainfall and snowmelt in the mountainous areas.

When reading the historic information of this report for ANSAC it is important to realize that nearly all accounts of flow condition along the Verde River and tributary streams describe a river affected by human activity. There were numerous agricultural diversions directly from streams that when considered as a whole amount to a major loss of base flow starting in about 1860. The accounts by Whipple and his party in 1854 probably were of the river's natural condition. (Appendix B).

There were significant human impacts on the natural flow of streams long before withdrawal of water from the large basin-fill and carbonate aquifers using deep wells. In addition to deep well pumping in the basin fill aquifers that started in 1926, other early impacts on base runoff of streams in the upper watershed include stock tanks, reservoirs for RR and municipal use, diversions for mining and the pipeline diversion from Del Rio Springs to Prescott and cattle grazing.



Wirt, L., 2005, The Verde River headwaters, Yavapai Count, Arizona *in* Wirt, Laurie, DeWitt, Ed, and Langenheim, V.E., eds., Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-CentralArizona: U.S Geological Survey Open-File Report 2004-1411, 33 p.

Figure 2. Study reach for upper area.

Table 1.-- Distance from Sullivan Lake Dam to major springs, tributaries and features along the upper Verde River.

[Distances are approximate and have not been surveyed]

Major tributaries or physiographic features	Miles	Kilometers
Del Rio Springs via Little Chino Creek	-3.0*	-4.8*
Lower Granite Spring*	1.0**	1.6**
Sullivan Lake Dam	0.0	0.0
Stillman Lake (upstream end)	1.0	1.6
Stillman Lake (downstream end)	1.9	3.1
Granite Creek confluence	2.0	3.2
Continuous flow begins	2.1	3.4
Upper Verde River springs (upstream end)	2.2	3.6
Stewart Ranch (west access)	3.2	5.1
Muldoon Canyon	8.0	12.9
Paulden gauge (09503700)	9.8	15.8
Verde Valley Ranch	10.3	16.6
Bull Basin Canyon	11.5	18.5
Duff Spring	13.9	22.4
Hell Canyon	18.0	29.0
U.S. Mine	19.4	31.2
Perkinsville diversion ditch	23.7	38.1
Perkinsville	24.0	38.6
Verde River near Orchard Fault	26.0	41.8
RR Crossing downstream of Perkinsville	26.6	42.8
Mormon Pocket springs	31.0	49.9
Sycamore Canyon	34.9	56.2
Clarkdale gauge (09504000)	36.6	58.9

*Distance upstream from Sullivan Lake dam
**Distance upstream from Granite Creek and Verde River confluence

Wirt, L., 2005, The Verde River headwaters, Yavapai Count, Arizona in Wirt, Laurie, DeWitt, Ed, and Langenheim, V.E., eds., Geologic Framework of Aquifer Units and Ground-Water Flow-paths, Verde River Headwaters, North-Central Arizona: U.S Geo-logical Survey Open-File Report 2004-1411, 33 p.

Before human development, the groundwater systems of the Upper Verde River watershed were in a quasi state of equilibrium. Long-term Inflow was equal to long-term outflow with no net change of water stored in the ground. Obviously there was natural climate variability, forest fires, plant disease, etc. that affected recharge to and discharge from aquifers but in the long term, there was no change in groundwater storage. Hydrologists, engineers and geologists have quantified the pre-development (possibly natural) conditions using available data and hydrologic knowledge.

In my analysis, the effects of climate change, if any, are considered insignificant because according to Thomsen and Eychaner (1991), "Tree-ring data do not indicate a significant change in precipitation from 1602 to 1970." A brief discussion of the use of tree rings and how not to use tree rings for hydrology post-diction is in Appendix J of this report.

HISTORICAL BACKGROUND

Settlement in the arid and semi-arid upper Verde River watershed was highly dependent on water supply. Most of the early settlers were interested in mining, raising livestock and agriculture. These economic activities required water and in a short time there was increasing competition for water supplies. At one time, the base flow of Granite Creek powered a grist mill a short distance above Prescott and also a couple of Arrastras in 1866. There were hundreds of acres of cultivated land in the Prescott area (page 14 Appendix C).

Natural water supplies were important in shaping early settlement. Farmers were attracted to places where soil was adequate and where streams could be easily diverted for use on crops. Federal policies encouraged settlement with irrigation during the latter part of the nineteenth century. "As the demand for water approached the supply of water, the need to secure a permanent source of water gave rise to water laws, such as the prior appropriation doctrine, which established the principle of "first in time, first in right." The development of the prior appropriation doctrine provided strong incentives for farmers to "use it or lose it" where water was concerned. The prior appropriation doctrine also codified a widely held perception at the time that water left flowing in streams was a "waste." Beneficial use became a condition for securing a water right. (National Research Council, 1996).

Irrigated agriculture was the single largest user of water where initial use typically was by direct diversion, using low dams, from perennial and intermittent streams. Along several streams water flowed under stream sediments where shallow wells were hand dug and water pumped to irrigate adjacent agriculture. An early supply for Prescott was a shallow well along Granite Creek (Appendix C). There were many rather small diversions along streams that together amounted to a significant reduction in base flow along the tributary streams and the Verde River.

The Prescott Water Works pumping plant at Del Rio Springs started operation on September 6, 1901 to supply Prescott with one-half million gallons of water per day. In the early 1900s lawsuits had started and been settled in court as Judge Sloan, for example, had decided against John Duke and in favor of Prescott (Arizona weekly journal-miner. (Prescott, Ariz.) July 17, 1901). Mr. Duke claimed Prescott was diverting his water along Granite Creek. So as early as 1899 and 1900 Prescott was accused of "taking" water used by others (page 10 Appendix C).

In 1893, the Santa Fe, Prescott and Phoenix Railway had completed its tributary line, named the "Peavine" because of the way it wound round and clung to the mountains, from Prescott through Granite Dells and Chino Valley to its junction with the Atchison, Topeka and Santa Fe line at Ash Fork. The railroad transported the potable water from Del Rio to the many locations along its northern lines that were not blessed with adequate water including the towns of: Ash Fork, Seligman, Williams, Winslow and eventually, the Grand Canyon.

The Seligman Dam was begun in 1898, three miles southwest of Seligman. A contractor built the dam, with the railway delivering stone, sand and cement on its cars. Sandstone was hauled 43 miles from Rock Butte, the facing stone came from Holbrook 175 miles away, and sand was shipped 150 miles from Sacramento Wash. The dam, its total cost in excess of $150,000, has a storage capacity of 703 acre-feet (Item 5 Appendix A). (See Item 8 of Appendix A for additional background).

Note

Nearly all of the available original Federal Land Surveys (plats and Field notes) along the Verde River and tributary streams were examined for this analysis. These surveys provide considerable background information and are discussed later and are also presented in Appendixes B-G of this report.

Also, the Whipple survey of 1853-54 that is related to an original land survey and also the latest geology is presented in Appendix B.

HYDROLOGY

Natural and ordinary perennial/intermittent streamflow is comprised of surface runoff and base runoff. Surface runoff is derived from precipitation and snowmelt. Base runoff is maintained by ground-water discharge to the Verde River and tributary streams. Base flow is comprised of ground-water discharge from mountain front springs and seeps (Base Qmf on Figure 3 below) and Quaternary aquifers (Base Qqa) and basin fill and deeper aquifers (Base Qbfa).

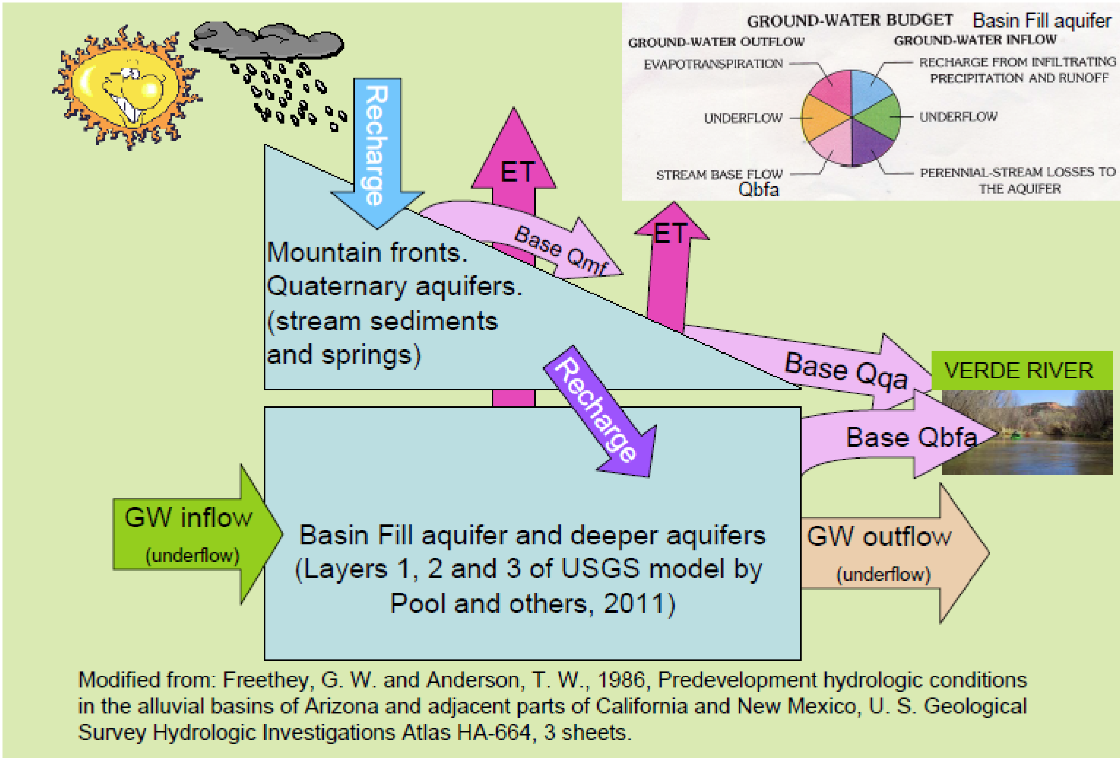


Figure 3.—Diagram showing flow components for natural conditions.

Natural streams and washes in Big and Little Chino Valleys were perennial, intermittent and ephemeral. There was perennial/intermittent flow where the ground-water table was/is shallow and intercepted by the land surface, such as near the topographic outlets of the valleys. These low-altitude springs often create cienegas, or spring-fed marshes. The largest low-altitude spring in Little Chino Valley is Del Rio Springs. A 4-mi reach of lower Williamson Valley Wash is supplied by ground water, or spring fed, as are reaches of Walnut Creek, lower Granite Creek, and lower Sycamore Creek.

> Wirt, F.N., DeWitt, Ed, and Langenheim, V.E., 2005, Hydrogeologic Framework, *in* Wirt, Laurie, DeWitt, Ed, and Langenheim, V.E., eds., Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-Central Arizona: U.S. Geological Survey Open-File Report 2004-1411-D, 27 p.

Much has been said about the source of the Verde River and the recent USGS regional model of groundwater-streamflow interaction. A simple fact is regional models do not always represent headwater springs and Quaternary sediments that are above (younger than) the modeled aquifers like the basin fill of the Big and Little Chino aquifers. In the case of the upper Verde watershed, many of the once perennial/intermittent tributary streams were and are hydraulically perched above the basin fill aquifers where groundwater is withdrawn by deep wells. It is this deeper groundwater that is modeled above the Paulden gage by the USGS and not the mountain front springs and relatively small alluvial aquifers along stream channels.

These streams were depleted long before deep wells were used in the watershed. Early settlers diverted water for irrigation using low rock dams and shallow wells with centrifugal pumps all along tributary streams like Granite Creek, Walnut Creek, Williamson Valley Creek and Big Chino Creek. Based on original Federal Land Survey plats and field notes, more than 8000 acres of land along headwater streams were cultivated and irrigated by settlers. This amount of water applied to this acreage corresponds to an early depletion of base flow in the Verde River even before construction of Watson Lake dam.

The numerical model structure of a recent and important model used by Pool and others (2011) did not include a layer above basin fill (layer 1) depicted in Figure 3. In other words, it did not accommodate steep hydraulic gradients and perched conditions along mountain front areas and also along tributary streams. *Some of these perched sediments along the tributary streams can be thought of as a subflow zone—a term often used by ADWR and unique to Arizona water law.* Such an overlying layer could accommodate water storage in recharge areas, define the clay lenses that restrict vertical flow of water, define recharge to basin fill along diversions and base runoff along tributary streams to the Verde River. (See Item 9 of Appendix A for more detail on modeling).

One of the first and reliable determinations of the average natural or virgin flow of the Verde River was by the USBR in the Department of Interior report "The Colorado River" (March 1946). This report was to serve as the basis for planning future developments for the maximum utilization of water supplies present and ultimately available (e.g. The Colorado River Compact.).

> USBR, 1952, Report on Water Supply of the Lower Colorado River Basin: US Department of Interior, Bureau of Reclamation Project Planning Report, (p. 152), 444 p.

The method used in this assessment of the Verde River eliminates all or much of the effect of human impacts by using annual runoff data (USBR, 1952) which quantifies the amount of water that would be present at the mouth of the river if there were no diversions (the natural and ordinary condition).

A second report defining natural or pre-development runoff was the basin accounting method for natural stream base flow developed by Freethey and Anderson (1986) that was used to estimate base runoff (the 90th percentile of daily discharge). This study divided the basin and range physiographic province into 72 basins that represent separate groundwater systems. Four of these basins are in the Verde River watershed. While this method has been displaced by recent groundwater modeling, it was still appropriately used to guide this analysis of navigability. A limiting feature of HA-664, however, is that base runoff is only for the basin fill and underlying aquifers.

Freethey, G. W. and Anderson, T. W., 1986, Predevelopment hydrologic conditions in the alluvial basins of Arizona and adjacent parts of California and New Mexico, U. S. Geological Survey Hydrologic Investigations Atlas HA-664, 3 sheets.

A third study combines climatic, surface-water, ground-water, water-chemistry, and geologic data to describe the hydrogeologic systems within the upper and middle Verde River watersheds and to provide a conceptual understanding of the ground-water flow system (Blasch, K.W., Hoffmann, J.P., Graser, L.F., Bryson, J.R., and Flint, A.L., 2006, Hydrogeology of the upper and middle Verde River watersheds, central Arizona: U.S. Geological Survey Scientific Investigations Report 2005–5198,101 p., 3 plates.). The study area includes the Big Chino and Little Chino subbasins in the upper Verde River watershed and the Verde Valley subbasin in the middle Verde River watershed.

A fourth report, discussed again and in detail in Item 9 Appendix A, on a numerical flow model (MODFLOW) of the groundwater flow system in the primary aquifers in northern Arizona was rather recently developed to simulate interactions between the aquifers, perennial streams, and springs for predevelopment and transient conditions during 1910 through 2005. Simulated aquifers include the Redwall-Muav and basin-fill aquifers. Perennial stream reaches and springs that derive base flow from the aquifers were simulated, including the Verde River, and perennial reaches of tributary streams. While this report was limited to the basin fill aquifer-base runoff connection in the upper Verde, it was useful for this analysis of navigability.

Pool, D.R., Blasch, K.W., Callegary, J.B., Leake, S.A., and Graser, L.F., 2011, Regional groundwater-flow model of the Redwall-Muav, Coconino, and alluvial basin aquifer systems of northern and central Arizona: U.S. Geological Survey Scientific Investigations Report 2010-5180, 101 p.

“Recharge rates at each ephemeral channel could be better quantified by using more frequent or continuous water-level monitoring along with colocated observations of water-mass change by using gravity methods. Aquifer storage properties, including extents of confined and unconfined groundwater in each aquifer and perched aquifers, are poorly defined.” (Pool and others, p. 90, 2011)

“A thin layer of Quaternary alluvium overlies the fine-grained facies of upper basin fill near the Big Chino Wash and forms a local perched aquifer that has hydraulic heads that are as much as 100 ft above the hydraulic heads of the lower basin fill. A thin layer of Quaternary alluvium also is a local aquifer near Williamson Valley Wash.” (Pool and others, p. 31, 2011)

“Perched aquifers may form locally where the Quaternary alluvium overlies low permeability rocks or the fine-grained facies of basin fill.” (Pool and others, p. 31, 2011). (See Item 1 Appendix A for sketch of perched aquifer.)

“Groundwater likely flows vertically between aquifers in many areas, but this flow component is poorly defined throughout most of the study area. Vertical groundwater flow could be better defined by the development of water-level records at colocated deep and shallow wells that monitor different aquifers or permeable zones. Broad assumptions were used to distribute recharge throughout the model. Better information defining recharge distributions, especially ephemeral channel recharge, would result in improved transmissivity distributions. Reasonably accurate storage and transmissive properties are needed for the proper simulation of the effects of withdrawals on water levels and groundwater discharge to streams and springs.” (Pool and others, p. 89, 2011).

This assessment of navigability uses the results of USGS reports/models and also, most importantly, defines the total base runoff by calculating base runoff from the Quaternary alluvium area that includes the stream sediments perched above the basin fill (layer 1) and the mountain front areas where there is runoff and recharge. Again, this part of the total base runoff was not modeled by the USGS. A report by the USBR (1952) that calculated the Virgin flow for the mouth of the Verde River is an important part of this analysis.

Estimating natural streamflow

Three methods of estimating the natural and ordinary streamflow of the Verde River above the USGS Clarkdale gage are use for this analysis. Two of the methods use records of streamflow, irrigated land and published information on Virgin flow of the Verde River. The third method, a slope-conveyance method that is clearly an estimate, uses measured channel width and depth of the Verde River by the Federal Land Surveyors. The first method (Method 1) uses records of cultivated land.

The following presents two independent and detailed analyses and estimates of the natural (Virgin) median and average streamflow (including total and baseflow) at four key gaging stations along the Verde River. Both methods use USGS records of streamflow at gages 09503700, 09504000, 09506000 and 09510000. The average annual and median annual discharge for the period of record is used. A major objective is to define natural conditions for the study reach defined by gages 09503700 and 09504000. The results of these analyses are given in tables 1of 2 and 2 of 2 followed by a description of the methods. Tables 1 of 2 and 2 of 2 are best viewed as one continuous table.

Table 1 of 2. Estimates of the natural (Virgin) median and average streamflow (total and baseflow).

USGS Gage	Drainage Area Sq. mile	Q50 pre- (B) cfs	Mean Annual flow (C) cfs	Virgin Mean annual flow (D) cfs
(A)	2170	*	*	90
5037	2507	30	48	*
5040	3503	86	179	*
5060	5009	177	394	*
5100	6161	464	651	751

A - At Sullivan Lake that corresponds to HU 15060201(Krug, W. R., Warren A. Gebert, and David 1. Graczyk, 1987, PREPARATION OF AVERAGE ANNUAL RUNOFF MAP OF THE UNITED STATES, USGS Open File Report 87-535.).
B - Median pre-development flow from USGS GW model (Pool and others, 2011). (Pool, D.R., Blasch, K.W., Callegary, J.B., Leake, S.A., and Graser, L.F., 2011, Regional groundwater-flow model of the Redwall-Muav, Coconino, and alluvial basin aquifer systems of northern and central Arizona: U.S. Geological Survey Scientific Investigations Report 2010-5180, 101 p.)
C - Mean annual flow for gaged record with 5 cfs added per USGS GW model (Pool and others, 2011).
D - First no. is from HU and second no. is from USBR. (USBR, 1952, Report on Water Supply of the Lower Colorado River Basin: US Department of Interior, Bureau of Reclamation Project Planning Report, (p. 152), 444 p.)

Table 2 of 2. Estimates of the natural (Virgin) median and average streamflow (total and baseflow).

USGS Gage	METHOD 2: Q50 Virgin (F) cfs	METHOD 2: Virgin mean annual flow (F) cfs	Average annual ET Fed Survey (G) cfs	METHOD 1: Virgin Fed Survey cfs Q50(I)	METHOD 1: Virgin Fed Survey cfs Q90(J)	METHOD 1: Virgin mean annual flow (H) cfs
(A)	*	*	*	*	*	*
5037	58	76	35	60	56	78
5040	114	207	36	117	111	210
5060	277	494	*	*	*	*
5100	*	751	*	*	*	*

F - The 100 cfs difference beween the Virgin average annual runoff and the gaged mean annual flow was distributed between the two general areas of cultivated land where base runoff was diverted from stream channels. These two areas are the watershed above gage 5037 and the watershed between gage 5040 and 5060 where losses of base runoff to ET were distributed as a percent of total cultivate lands for these two areas as given in Hayden (1940) on pages 75 and 83.(Hayden, T. S., 1940, Irrigation on upper Verde River watershed from surface waters: unpublished report of SRP, 329 pages. According to Hayden 28 percent of the irrigation was above gage 5027 and 72 percent was in the Verde Valley.
G - Amount is from cultivated lands shown on the original Federal Land Surveys. Water use for the total acres (8385 and 8505 above USGS gages 09503700 and 09504000, respectively, was determined using the weighted irrigtion factor of 3.15 ac-ft/acre (Pool and others page 37, 2011).
H - Amount in column 7 is the pre-development mean annual flow plus the average annual ET in column 4 and minus the average annual loss to ET (5 cfs) along the tributary channels. Again, the average annual ET is from irrigated lands typically watered by diversion from streams using low rock dams and shallow wells located in the stream sediments.
I - Amount in column 5 is the pre-development median plus the average annual ET minus the avg. annual loss to ET (5 cfs) along the 80 miles of trib. channels.
J - Amount in column 6 is the pre-development median plus the avg annual ET minus the summer (maximum) loss to ET (11 cfs) along the tributary channels. (See slide 32 of Appendix A for computation of ET loss along channels).

Site A in the 1st column corresponds to USGS Hydrologic Unit 15060201. The Virgin mean annual runoff for Site A column 5 (1of2) is presented for comparison purposes at the completion of these analyses. The 3rd and 4th columns (1of2) are the pre-development median and mean annual flow adjusted by 5 cfs loss of base flow for depletion of basin fill aquifers.

Method 1

The human-caused reduction of base flow by diversion of water from streams using low rock dams and shallow wells in the stream sediment was estimated by the product of a consumptive use factor and the cultivated acres.

Cultivated lands in the Verde River headwaters along areas such as Granite Creek, Williamson Valley Creek, Big Chino Creek and Walnut Creek went somewhat unnoticed because (1) they were not visited during early assessment of irrigated lands and (2) they were not “surveyed” to escape taxation (Turney, 1901). Water was used continuously by some settlers with only a squatter's title. Thus, the use of original Federal Land Survey plats and field notes on file at the Government Land Office (GLO) is considered a good means estimating water use by farming because the cultivated lands were documented at the time of the surveys.

> Turney, O. A., 1901, Water Supply and Irrigation on the Verde River and Tributaries, Cleveland Daily Record, 20p.

According to the USGS “centrifugal pumps are adapted to raising water heavily charged with sediment” where lifts are a few feet. “Centrifugal pumps are usually driven by water, steam, or gasoline motors, with which they are connected by belting or shaft and gearing, and they may be erected independently of the motors and at some distance from them ”(Wilson, p.50).

> Wilson, H. M., 1896, Pumping water for irrigation; USGS Water Supply and Irrigation Paper 1, 54th Congress, 2nd Session, House of Representatives, Document 108; 57 p.

Irrigation water use factor per acre of land: The “fields were assigned a weighted irrigation factor of 3.15 ac-ft/yr that was developed from agricultural irrigation data from the Verde Valley (Arizona Department of Water Resources, 2000)” (Pool and others page 37, 2011).

> Pool, D.R., Blasch, K.W., Callegary, J.B., Leake, S.A., and Graser, L.F., 2011, Regional groundwater-flow model of the Redwall-Muav, Coconino, and alluvial basin aquifer systems of northern and central Arizona: U.S. Geological Survey Scientific Investigations Report 2010-5180, 101 p.

Cultivated acres were determined along intermittent/perennial Granite Creek, Williamson Valley Creek and Walnut Creek using the original Federal Land Survey plats and field notes on file at the Government Land Office (GLO). Cultivated acres along Big Chino Creek was estimated using 1940 aerial photos of the SCS. Cultivated acres for four irrigated parcels along the Verde River were from Hayden (1940).

Hayden, T. S., 1940, Irrigation on upper Verde River watershed from surface waters: unpublished report of SRP, 329 pages.

Available GLO land surveys along Big Chino Creek typically were made before land along the channel was cultivated.

Care was taken to separate cienegas, where the ground-water table is shallow and intercepted by the land surface, from human diversions and cultivated land. For example about 190 acres at Del Rio Springs was shown as cultivated with a ditch running by the land. A field inspection and aerial photos show the area probably was a cienega and thus was not included as cultivated land for this analysis.
Areas irrigated by low diversion dams and shallow wells in the stream sediments (cultivated land).

Computation of total base runoff

METHOD 1

Granite Creek

Township	acres
T14N R2W	1380
T15N R1W	100
T16N R1W	370
T17N R2W	350
Total	2200

See Appendix C for Federal Land Surveys and newspaper accounts.

Computation of total base runoff

METHOD 1

Williamson Valley Creek

Township	acres
T16N R5W	200
T16N R4W	2140
T16N R3W	250
T17N R5W	220
T17N R4W	770
T17N R3W	20
Total	3600

See Appendix D for Federal Land Surveys and newspaper accounts.

Computation of total base runoff

METHOD 1

Walnut Creek

Township	acres
T18N R6W	50
T18N R5W	1180
T18N R4W	55
T18N R3W	110
Total	1395

See Appendix E for Federal Land Surveys and newspaper accounts.

Computation of total base runoff

METHOD 1

Big Chino Cree

Townships

T20N R4W, T19N R4W, T19N R3W, T18N R3W, T18N R2W, T17N R2W

Acres (mostly from SCS 1940 aerial photos)

Total 900 (Sum of 14 parcels. Small parcels in marshy areas not included because ET of cultivation is offset by natural ET.)

See Appendix F for aerial photos, Federal Land Surveys and newspaper accounts.

Computation of total base runoff

METHOD 1

Hayden, T. A., 1940

UPPER VERDE CANYON

IRRIGATED LAND - UPPER VERDE RIVER. T. A. Hayden, May-June, 1940. T___N.,R____
(* Millsite & Water-right Records, Yavapai Co. "P" denotes Promiscuous Records.)

Tr No	Sec	Subdivision	Acres	Stream	Ditch	WATER APPROPRIATIONS: First Cultiv. Year	First Cultiv. Source of data	Recorded Filings: Name of Locator	Year	Book*	Page
	Campbell Ranch T.17N., R.1W.										
	7	NE¼	32	Verde	Campbell N. Side of river	1874	H.L.H.	T.E. Campbell			
	Perkins Ranch T.18N., R.2E.										
	31	S½	75	Verde	Perkins	1864	H.L.H.	M.A. & R.E. Perkins			
	Armon Ranch T.17N., R.2E.										
	12		4	Verde	Armon	1914	H.L.H.	David Armon			
	Alvarez Ranch T.17N., R.2E.										
	12		9	Verde	Alvarez	1901	H.L.H.	Rosindo Alvarez			
			120								

Hayden, T. S., 1940, Irrigation on upper Verde River watershed from surface waters: unpublished report of SRP, 329 pages.

Side Note: I recently discussed past boating on the river with the daughter of Rosindo Alvarez (see above table) and when she was young recalled seeing a couple of canoes pass her home on the Verde River.

Computation of total base runoff — **METHOD 1**

The following is presented for interest only and was not used for this analysis. Any human impact from irrigation in Sycamore Ck (Dragoon Ck) was not included in Method 1.

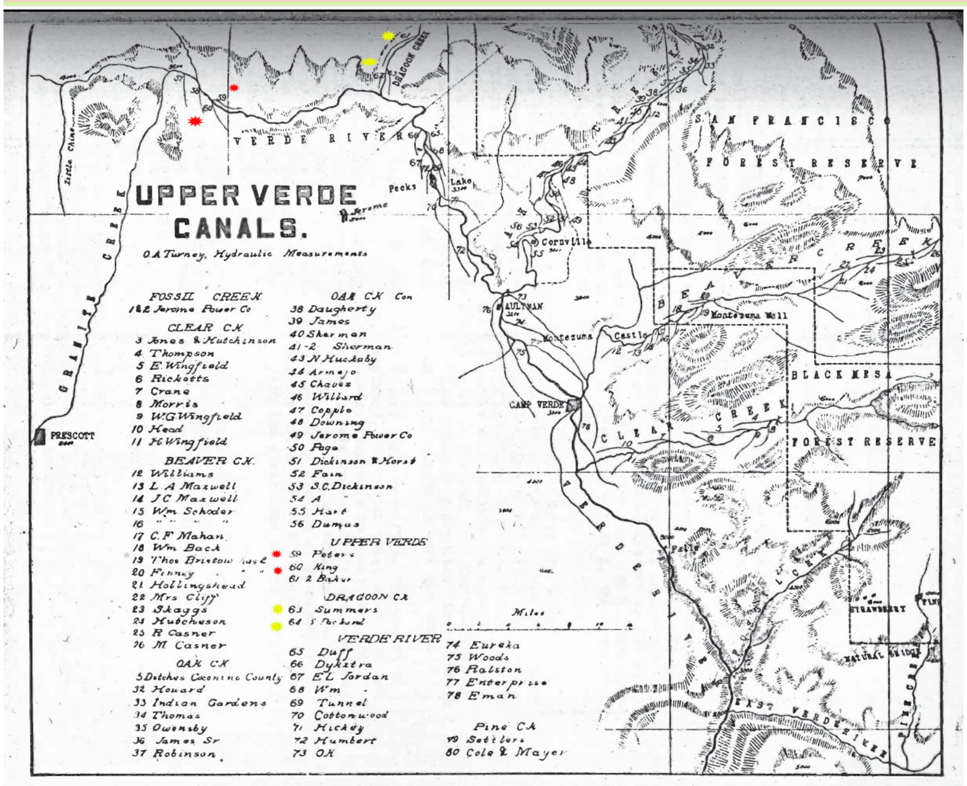
GRANITE AND DRAGOON CREEKS.

The upper Verde near Granite Creek was not visited. In this section are No. 59, belonging to Peters Bros.; No. 60, belonging to Thomas R. King, and Nos. 61 and 62, to Baker. Dragoon Creek was not visited. On this Creek are John Summers, No. 63, and Nos. 64 and 65, belonging to Packard.

The Stroud report two years ago reported Packard as having 30 acres and a ditch of 100 inches capacity, located in 1885. If we allow the remaining ditches not visited in this neighborhood 15 inches each, we have a total of 175 inches.

See map on next slide.

Turney, O. A., 1901, Water Supply and Irrigation on the Verde River and Tributaries: Cleveland Daily Record, 20p. (The Sub-Committee of the joint Canal Committee was composed of J. W. Woolf, W. B. Cleary and T. W. Stewart, who represented The Arizona Water Co.. The Arizona Canal Co., The Grand Canal Co.. The Maricopa Canal Co., The Salt River Valley Canal Co., the Consolidated Canal Co., the Mesa Canal Co.. the Utah Canal Co., the Tempe Canal Co., and the San Francisco Canal Co.)



See Item. 12. Claims to surface water of Appendix A for additional information.

Computation of total base runoff

METHOD 1

Total cultivated land

Location	Acres	Flow, cfs [1]
Granite, Williamson Valley, Walnut, and Big Chino Creeks	8095	35
USGS Clarkdale gage	8215	36

[1] Base flow lost from Verde River because of diversions for irrigation of cultivated land. Diversions typically are low dams and shallow wells in stream sediment and cultivated land typically is on Holocene sediments (Lynx soil series that is recent alluvium (Wendt, 1976).

[1]Amount of base runoff lost to ET from cultivated land shown in column 4 (2of2).

Wendt, G. E, and others, 1976, Soil survey of Yavapai County, AZ -Western Part: U. S. Soil Conservation Service,121p.

It's interesting that the total cultivated land of 8095 acres in the above table is only 45% of the reported 18,070 acres under cultivation in 1890 (Black, John A., 1890, ARIZONA THE LAND OF SUNSHINE AND SILVER HEALTH AND PROSPERITY, THE PLACE FOR IDEAL HOMES, COMMISSIONER OF IMMIGRATION, Republican Book and Job Print, Phoenix, Arizona, 143p.). Some of this computed difference is probably because Method 1 used the ET of some cultivated land that was offset by ET when the land was marshy.

Computation of total base runoff

METHOD 1

The median (Q50) Virgin flow, column 5 (2of2) is column 3 (1of2) adjusted for the losses to ET in column 4 (2of2) and the average annual loss to ET of 5 cfs along the approximately 80 miles of tributary channels (See **Item 2** Appendix A).

For example:
Q50 Virgin at gage 5037 = 30 + 35 - 5 cfs = 60 cfs
5040 = 86 + 36 - 5cfs = 117 cfs

Column 6 for Q90 is same manner but with average max. (summer) loss to ET long the trib. Channels:

Q90 Virgin at gage 5037 = 30 + 35 - 11 cfs = 54 cfs
5040 = 86 + 36 – 11 cfs = 111 cfs

Computation of total base runoff

METHOD 1

The mean annual Virgin flow, column 7 (2of2) is column 4 (1of2) adjusted for the losses to ET in column 4 (2of2) and adjusted for the average annual loss to ET of 5 cfs along the approximately 80 miles of tributary channels (See item 2 of Appendix A).

Mean annual Virgin at gage 5037 = 48 + 35 - 5 = 78 cfs
5040 = 179 + 36 -5 = 210 cfs

This completes METHOD 1

Method 1 is for consumptive use by crops and does not include domestic, mining, stock tanks and railroad use.

For example:

> Upper watershed .--The railroad filled a large number of tank cars on a regular basis that amounted to about 1 cfs at Del Rio Springs. Also, about 1 cfs was pumped at Del Rio Springs into a pipeline to Prescott for domestic use. It's easy to attribute several cfs loss of annual runoff to stock-tank and railroad reservoirs but the associated loss of base runoff could be roughly estimated but is not included.
>
> Upper and below Clarkdale gage.—Based on available industrial claims (Item 12, Appendix A) to water used along the Verde River downstream of Granite Creek mostly in the Jerome/Clarkdale area before 1912 total at least 20 cfs. Stockwater and Irrigation claims total between 2 and 3 cfs for this apparent small sample.

Thus, the Method 1 estimates of virgin flow for the Verde River are conservatively low.

Method 2

Nearly all of the difference between the Virgin average annual runoff and the gaged mean annual flow was from ET of cultivated land in the upper watershed (along Granite Creek, Williamson Valley Creek, Chino Creek, Pueblo (Walnut) Creek) and the Verde Valley (along the Verde River, Oak Creek, Beaver Creek and West Clear Creek). The difference is associated with losses to ET from irrigation, stock tanks and other human activity from the Mountain fronts, Quaternary aquifers (stream sediments and springs) and land surface of the watershed. Most of this loss is from direct diversion from stream channels using low rock dams and shallow wells

The irrigated land for these areas is given in the Hayden (1940) Report. The approximate 100 cfs loss to ET was simply distributed between the two areas on the basis of irrigated acres in the Harden Report. According to the Hayden Report the ratio 28 cfs was lost to ET from irrigated land above gage 09503700 and 72 cfs was lost in the Verde Valley.

The median and mean annual Virgin flow, column 3 (2of2) and 4 (2of2), are respectively, columns 3 (1of2) and 4 (1of2) adjusted for the 28 cfs and 72 cfs losses to ET.

For example:

Q50 Virgin at gage 09503700 = 3 0 + 28 cfs = 58 cfs
09504000 = 86 + 28 cfs = 114 cfs
09506000 = 177 + 28 + 72 = 277cfs

Mean annual Virgin at gage 09503700 = 48 + 28 cfs = 76 cfs
09504000 = 179 + 28 cfs = 207 cfs
09506000 = 394 + 28 + 72 = 494cfs

This completes Method 2.`

According to a discussion of irrigation practices noted by a Salt River Valley based joint Canal Committee when its members visited the Verde Valley in 1901 (Turney, O. A., 1901, Water Supply and Irrigation on the Verde River and Tributaries, Cleveland Daily Record, 20p.) ,the Canal Committee inspected and measured the flow in the Verde River and the numerous canals along the Verde River, Beaver Creek, Clear Creek and Oak Creek. They were critical of what they called over-watering irrigation practices. For example, for a group of canals they found that a total of 4611 miner’s inches (115 cfs) was delivered to a total of 4399 acres (their measurements of July 1901). This was equivalent to 18.6 ft of water per acre of cultivated land for a 9 month irrigation period. The Committee also noted that some cultivated land in the upper watershed went unnoticed because (1) they were not visited during early assessment of irrigated lands and (2) they were not “surveyed” to escape taxation. Water was used continuously by some settlers with only a squatter's title.

The following newspaper article (July 1900) describes the concern of water users in the Phoenix area downstream over the irrigation practices in the Verde Valley. The strong language clearly shows the concern over the large amount of water diverted from the Verde River where most of the diverted water apparently does not return to the river. Note: This was before deep well pumping of the basin fill aquifers.

STOP THE WATER STEALING.

The Verde is the most important affluent of the Salt river. The two rivers unite at a point but a short distance above the dams and headgates of the canal systems of the valley. Any diminution of the flow of the Verde river is, therefore, a matter of profound importance to the canal companies and the water consumers of this valley. The normal flow of the Verde river at the point where it empties into the Salt has been steadily decreasing for some time, and for the past year or two the lessened flow has been so marked that every canal and every farm in the valley has suffered from a shortened supply of irrigation water. There is no mystery attaching to this condition of affairs. No forest sharps nor other experts are required to explain the situation. The simple fact is that the waters of the Verde river in its upper reaches, in Yavapai county, are unlawfully diverted by ranchers in such volume that it is not difficult to foresee that soon the total normal flow of the river will be diverted by the mountain farmers.

The strange feature of the situation, as forcibly stated by Major Evans in Yesterday's Republican, is that the canal companies and the water consumers of this valley should tolerate this state of affairs for a day. There can be no question as to the rightful ownership of the waters of the Verde river. They belong to the water appropriators of the Salt River valley, and the diversion

the Salt River valley, and the diversion

of a single gallon through the newer ditches in the mountain valleys is without a shadow of law or right. An injunction would lie against these wrongful users of the waters of the upper Verde beyond question.

About the only excuse The Republican has heard so far for non-action on the part of the Salt River valley is the "seepage theory"——that is to say, the theory that when the waters of a river are diverted to the irrigation of lands which drain to the river channel, the greater portion of the water so diverted passes back into the channel more or less farther down stream after having performed its duty of irrigation and the flourishing Buckeye country southwest of Phoenix is cited as an instance in point. The proportion of irrigating water which flows back into the parent stream eventually cannot be known with exactness. But the experts of the geological survey after a series of tests in Arizona reported it as their opinion that the returned water does not in any case exceed 60 per cent of the volume diverted. It is self evident that not 60 per cent of the waters of the Verde reapear in that stream between its mouth and the newly irrigated area in the upper reaches. At best the maximum return from seepage does not appear until after a series of years of full irrigation, and under the most favorable conditions this valley will continue to lose enormously from this unlawful diversion. Major Evans' warning should be heeded without delay.

Arizona republican. (Phoenix, Ariz.) 1890-1930, July 19, 1900, Page 2, Image 2

Image provided by Arizona State Library, Archives and Public Records; Phoenix, AZ

Persistent link: http://chroniclingamerica.loc.gov/lccn/sn84020558/1900-07-19/ed-1/seq-2/

A recent USGS study (Garner and others, 2013) that modeled the Verde Valley aquifer (during 1910-2005) showed that base flow at the upstream end of the study area (USGS Clarkdale gage), as of 2005, was about 4,900 acre-feet per year (7 cfs) less than it would have been in the absence of human stresses. This loss was from deep well dewatering of the Little Chino aquifer and did not include diversions from mountain front springs and seeps (Base Qmf on Figure 3) and Quaternary aquifers. At the downstream end of the Verde Valley, base flow had been reduced by about 10,000 acre-feet per year (13 cfs) by the year 2005 because of human stresses (mostly deep well pumping) in the Verde Valley.

Garner, B.D., Pool, D.R., Tillman, F.D., and Forbes, B.T., 2013, Human effects on the hydrologic system of the Verde Valley, central Arizona, 1910–2005 and 2005–2110, using a regional groundwater flow model: U.S. Geological Survey Scientific Investigations Report 2013–5029, 47 p.

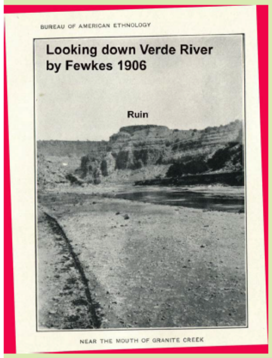
Method 3

Method 3 uses conveyance-slope estimates of historic base runoff using Federal Land Survey data.

Estimates of base flow in Verde River at east side of section 12, T17N R2W on May 1909 and at boundary between sections 1 and 12, T17N R1W also during May 1909 using width and depth of Federal Land Surveys.

Computation of total base runoff

METHOD 3



Photograph to the left is by Fewkes (1906) looking downstream from left side of channel at location 3,000 ft upstream from east side of section 12, T17N R2W where Federal Surveyors measured width and depth of flow in the Verde River. Federal Surveyors also measured both the width and depth of flow at a second site about 6 miles downstream between sections 1 and 12 T17N R1W.

Fewkes, Jesse W., 1912, Antiquities of the Upper Verde River and Walnut Creek Valleys, Arizona: Bureau of American Ethnology, 28th Annual Report, 1906-07, p. 185-220.

Records of streamflow at the USGS Paulden gage located a few miles downstream shows there is perennial base flow in the Upper Verde River. The flow in the previous scene appears to be base flow (unlikely base runoff because of irrigation diversions along Granite Ck, Walnut Ck, Williamson Valley Wash and other tributaries) because of the smooth water surface. The Federal Survey was made 3 years later during May 1909. May is typically a dry month. Also, there was no mention of rainy weather in the records of the Federal Land Survey. Therefore, the flow at the time of the Federal survey was probably base flow.

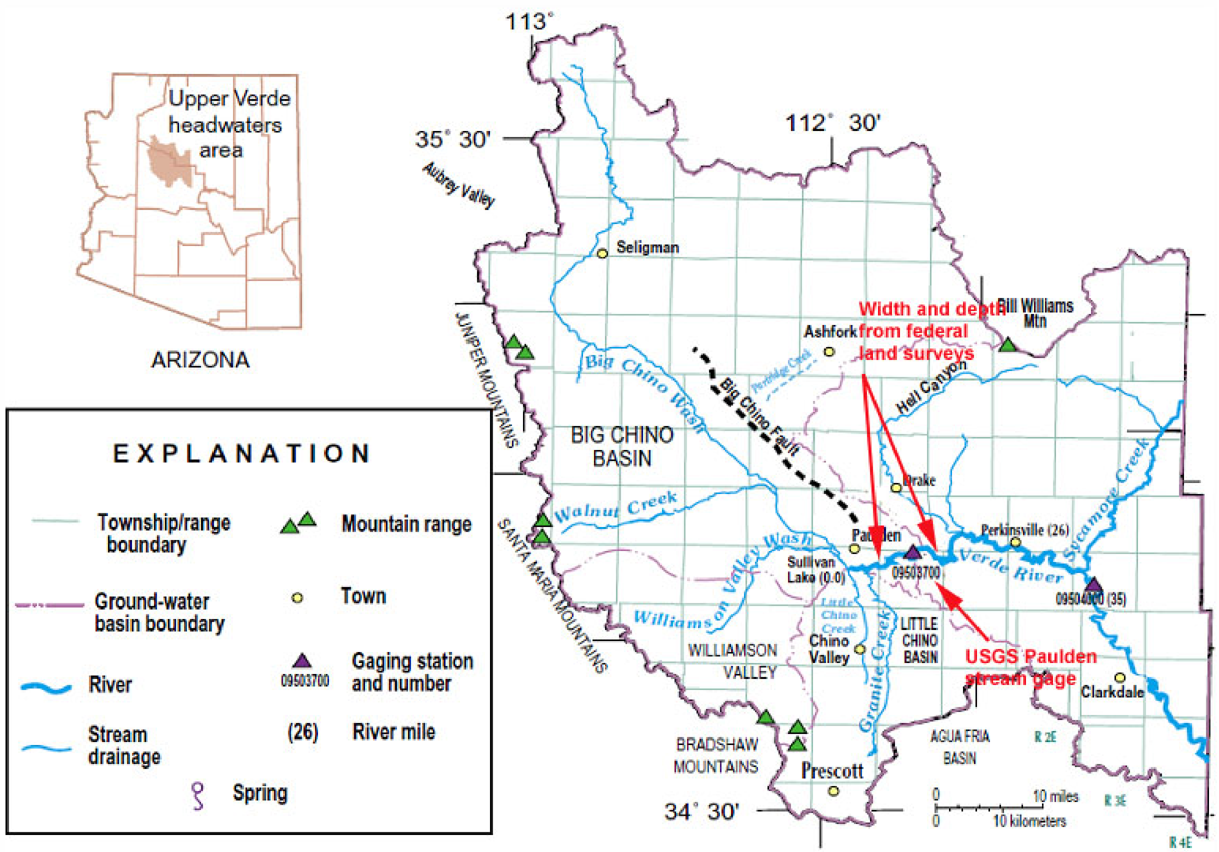


Figure 4.— Major geographical features of the upper Verde River headwaters area showing two sites where channel width and depth were measured by Federal Surveyors.

Wirt, Laurie, and Hjalmarson, H.W., 2000, Sources of springs supplying base flow to the Verde River headwaters, Yavapai County, Arizona: U.S. Geological Survey Open-File Report 99–0378, 50 p.

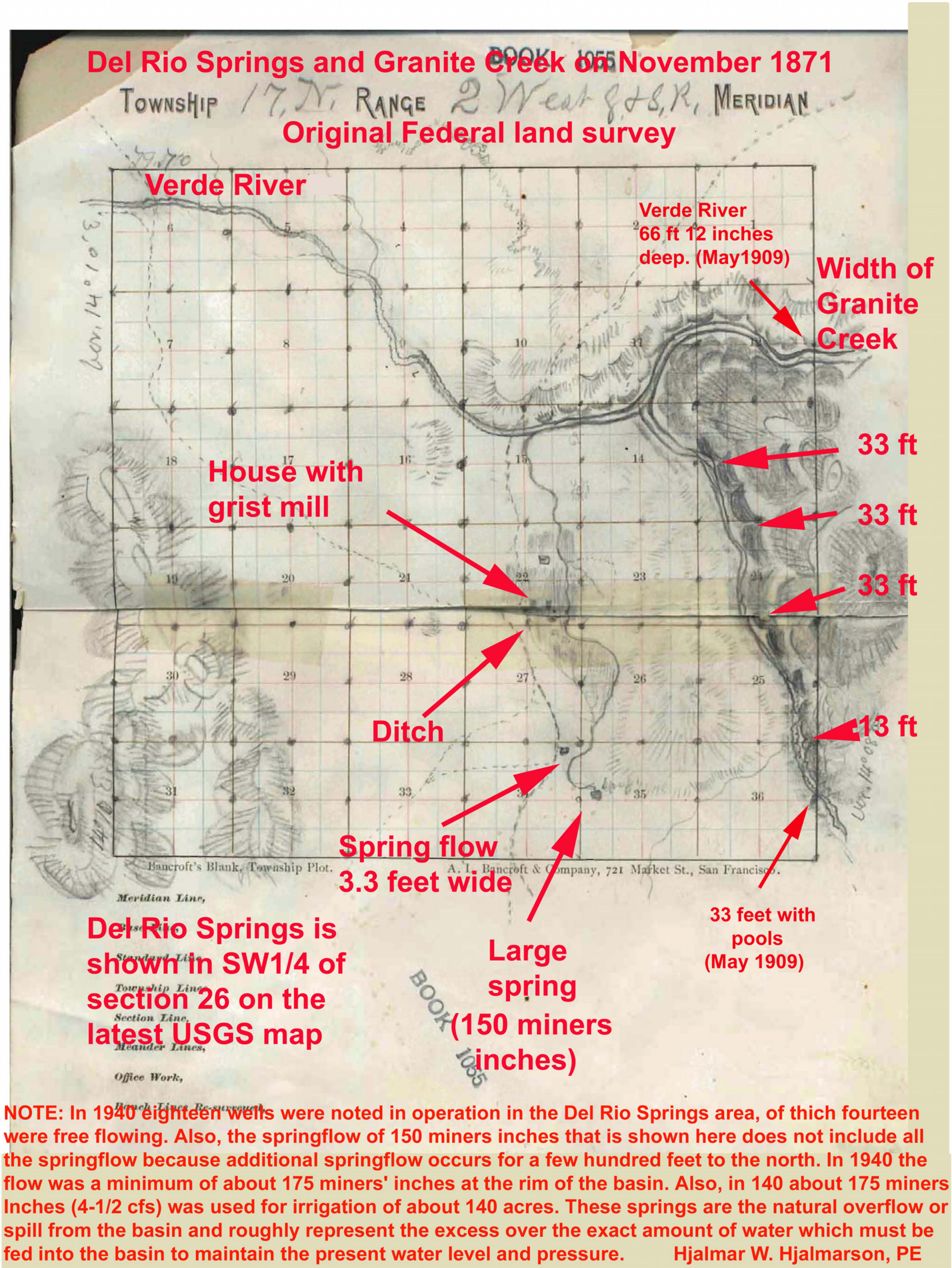


Figure 5.—Site where Federal Surveyors measured width and depth of base flow.

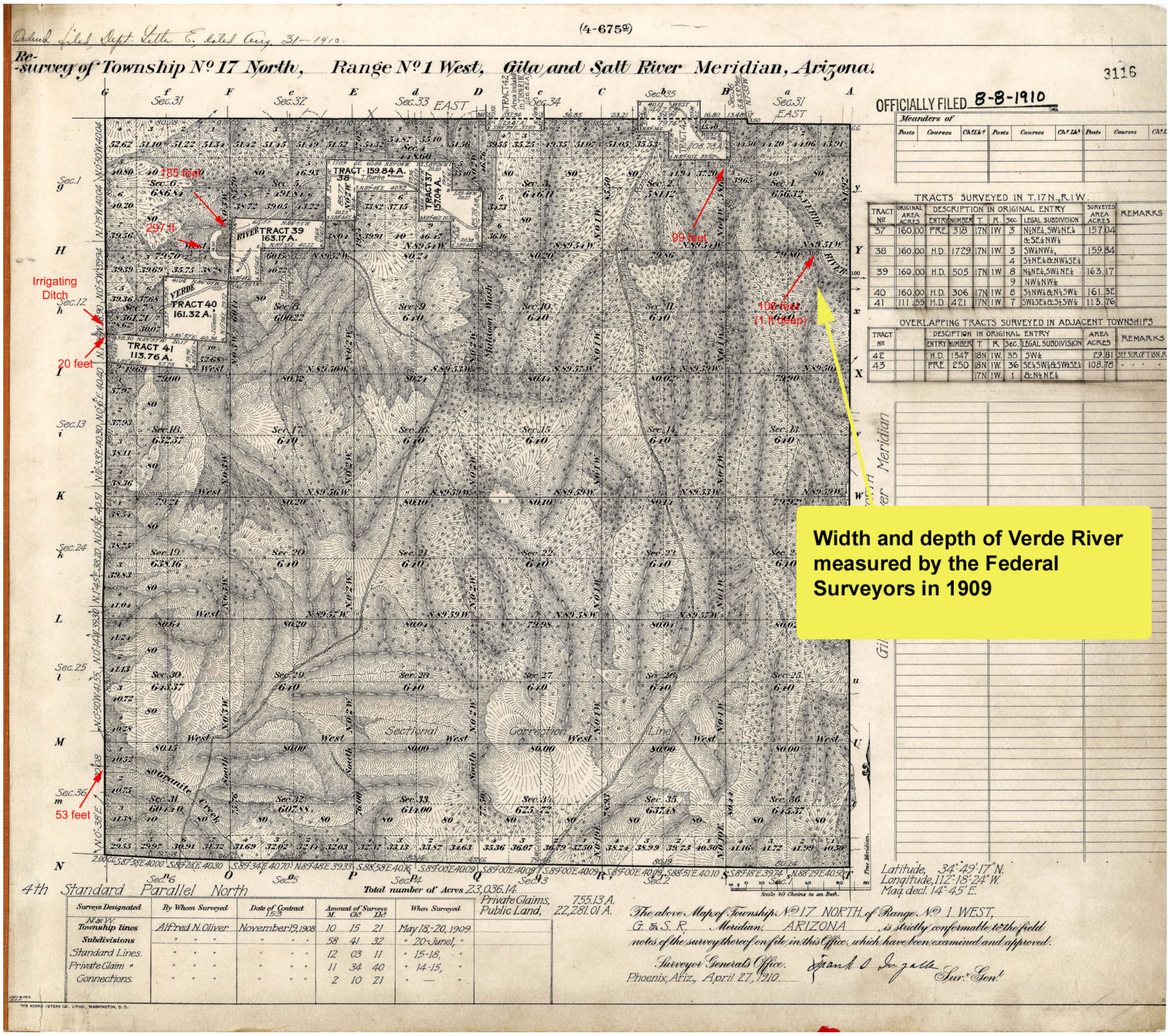


Figure 6.—Site where Federal Surveyors measured width and depth of base flow.

The surveyors, in May 1909, measured channel widths of 66 ft and 108 ft along the boundary lines at the two sites and they observed that flow was perpendicular, or nearly so, to the boundary lines. A depth of 12 inches (1 ft) was also measured at both sites but the surveyors did not identify the channel shape. Also, it is unknown if the measurement was of maximum, average or typical depth. Even with this missing information at attempt is made to utilize this information. Thus, computations of discharge are made for feasible depths and shapes.

Monthly statistics for 09510000 for early years

Mean monthly discharge for May 1909 when Federal survey of T17N R1W was made = 199.9 cfs.

This amount of May discharge is 42% of the mean monthly discharge for the early years at Verde River near the mouth.

00060, Discharge, cubic feet per second,

YEAR	Monthly mean in ft3/s (Calculation Period: 1904-01-01 -> 1924-01-31) Period-of-record for statistical calculation restricted by user											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1904	236.8	226.3	184.0	118.5	126.3	62.9	729.1	1,625	481.6	188.1	209.6	240.9
1905	1,420	7,713	8,781	5,226	832.5	282.6	245.4	566.8	771.3	543.5	3,433	875.1
1906	811.8	1,202	5,468	1,029	246.9	149.9	233.8	742.9	210.8	181.3	312.0	2,641
1907	2,429	2,619	3,767	838.1	251.3	208.9	217.2	430.3	403.9	614.3	375.2	323.4
1908	306.5	1,973	1,395	301.[illegible]	443.3	[illegible]45.6	462.5	879.9	356.4	264.7	281.5	3,129
1909	1,760	1,459	2,029	1,2[illegible]8	199.9	1[illegible]6.2	379.0	1,255	475.2	160.2	221.1	354.2
1913										204.4	338.5	306.5
1914	956.7	3,045	716.5	251.5	153.9	113.6	204.0	234.4	229.8	326.9	269.7	652.1
1915	1,242	2,447	3,591	2,180	2,663	206.9	326.8	348.6	231.1	177.4	248.5	392.7
1916	8,231	3,766	5,184	696.0	231.5	158.9	201.0	507.5	1,296	725.8	326.8	340.5
1917	1,222	1,495	1,759	6,002	1,253	234.4	417.0	726.5	388.5	247.0	243.1	265.9
1918	393.9	904.5	4,613	355.2	159.8	137.3	191.1	544.5	190.3	193.4	345.8	457.8
1919	345.4	953.0	1,560	1,333	173.1	118.4	2,126	905.7	471.1	741.4	2,850	2,230
1920	2,235	8,956	1,883	1,041	305.5	208.5	179.7	455.5	227.7	240.8	463.1	341.8
1921	315.3	334.7	522.4	235.6	167.4	125.9	296.5	1,695	367.3	442.2	287.9	1,437
1922	2,594	2,749	3,279	1,070	256.5	162.8	208.5	332.7	239.9	184.7	282.7	1,229
1923	347.3	1,222	2,207	793.6	193.2	115.9	198.7	254.1	1,929	269.7	967.5	3,500
1924	993.8											
Mean of monthly Discharge	1,520	2,570	2,930	1,4[illegible]0	479	[illegible]60	414	719	517	336	674	1,100

** Incomplete data have been used for statistical calculation

The Manning equation for open channel is used to estimate discharge in the Verde River. The equation is:

$$Q = VA = \left(\frac{\xi}{n}\right) AR^{\frac{2}{3}} \sqrt{S}$$

Where:

Q = Flow rate through culvert [ft^3/s or $m^3/2$]

V = Average velocity in the culvert barrel [ft/s or m/s]

ξ = Constant, 1.49 for U.S. and 1.0 for SI

n = Manning's Roughness Coefficient

A = Cross sectional area of the flow [ft^2 or m^2]

R = Hydraulic Radius [ft or m]

S = Channel Slope [ft/ft or m/m]

Twelve computations are made where

(1)the cross section is defined by a common parabola shape with a maximum depth = 1 ft,

(2)the depth is the maximum of 1 ft and the cross section shape is a V, and

(3)the channel has a rectangular shape with a mean depth of 1 ft. This shape is unlikely and the computation represents an upper limit for base flow.

Channel slope and Manning n for a USGS verification of Manning n at the USGS Paulden gage were used for the three shapes at each site. Average channel slope for the channel with the maximum likely Manning n value were also used in a like manner. The computations are shown in the following table:

Row	See below	Shape	W	meanD	s	n	Q
1	a, c	parabola	66	0.67	0.0040	0.050	63.558
2	a, c	V	66	0.50	0.0040	0.050	38.985
3	a, c	rectangle	66	1.00	0.0040	0.050	124.057
4	b, d	parabola	66	0.67	0.0008	0.029	49.007
5	b, d	V	66	0.50	0.0008	0.029	30.060
6	b, d	rectangle	66	1.00	0.0008	0.029	95.655
7	a, c	parabola	108	0.67	0.0040	0.050	104.003
8	a, c	V	108	0.50	0.0040	0.050	63.794
9	a, c	rectangle	108	1.00	0.0040	0.050	203.003
10	b, d	parabola	108	0.67	0.0008	0.029	80.193
11	b, d	V	108	0.50	0.0008	0.029	49.189
12	b, d	rectangle	108	1.00	0.0008	0.029	156.527

a Average slope of channel
b Slope from n-verification measurementat USGS Paulden gage
c Maximum estimated Manning roughness coef.
d Verified Manning roughness coef at usgs Paulden gage.

The base flows for the most likely general shapes are shown below. It is assumed the measured depth by Federal Land Surveyors was not the mean channel depth.

Estimated base flow, in cfs, using channel conveyance-slope method for measured width and depth from 1909 Federal Land Survey

	Cross section shape	
	Parabola	V
	63	40
	49	30
	104	64
	80	49
Mean	74	46

Avg. = 60 cfs

The following are the notes of the 1909 survey. Distances are in number of chains (1 chain = 66 ft) and links (1 link = .66 ft). (80 chains = 1 mile).

Computation of total base runoff

METHOD 3

	North bet. secs. 7 and 12
	Over top of mountain covered with loose boulders.
4.25	Descend into canyon.
18.00	Cross Verde river , running water 12 ins. deep, 100 lks. wide course E. and ascend steep S. slope
35.60	Over rolling top of mountain covered with loose rocks through cedar timber and underbrush.
38.89	Fall 75 lks. E. of ¼ sec. cor. which I reset as follows, set a malpais stone 22 x 16 x 6.ins. 16 ins. in the ground for ¼ sec. cor. marked 09¼ on N. face; from which A cedar 6 ins. diam, bears. N. 40° E. 60 lks. dist. marked 09¼S7BT. A cedar 20 ins. diam., bears S. 65° W. 17 lks. dist. marked 09¼S12BT.

West boundary of Tp. 17 N. Rg. 1 W.

Chains	
	Course of this half mile is N. 1° 06' W. 38.90 chs. Thence from ¼ sec. cor. North
60.65	Cross fence bears E. and W. and leave timber and brush.
78.84	Fall 6 lks. E. of cor. of secs. 1, 6, 7 and 12, which I reestablish as follows; set a malpais 20 x 8 x8 ins.. 15 ins. in the ground for cor. of secs. 1, 6, 7, and 12 marked 09 on N. E. face; with 5 notches on S. and 1 notch on N. edges; and raise a mound of stone 2 ft. base 1 1/2 ft. high W. of cor. Pits impracticable. Course of this half mile is N. 0° 05' W. 39.94 chs. Land, mountainous. Soil, rocky; 4th. rate. Timber cedar. Underbrush, cedar. Mountainous land covered with loose rocks, and heavily timbered and covered with dense underbrush, exceptionally difficult to survey 78.84 chs.

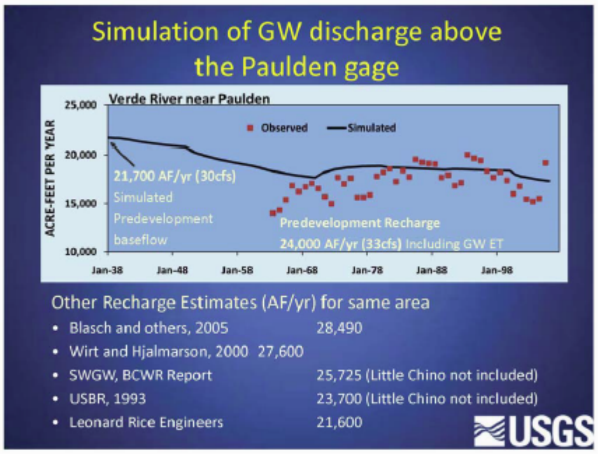
24,80	Cross wash 20 lks. wide course N. W.
30.00	Ridge bears E. and W. and descend.
37.00	Cross wash lo lks. wide course N. W. and ascend.
40.00	Set a limestone 24 x 8 x 8 ins. 18 ins. in the ground for ¼ sec. cor., marked 09¼ on W. face; from which
	A pinon 6 ins. diam., bears S. 45° E. 34 lks. dist., marked 09¼S12BT .
	A pinon 10 ins. diam., bears N. 41° W. 36 lks. dist., marked 09¼S11BT.
41.50	Ridge bears N. E. and S.W. and descend
53.00	Along W. slope, descending.
60.60	Cross wash 10 lks. wide course N. W. and ascend S. W. slope.
70.00	Ridge bears E. and W. and descend steep N. W. slope.
78.00	Cross wash 35 lks. wide course N. E. and ascend along SE slope.
80.00	Set a limestone 18 x 9 x 5 ins. 12 ins. in the ground for cor. of secs. 1, 2, 11 and 12, marked c9 on N. E. face; with 5 notches on S. and 1 notch on E. edges; from which.
	A cedar 4 ins. diam., bears S. 68° W. 165 lks. dist., marked 09T17NR1WS11BT.
	A cedar 4 ins. diam., bears N. 45° W. 90 lks. dist. marked 09T17NR1WS2BT.
	No other trees available. Raise a mound of stone 2 ft. base 1½ ft. high W. of cor. Pits impracticable.
	Land, rough and mountainous.
	Soil, rocky; 4th. rate.
	Timber, cedar.
	Underbrush, cedar.
	Mountainous land covered with loose rock heavily timbered and covered with dense undergrowth 80,00 chs.
	May 23: At this cor. I set off 20° 34½' N. on the decl. arc; and observe the sun on the meridian at noon; the resulting lat. is 34° 53½' N.

	S. 89° 50' E. on a random line bet. secs. 1 and 12
40.00	Set temp. ¼ sec. cor.
79.80	Intersect E, bdy. of Tp. 2 lks. S. of the cor. of secs. 1, 6, 7 and 12.
	Thence I run
	N. 89° 51' W. on a true line bet. secs. 1 and 12.
	Descending rough broken S W. slope covered with loose rocks.
18.50	E. bank of Verde River, running water 1 ft. deep, course S.
20.10	W. bank of Verde River, and ascend precipitous E. slope
25.40	Enter heavy timber and underbrush and along on top ridge bears N. W. and S. E.
39.90	Set a limestone 18 x 10 x 10 ins. 12 ins. in the ground for ¼ sec. cor., marked 09¼ on N. face; from which
	A cedar 5 ins. diam., bears S. 50° E. 5 lks. dist. marked 09¼S13BT.
	A pinon 7 ins. diam., bears N. 45° W. 37 lks. dist. marked 09¼S1BT.
54.00	Descend S. W. slope.
63.00	Leave timber and brush.
70.40	Cross wash 75.lks. wide course N. W. and ascend.
73.40	Ridge bears N. and S. and descend.
75.10	Cross wash 35 lks. wide course N. ascend.
79.80	The cor. of secs. 1, 2, 11 and 12.
	Land, mountainous and rough.
	Soil, rocky; 4th. rate.
	Timber, cedar and pinon.

Computation of total base runoff

METHOD 3

The conveyance-slope estimates strongly suggest that the base flow of the Verde River in 1909 was considerably greater than the simulated flow of the USGS (Pool and others, 2011) as shown below.



Pool, D.R., Blasch, K.W., Callegary, J.B., Leake, S.A., and Graser, L.F., 2011, Regional groundwater-flow model of the Redwall-Muav, Coconino, and alluvial basin aquifer systems of northern and central Arizona: U.S. Geological Survey Scientific Investigations Report 2010-5180, 101 p.

Computation of total base runoff

METHOD 3

The following is previously mentioned information for the verification of Manning n at the Verde River near Paulden

Verde River near Paulden

Reach location: Latitude 34°53'40", longitude 112°20'32". Reach begins about 80 ft below streamflow-gaging station 09503700, Verde River near Paulden (Aldridge and Garrett, 1973).

Drainage area: 2,530 mi^2.

Bed-material size: See *channel description.*

Channel description: The low-flow channel is 40 to 50 ft wide and has irregular, vertical banks about 2 ft high. The bed of the low-flow channel is composed of compacted sand, cobbles, and scattered boulders as much as 2 ft (610 mm) in diameter. Above this channel are grass-covered benches. The right bench is narrow and bare except for a growth of very short grass; the bank slopes steeply above the bench. The slope of the left bank is gentle. The reach expands slightly throughout its length. The river is perennial, and flow is unregulated.

Remarks: H.W. Hjalmarson (hydrologist, U.S. Geological Survey, written commun., 1965) stated:

"The computed n value seems lower than would be indicated by the size of the bed material, but most of the rocks were immersed in a smooth flow of water and caused very little turbulence. The top of the surge was marked throughout the reach before and after the current-meter measurement."

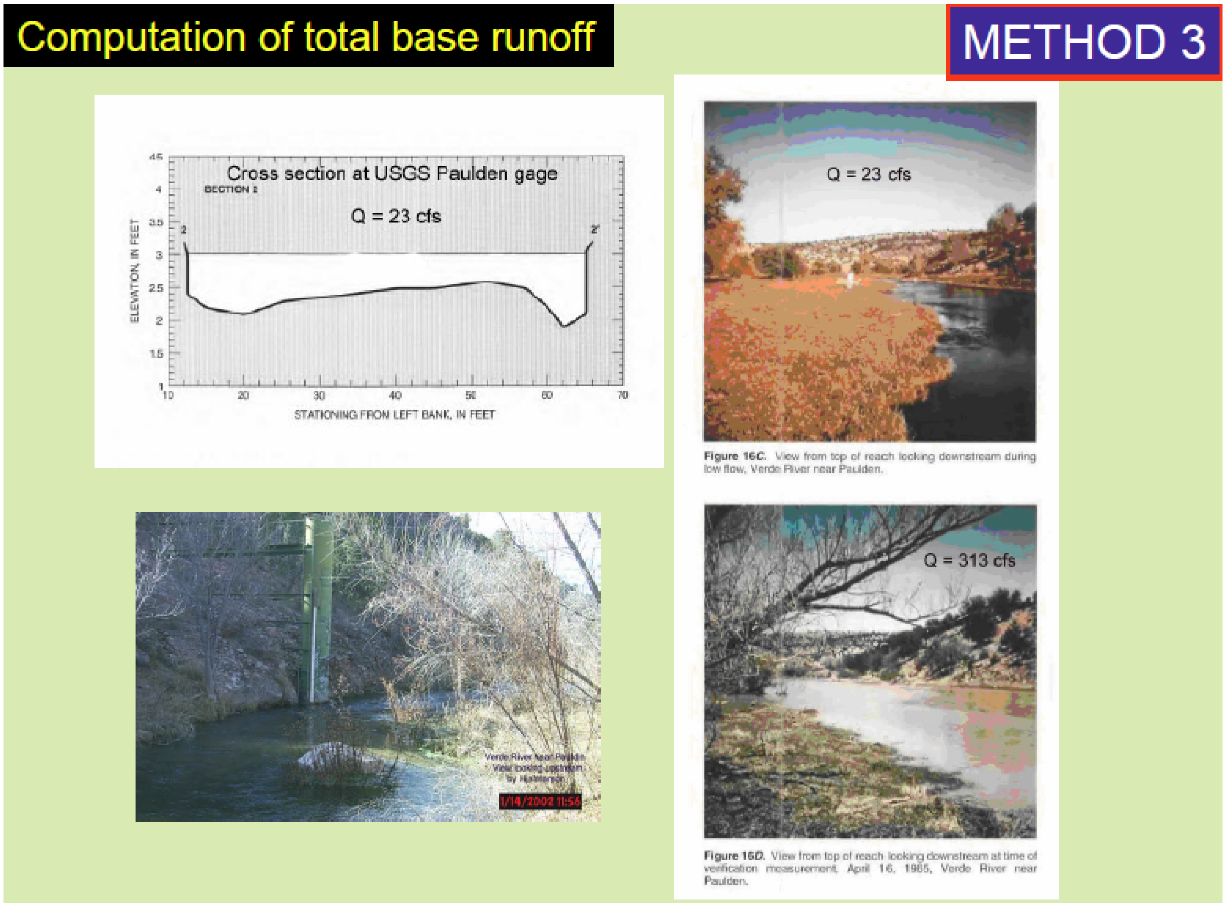
Table 25. Flow data and computed roughness coefficient, Verde River near Paulden

Date of flow	Discharge, in cubic feet per second	Roughness coefficient	Rating
04-16-65	313	0.039	Fair

Table 26. Average-reach properties, Verde River near Paulden

Date	Area, in square feet	Top width, in feet	Hydraulic radius, in feet	Mean velocity, in feet per second	Froude number	Total length, in feet	Total fall, in feet	Water-surface slope
04-16-65	139	68.3	2.19	2.19	0.27	333	0.26	0.0008

Phillips, Jeff V. and Ingersoll, Todd, 1962, Verification of roughness coefficients for selected natural and constructed stream channels in Arizona: U.S. Geological Survey professional paper 1584, 78p.



Discussion and summary of natural hydrology

Three independent estimates were made using published USBR information on virgin flow at the mouth of the Verde River, cultivated land shown on Federal Land Survey plats and field notes, typically of the 1870s, and the measured channel width and depth for base flow made by the Federal Land Surveyors. These estimates suggest the natural and ordinary base runoff at the Verde River near Paulden gage was about 50-60 cfs or more than double the present base flow that is in the low to mid twenties. Obviously this is considerably more than the 7 cfs change in base flow from basin-fill aquifer depletion using deep wells (See Items 4 and 7 Appendix A).

The results of the three independent methods of estimating that amount of Q90,Q50 (median) and the mean annual base runoff follow:

Natural Q90 base runoff (cfs)

Method	09503700	09504000
1	**54**	**111**
2	*	*
3	*	*
Used	**54**	**111**

Natural **median** (Q50) base runoff (cfs)

Method	09503700	09504000	09506000
1	**60**	**117**	
2	**58**	**114**	**277**
3	74 & 46		
Mean	60	116	277
Used	**60**	**116**	

Natural (virgin) **mean** annual base runoff (cfs)

Method	09503700	09504000	09506000	09510000
1	**83**	**215**		
2	**76**	**207**	**494**	
USBR				751
Mean	80	211	494	
Used	**80**	**211**		

Method 1 required considerable effort as it used cultivated land and hydrologic information of the original Federal Land Surveys. All of the survey plats and associated field notes were painstakingly examined. This method is considered the most accurate/precise of the three methods.

In addition,1940 aerial photography was also used to estimate the acres of cultivated land irrigated by direct diversion and shallow wells along Big Chino Creek. This method which was used for the Big Chino Creek required some judgment when separating areas watered by human activity from areas watered naturally at cienagas. The estimated natural loss to ET along the perennial/intermittent tributary stream channels also required judgment. See Items 2 and 3 of Appendix A for computation of the unit loss to ET along the channels.

Also, water use was estimated only for irrigation while other uses like livestock (stock tanks), railroad (Ashfork and Seligman Dams and RR tank cars at Del Rio Springs), domestic (Del Rio Springs pipeline to Prescott), etc. were ignored. Obviously, the estimated amount of water use by humans is conservatively low.

Method 2 is rather simple as it distributed human affects (losses to ET) computed using the difference between mean annual flow for virgin condition (USBR, 1952) and for the record at the USGS gage 09510000. This difference was simply distributed between the Chino Valley area and Verde Valley area using the relative amount of irrigated acres given for each of the two areas in the Hayden (1940) Report.

Method 3, the conveyance-slope estimate using Federal Surveyor measurements, obviously is a rough estimate of the median natural flow. The two computations are useful samples that strongly suggest the base flow in 1909, before Watson Lake Dam and deep wells in the basin fill aquifers, was considerably greater than the gaged base flow at the USGS Paulden gage.

Nearly 30 channel widths were surveyed along the upper Verde River by the Federal surveyors. These widths were considerably greater than more recently measured widths as is discussed in the following section on hydraulics.

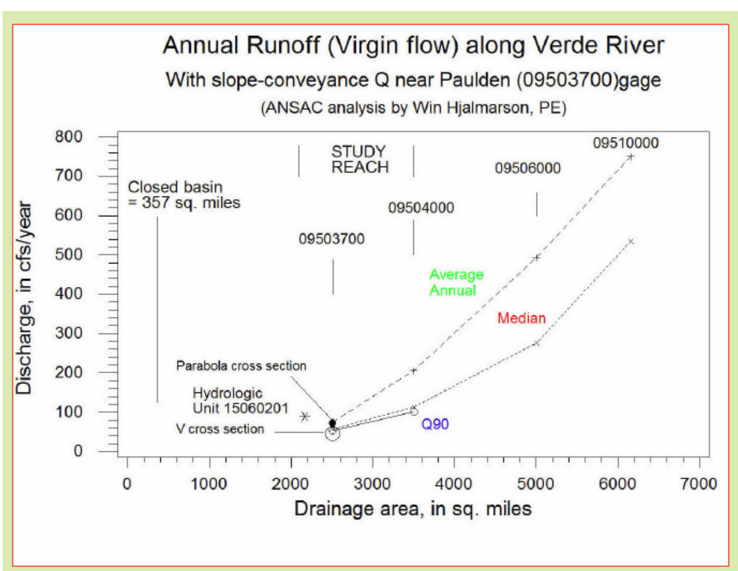


Figure 7.—Average annual, median and Q90 streamflow along Verde River.

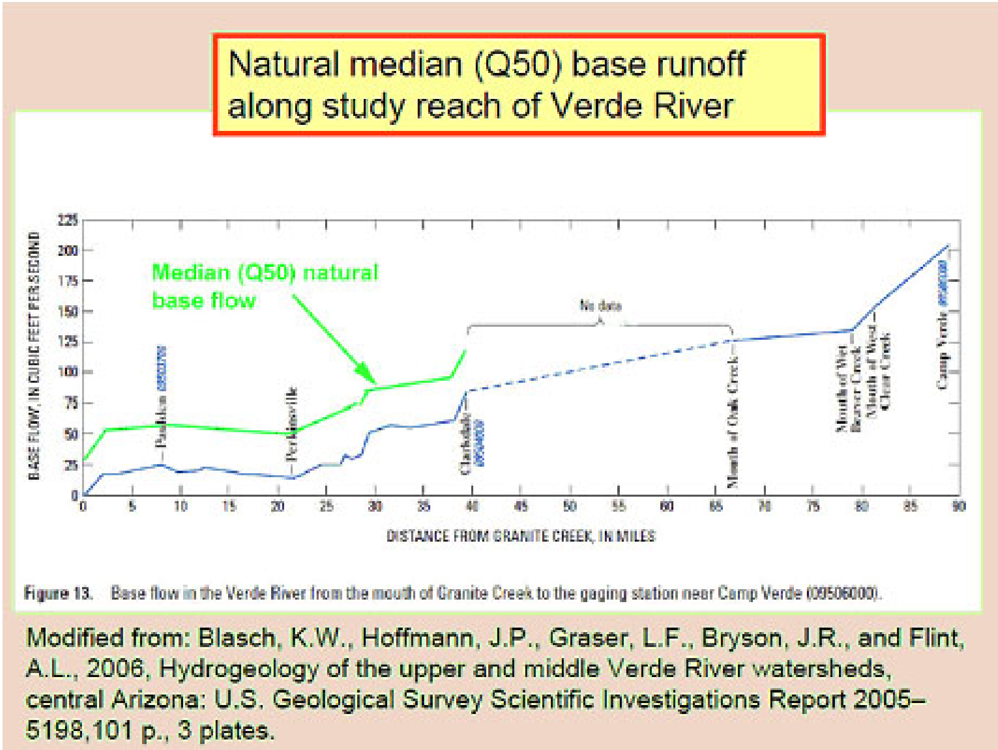


Figure 8.—Median natural base flow and recent base flow from mouth of Granite Creek to USGS gage near Clarkdale.

The close agreement of the three computations of median natural runoff (base runoff at gages 09503700 and 09504000 is remarkable. The close agreement of the two computations of the natural mean annual flow is also remarkable.

Station	Q90 cfs	Median (Q50) cfs	Mean annual cfs
95037000	54	60	80
09504000	111	116	211

This completes the Hydrology

HYDRAULICS AND CHANNEL GEOMETRY

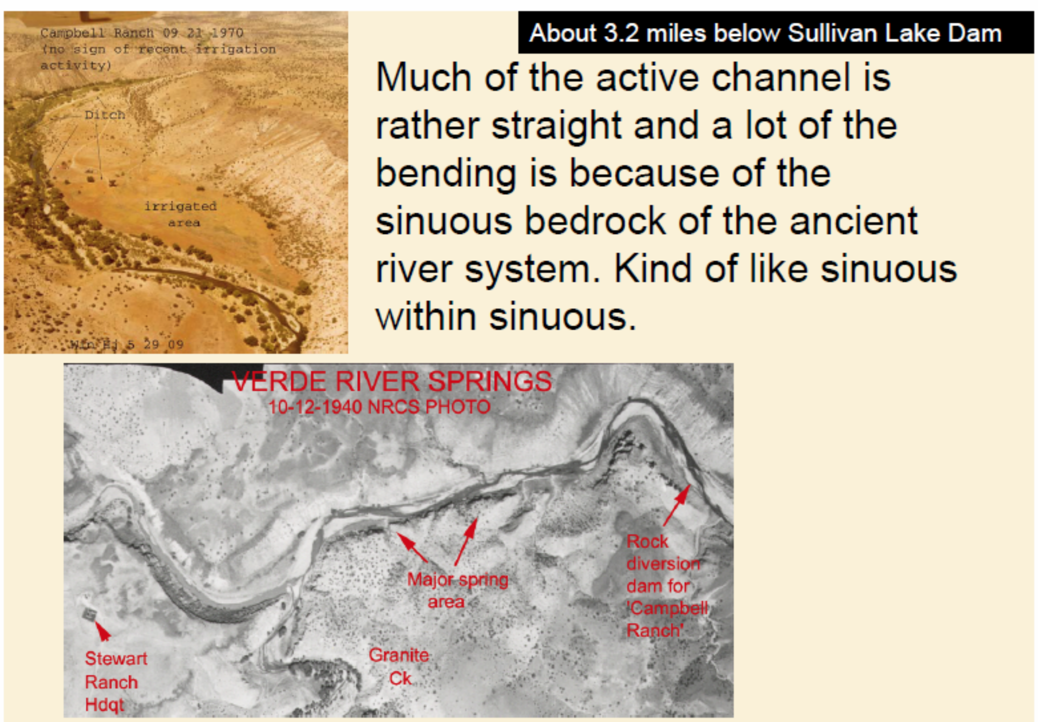
A simple way to think of the Upper Verde River is as an active sinuous river that resides in recent sediments (sand, gravel, cobbles) and boulder rock that reside in an old sinuous "canyon." Kind of like sinuous within sinuous. Much of the active channel is rather straight and some of the bending is because of the sinuous bedrock of the ancient river system. I'm “old-school” and to me, meandering doesn't really start until sinuosity value is more than about 1.5. Sinuosity of the active Verde typically is less than 1.5.

As we learned in the previous section of the report, the natural and ordinary base runoff at the upper end of the study reach was more than double the present base flow. Because the change in the base flow might have resulted in a change in channel geometry, possible temporal changes of channel geometry and hydraulic factors were examined.

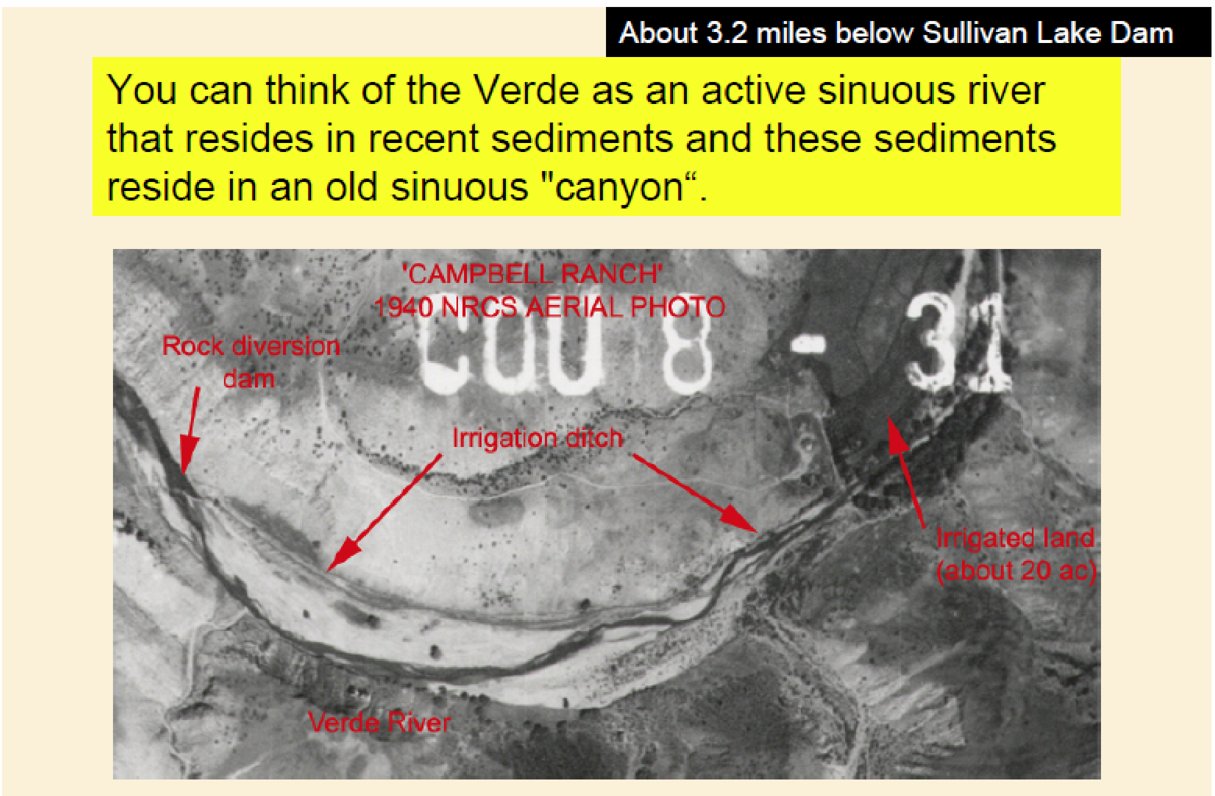
This section is in five parts:

1. General description
2. Federal Land Surveys
3. Recent channel geometry with several photos, channel cross sections, and current meter measurements.
4. Energy and morphology considerations
5. A summary with comparison of recent and natural channel condition.

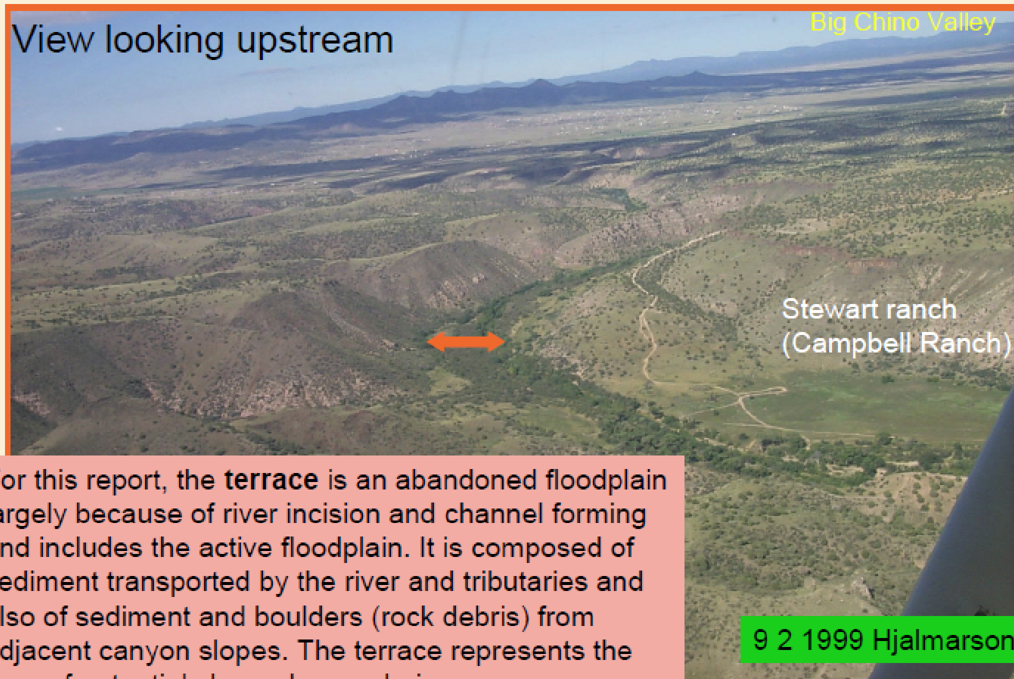
1.-- General description



The old irrigation ditch and the site of the rock diversion shown in the previous photographs, and also in the following aerial photograph, is along the left side of the Verde River upstream of the old Stewart Ranch (Campbell Ranch). There are remnants of this old ditch that was last used in about the 1960s when I was performing field work in the area for the USGS. The ditch and the site of the point of diversion that is some distance upstream of the irrigated land of the Stewart Ranch were examined by my friend and author Dick Tinlin (PhD U. Arizona, Hydrology) in about 1995. There was no evidence of channel change along the reach and the elevation of the channel bed appeared about the same since the ditch was constructed in the late 1800s.

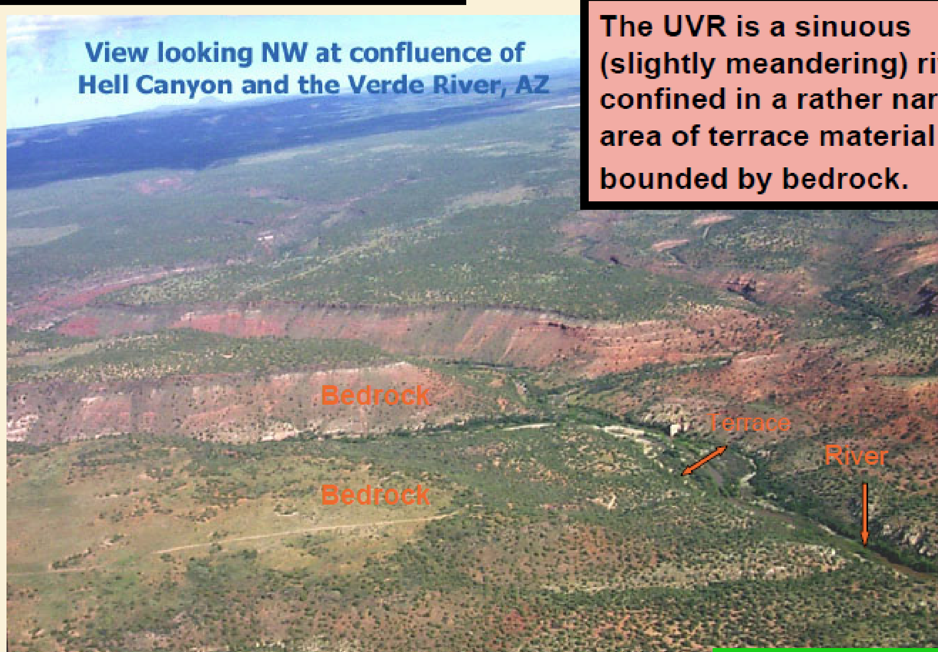


About 3.2 miles below Sullivan Lake Dam



For this report, the **terrace** is an abandoned floodplain largely because of river incision and channel forming and includes the active floodplain. It is composed of sediment transported by the river and tributaries and also of sediment and boulders (rock debris) from adjacent canyon slopes. The terrace represents the area of potential channel meandering.

About 18 miles below Sullivan Lake Dam



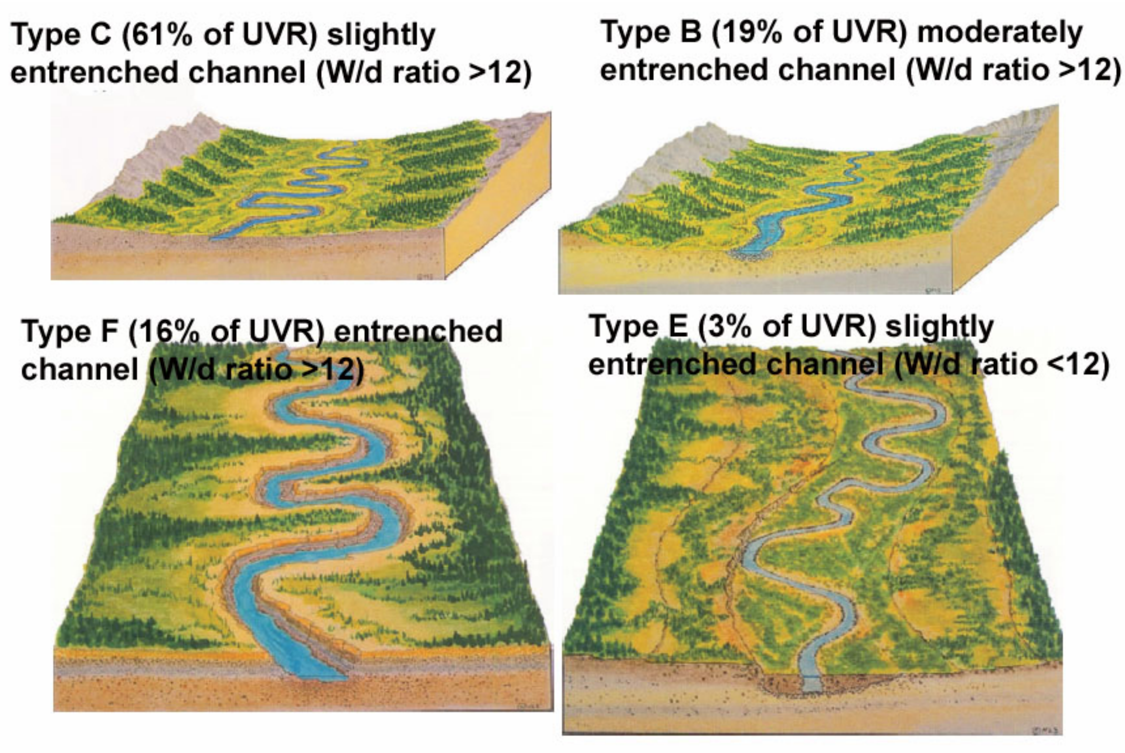
The UVR is a sinuous (slightly meandering) river confined in a rather narrow area of terrace material bounded by bedrock.

The USFS has identified and classed distinctive attributes of the Upper Verde River using the Rosgen method. The Rosgen method, while rather general, is used by several Federal agencies as a uniform classification of rivers. Some prominent physical characteristics of the river are useful for assessment of navigability.

Neary, Daniel G.; Medina, Alvin L.; Rinne, John N., eds. 2012. **Synthesis of Upper Verde River research and monitoring 1993-2008.** Gen. Tech. Rep. RMRSGTR-291. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 296 p.

Some of the river terrace sediments have been described as deposited by paleofloods. Some reaches are narrowly confined by relatively young basalt flows. Some reaches are relatively linear due to the bedrock confinement of the river, but others contain meanders that have formed within geologically recent river alluvium. Because of the confinement by bedrock, the channel/terrace of Upper Verde River can be characterized as moderately to highly confined, rather low gradient, and low relief.

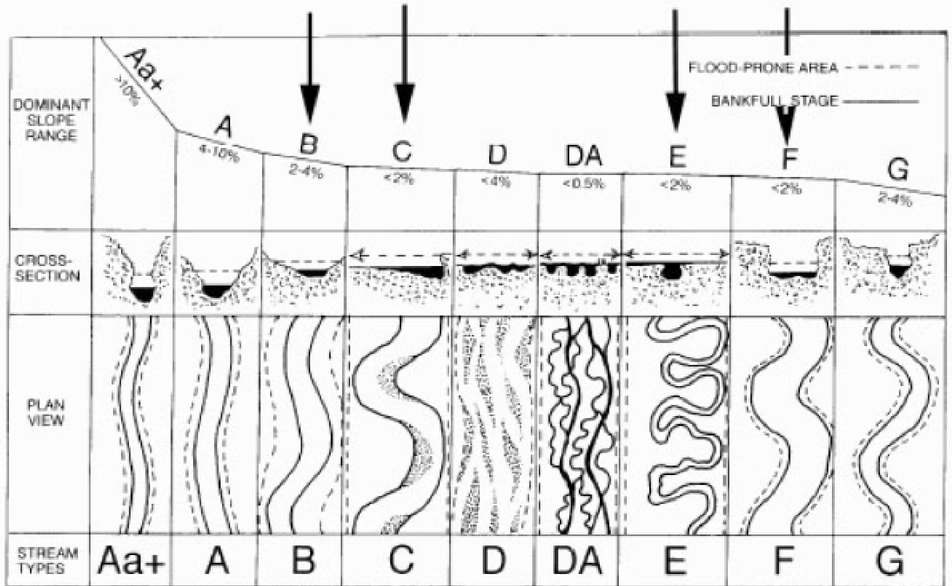
The meandering and channel characteristics are shown on diagrams in the next two figures.



Where W/d is the width/depth ratio.

USFS Report

Percent of study reach with indicated type of channel



Rosgen stream classification used by USFS

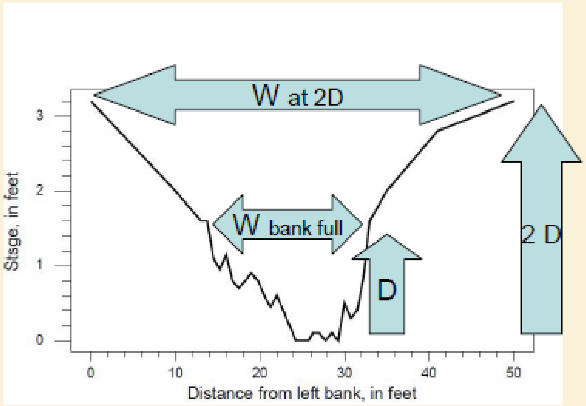
USFS Report

Bankfull: This stream stage is delineated by the elevation of incipient flooding, indicated by deposits of sand or silt at the active scour mark, break in streambank slope, perennial vegetation limit, rock discoloration, and root exposure.

Characteristics typical of C-, B-, F-, and E-type stream channels found in the UVR.

Stream type	Portion of UVR	Entrenchment ratio	Width/depth ratio	Sinuosity	Slope range
	%				%
C	61	>2.2	>12	>1.2	<0.1-3.9
B	19	1.4-2.2	>12	>1.2	<2.0-9.9
F	16	<1.4	>12	>1.2	<2.0-3.9
E	3	>2.2	<12	>1.5	<2.0-3.9

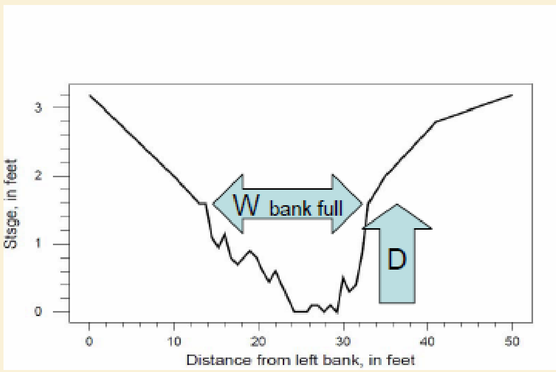
USFS Report



Entrenchment ratio:

The channel width at two times the bankfull depth divided by the channel width at bankfull.

$E \text{ ratio} = W_{2D} / W_{\text{bank full}}$



Width/depth ratio: Numerical ratio of stream width to stream depth.

$WD \text{ ratio} = W_{\text{bank full}} / D$

Keep in mind that USFS results are for the present (not natural) base flow and channel morphology.

USFS Report

Summary

% of study reach	Stream Type	General Description	Entrenchment Ratio	W/D Ratio	Sinuosity	Slope	Landform/Soils/Features
61	C	Low-gradient, meandering, alluvial riffle-pool, channels with point-bars. Broad, well-defined floodplains.	>2.2	>12	<1.4	<0.02	Broad valleys with terraces in assoc. with floodplains alluvial soils. Slight entrenchment with well-defined meanders. Riffle/pool bed morphology.
19	B	Moderately entrenched, moderate-gradient, riffle-dominated channel with infrequently spaced pools. Very stable plan and profile. Stable banks.	1.4 to 2.2	>12	>1.2	0.02 to 0.039	Moderate relief, colluvial deposition and/or residual soils. Moderate entrenchment and W/D ratio. Narrow, gently sloping valleys. Rapids predominate with occasional pools.
16	F	Entrenched, meandering riffle/pool channel, of low gradient, with high width/depth ratio.	<1.4	<12	1.4	<0.02	Entrenched in highly weathered material. Low-gradient, with high W/D ratio. Meandering, laterally unstable with high bank erosion. Riffle/pool bed.
3	E	Low-gradient, meandering, riffle/pool stream with low W/D ratio and little deposition. Very efficient and stable. High meander width ratio.	>2.2	<12	>1.5	<0.02	Broad valley/meadows. Alluvial materials with floodplain. Highly sinuous with stable, well-vegetated banks. Riffle/pool morphology, very low W/D ratio.

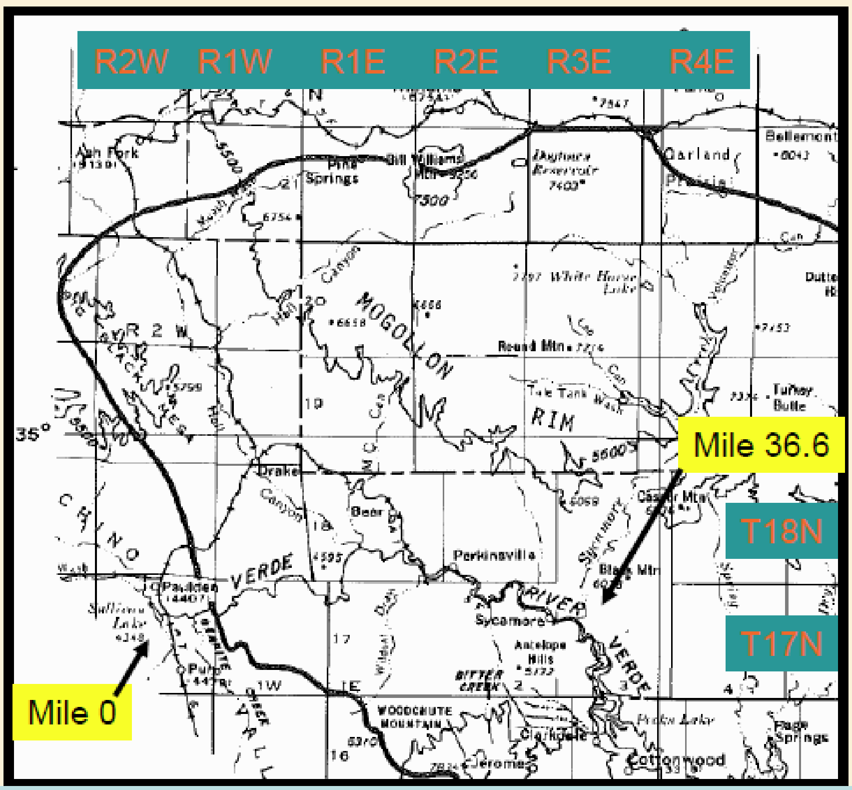
The Verde River typically is a single slightly entrenched channel with slopes less than 2%. Base runoff and the average annual flow typically are within a defined channel. There are numerous riffles and pools with a mix of nearly straight and sinuous reaches.

2.—Federal Land Surveys

Arizona BLM maintains current and historical information about land ownership and use in the United States. They maintain cadastral survey and historical data on lands patented, along with information on the mineral estate, resource conditions, and permits or leases on Federal lands.

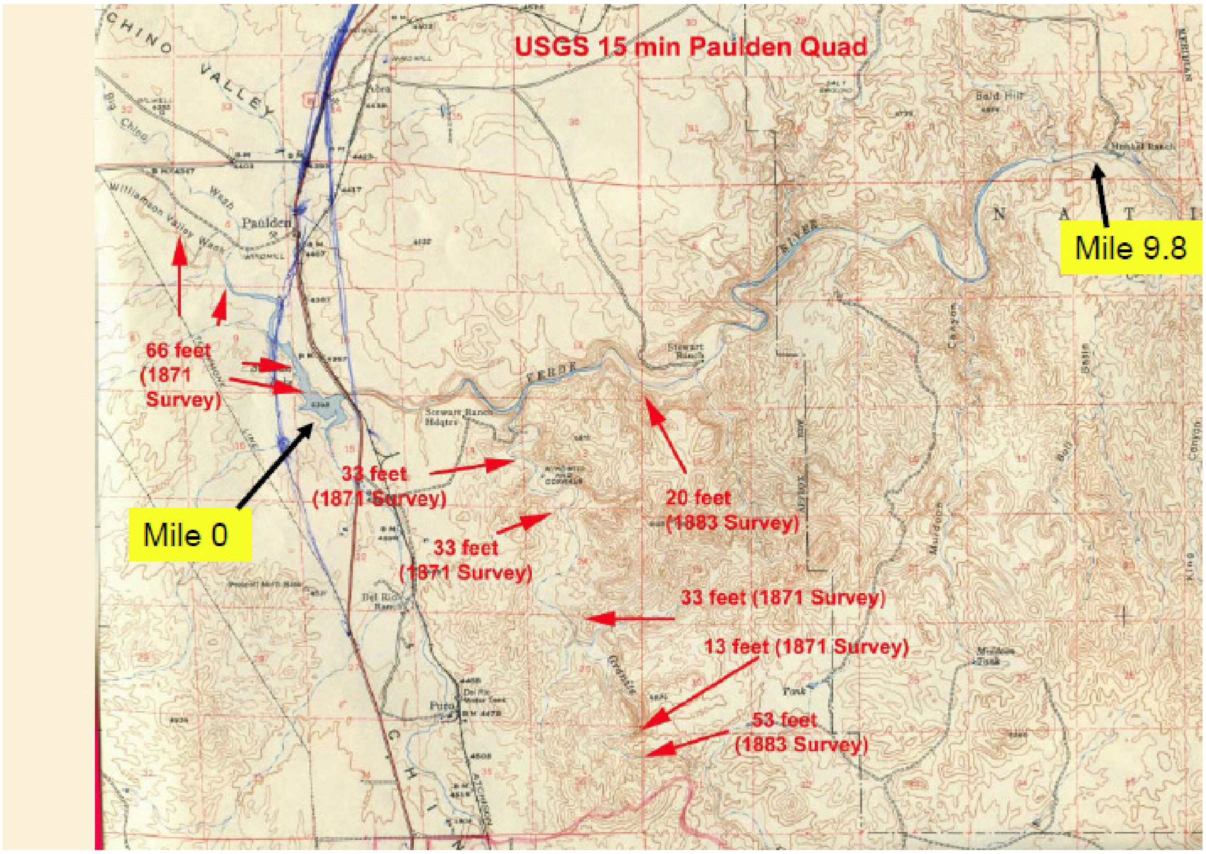
The Bureau of Land Management (BLM) and General Land Office (GLO) Records Automation web site provides live access to Federal land conveyance records for the Public Land States, including image access to more than five million Federal land title records issued between 1820 and the present. They also have images related to survey plats and field notes, dating back to 1810.

Reference map for land surveys.

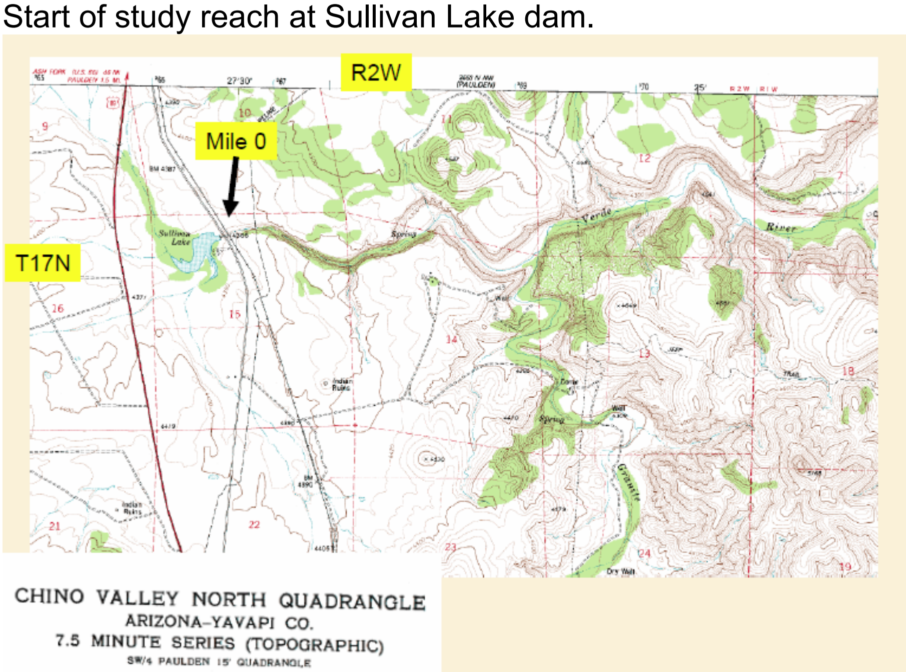


Base Map: Owen-Joyce, S., and Bell, C.K., 1983, Appraisal of water resources in the upper Verde River area, Yavapai and Coconino counties, Arizona: Arizona Department of Water Resources Bulletin 2, 219 p.

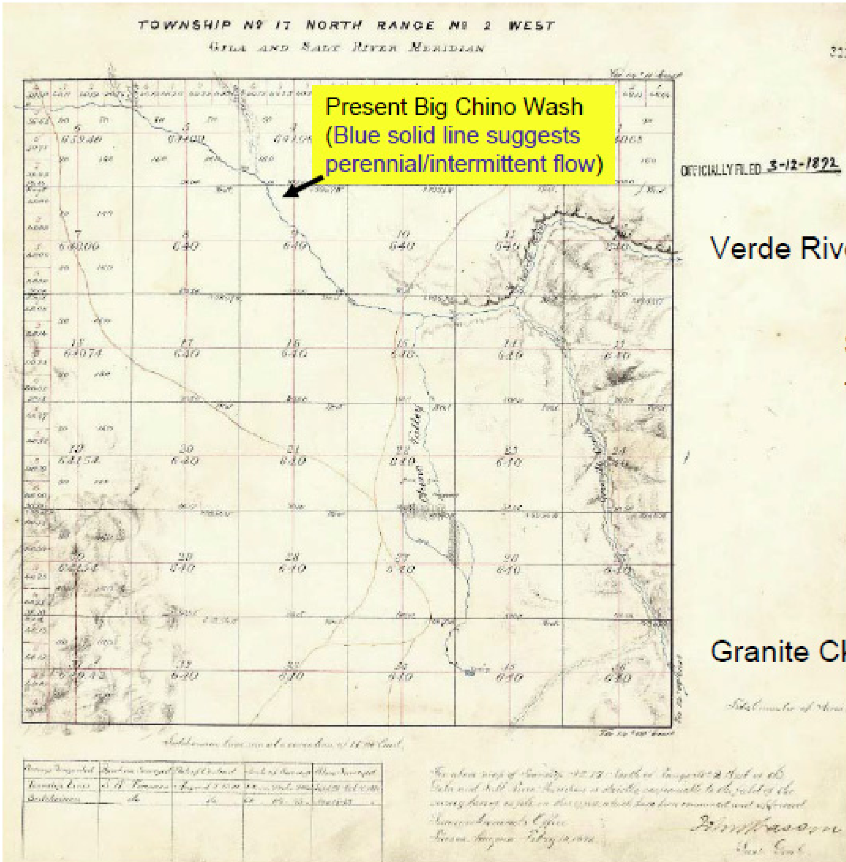
Channel widths from Federal Land Surveys are shown on a recent USGS map. The USGS gage near Paulden (09503700) is at river mile 9.8.



Start of study reach at Sullivan Lake dam.



T17N R2W



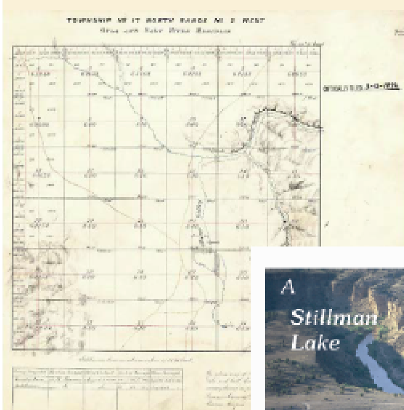
Verde River

Surveys of Sept. 1871 - Nov. 1871.

Granite Ck.

About 2 miles below Sullivan Lake Dam

T17N R2W



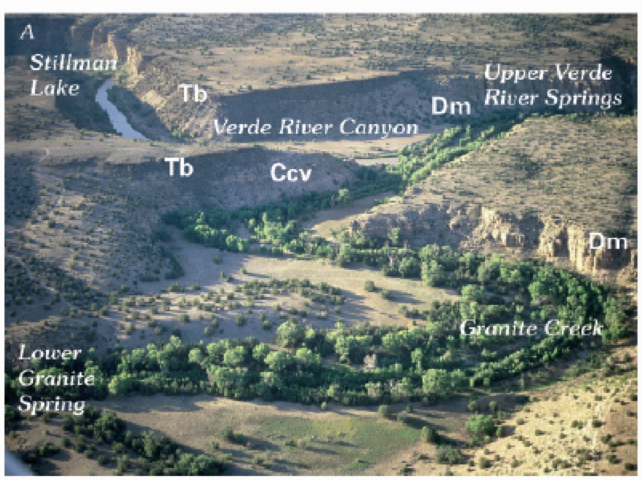
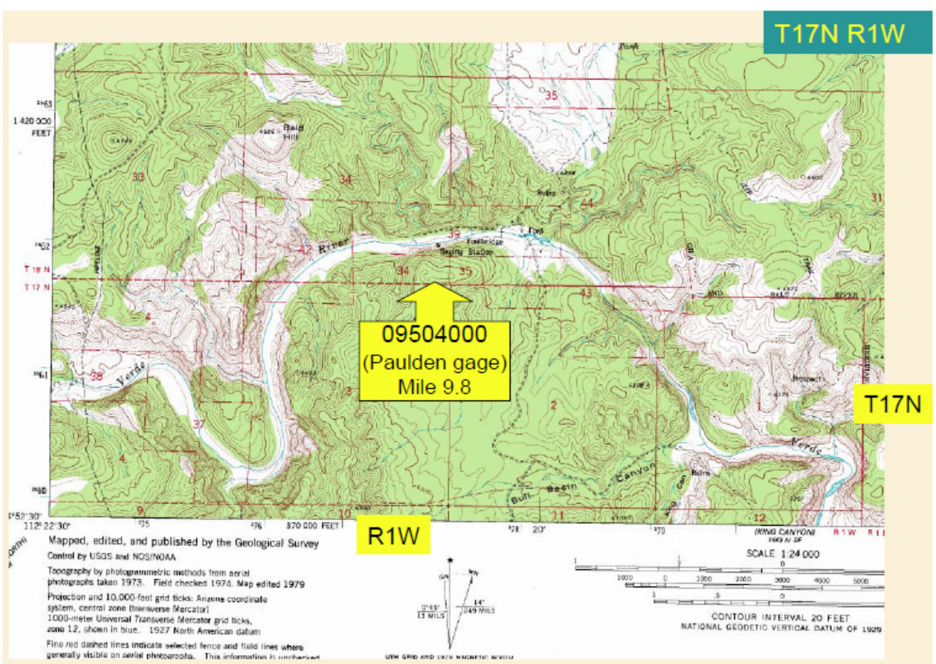
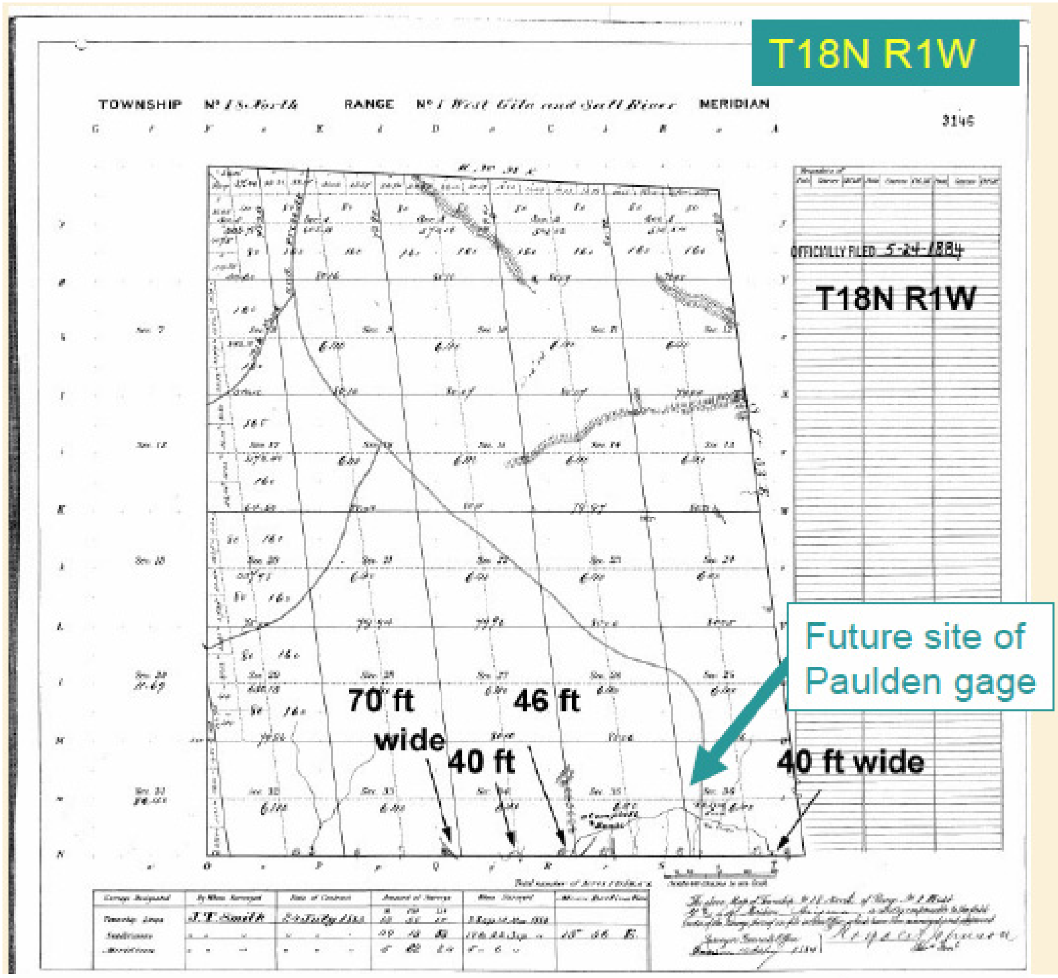
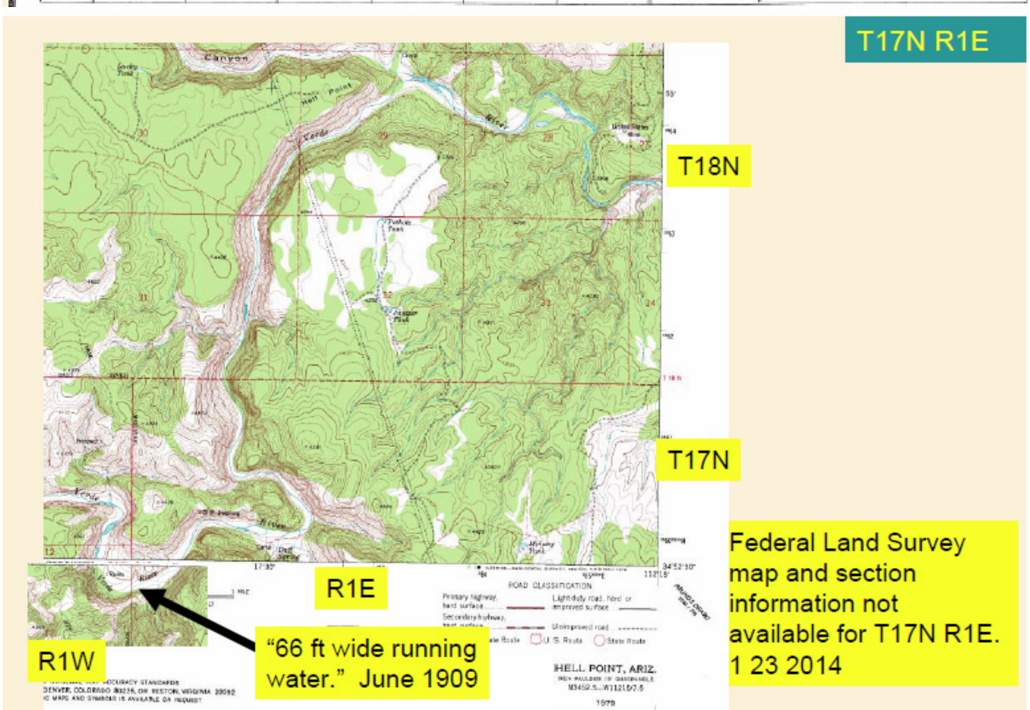


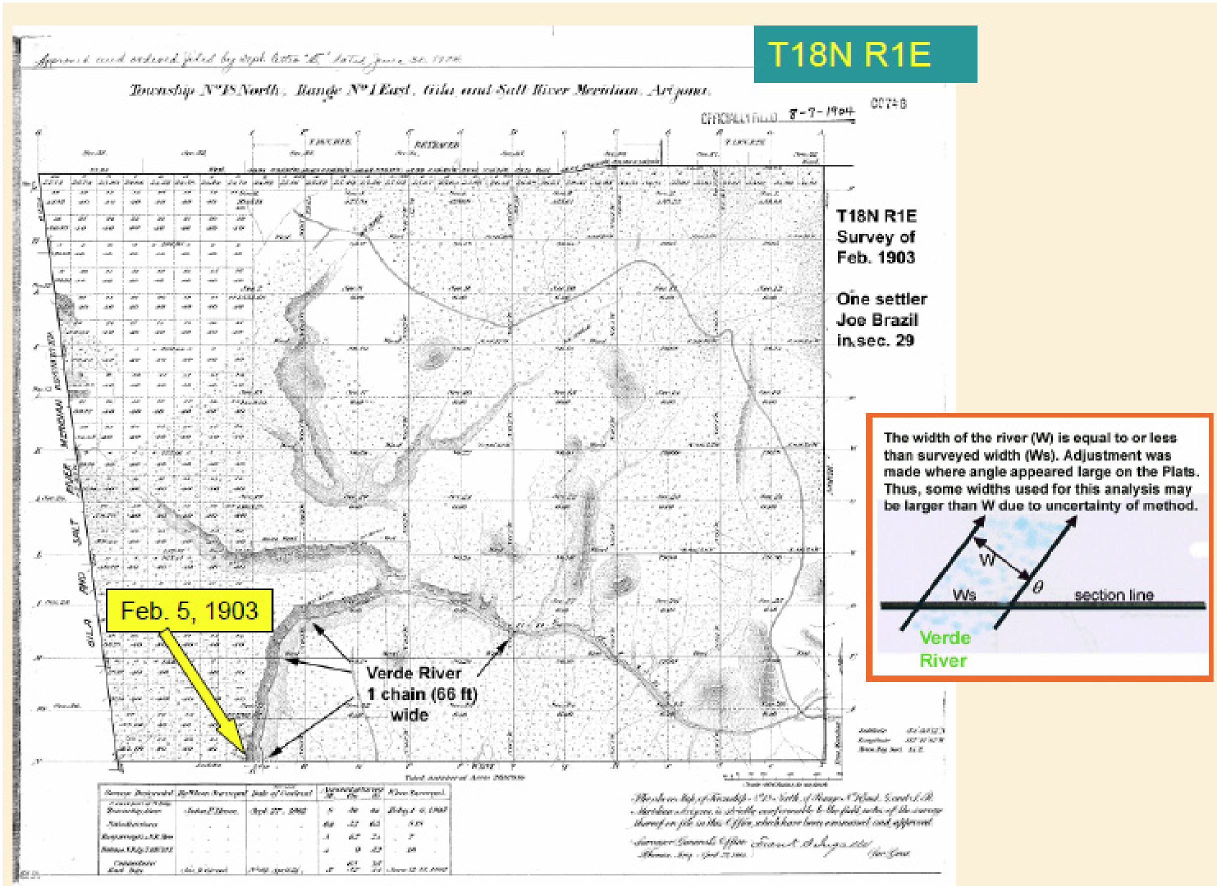
Figure A8. Aerial photographs of lower Granite Creek. A, Lower Granite Creek and its confluence with the upper Verde River. View is north. Last mile of both Granite Creek and the Verde River above confluence are perennial. Canyon walls of Devonian Martin Formation and Chino Valley Formation (Cambrian?) capped by Tertiary basalt; B, Rugged bedrock canyon in lower Granite Creek. View is south toward Little Chino ground-water basin. Dipping strata are Proterozoic Mazatzal Quartzite. Photographs by M. Collier.

T17N R1W


T17N R1W
09504000
(Paulden gage)
Mile 9.8
T17N
R1W
Verde
Mapped, edited, and published by the Geological Survey
SCALE 1:24 000
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929


T18N R1W
TOWNSHIP Nº 18 North RANGE Nº 1 West Gila and Salt River MERIDIAN
OFFICIALLY FILED 5-24-1884
T18N R1W
Future site of Paulden gage
70 ft wide
46 ft
40 ft
40 ft wide


T17N R1E
T18N
T17N
R1E
R1W
"66 ft wide running water." June 1909
Federal Land Survey map and section information not available for T17N R1E. 1 23 2014
HELL POINT, ARIZ.



USGS Water Supply Paper 100

Water-Supply and Irrigation Paper No. 100 Series P, Hydrographic Progress Reports, 27

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

REPORT

OF

PROGRESS OF STREAM MEASUREMENTS

FOR

THE CALENDAR YEAR 1903

PREPARED UNDER THE DIRECTION OF F. H. NEWELL

BY

JOHN C. HOYT

PART IV.—Interior Basin, Pacific, and Hudson Bay Drainage

WASHINGTON
GOVERNMENT PRINTING OFFICE
1904

Estimated monthly discharge of Verde River at McDowell, near Lehi, Ariz., for 1903.

[Drainage area, 6,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
January a			249	b 15, 310	0.041	b 0.047
February c			362	d 20, 104	.060	d .062
March 1–26 e			625	f 32, 231	.104	f .101
April 8–30 e			496	g 22, 627	.083	g .071
May	193	110	141	8, 669	.024	.028
June	372	55	136	8, 093	.023	.026
July	859	36	232	14, 265	.039	.045
August	1, 685	89	329	20, 229	.055	.063
September	1, 960	110	513	30, 526	.085	.095
October	830	185	318	19, 553	.053	.061
November	225	190	207	12, 317	.035	.039
December	253	215	227	13, 958	.038	.044
The period				217, 882		

Mean monthly discharge for Feb. 1903 when Federal survey of T18N R1E was made = 362 cfs. (See next slide for rest of comment)

Monthly statistics for 09510000 for early years

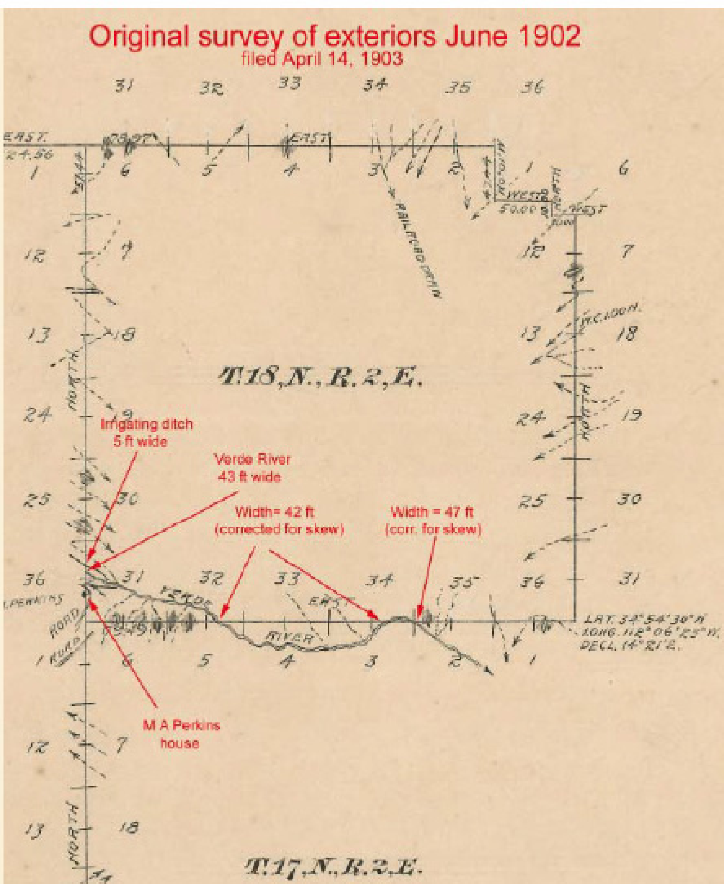
As previously stated: Mean monthly discharge for Feb. 1903 when Federal survey of T18N R1E was made = 362 cfs.

This amount of Feb. discharge is 14% of the mean monthly discharge for the early years. Also, it is the 3rd lowest Feb. flow at the mouth of the Verde River.

00060, Discharge, cubic feet per second,

YEAR	Monthly mean in ft3/s (Calculation Period: 1904-01-01 -> 1924-01-31) Period-of-record for statistical calculation restricted by user											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1904	236.8	226.3	184.0	118.5	126.3	62.9	729.1	1,625	481.6	188.1	209.6	240.9
1905	1,420	7,713	8,781	5,226	832.5	282.6	245.4	566.8	771.3	543.5	3,433	875.1
1906	811.8	1,202	5,468	1,029	246.9	149.9	233.8	742.9	210.8	181.3	312.0	2,641
1907	2,429	2,619	3,767	838.1	251.3	208.9	217.2	430.3	403.9	614.3	375.2	323.4
1908	306.5	1,973	1,395	301.2	443.3	145.6	462.5	879.9	356.4	264.7	281.5	3,129
1909	1,760	1,459	2,029	1,258	199.9	135.2	379.0	1,255	475.2	160.2	221.1	354.2
1913										204.4	338.5	306.5
1914	956.7	3,045	716.5	251.5	153.9	113.6	204.0	234.4	229.8	326.9	269.7	652.1
1915	1,242	2,447	3,591	2,180	2,663	206.9	326.8	348.6	231.1	177.4	248.5	392.7
1916	8,231	3,766	5,184	696.0	231.5	158.9	201.0	507.5	1,296	725.8	326.8	340.5
1917	1,222	1,495	1,759	6,002	1,253	234.4	417.0	726.5	388.5	247.0	243.1	265.9
1918	393.9	904.5	4,613	355.2	159.8	137.3	191.1	544.5	190.3	193.4	345.8	457.8
1919	345.4	953.0	1,560	1,333	173.1	118.4	2,126	905.7	471.1	741.4	2,850	2,230
1920	2,235	8,956	1,883	1,041	305.5	208.5	179.7	455.5	227.7	240.8	463.1	341.8
1921	315.3	334.7	522.4	235.6	167.4	125.9	296.5	1,695	367.3	442.2	287.9	1,437
1922	2,594	2,749	3,279	1,070	256.5	162.8	208.5	332.7	239.9	184.7	282.7	1,229
1923	347.3	1,222	2,207	793.6	193.2	115.9	198.7	254.1	1,929	269.7	967.5	3,500
1924	993.8											
Mean of monthly Discharge	1,[illegible]20	2,570	2,930	1,420	479	160	414	719	517	336	674	1,100

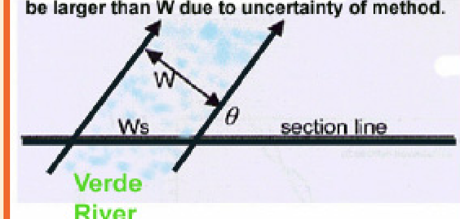
** Incomplete data have been used for statistical calculation



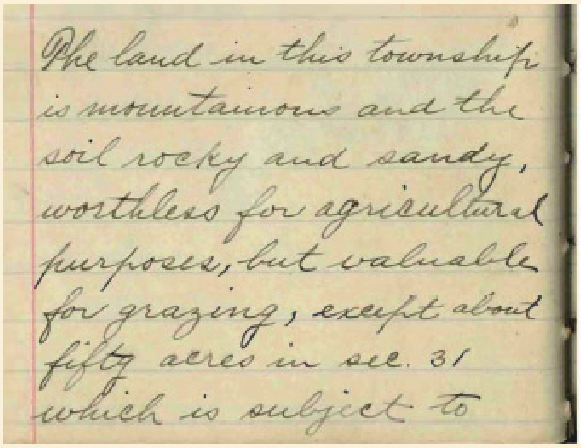
T18N R2E

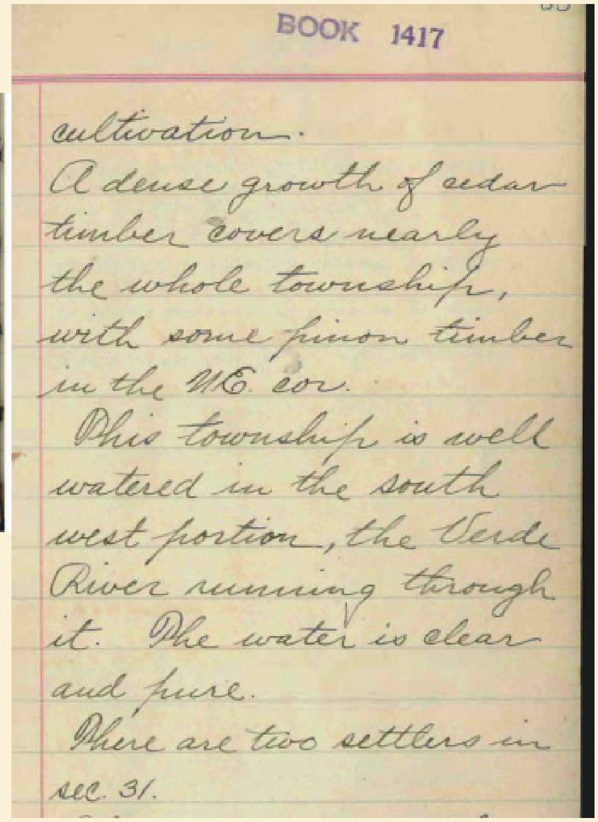
Present Perkinsville area on west side of plat. Note M. A. Perkins house with 5 ft. ditch.

The width of the river (W) is equal to or less than surveyed width (Ws). Adjustment was made where angle appeared large on the Plats. Thus, some widths used for this analysis may be larger than W due to uncertainty of method.



T18N R2E


Phe land in this township is mountainous and the soil rocky and sandy, worthless for agricultural purposes, but valuable for grazing, except about fifty acres in sec. 31 which is subject to


BOOK 1417

cultivation.
A dense growth of cedar timber covers nearly the whole township, with some pinon timber in the N.E. cor.
Phis township is well watered in the south west portion, the Verde River running through it. Phe water is clear and pure.
Phere are two settlers in sec. 31.

Verde River water is clear and pure.

T18N R2E

About 24 miles below Sullivan Lake Dam

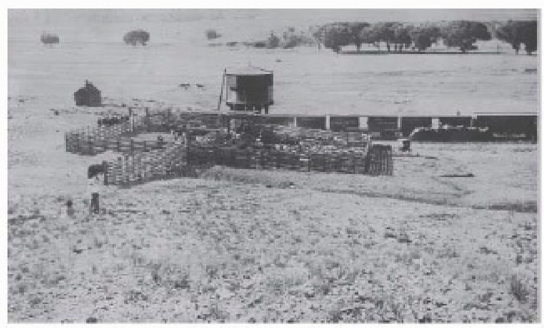
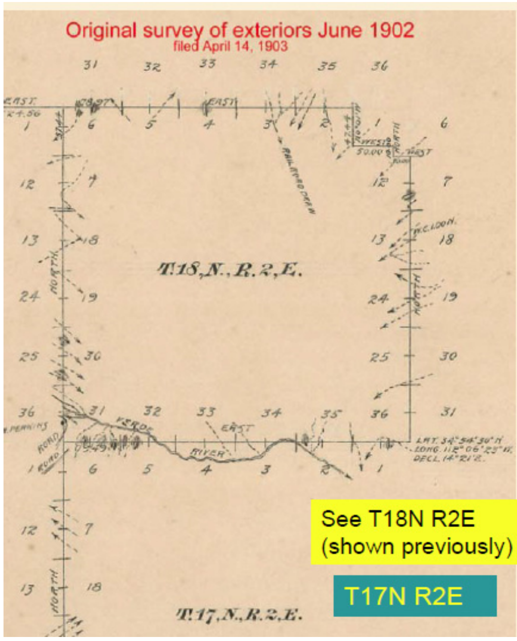
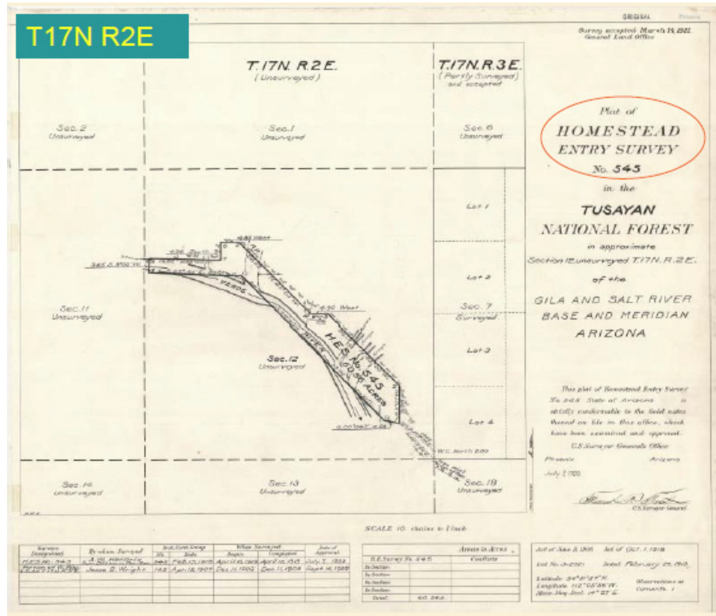


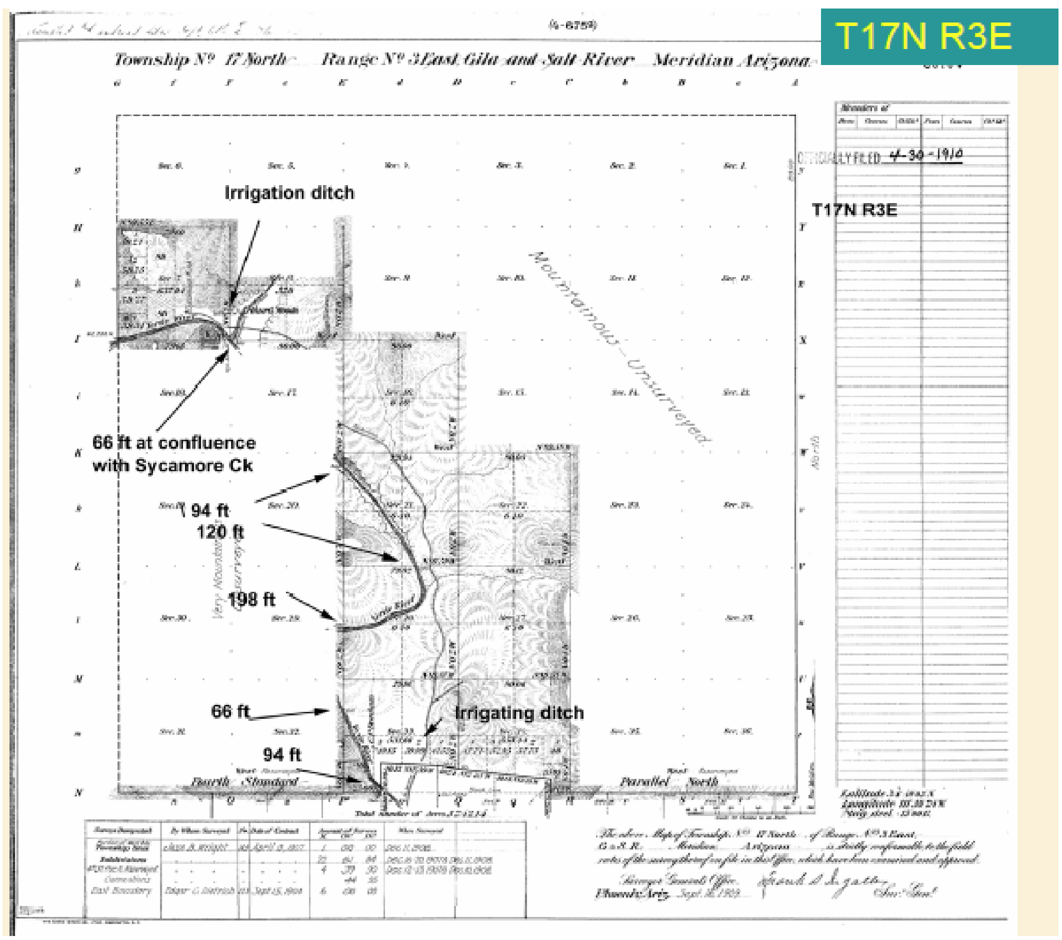
Figure 2.7—Photo looking south across the Perkinsville valley depicting the condition of the UVR circa 1920s. The river runs amidst a valley denuded of woody plants and irrigated bottomland (ditches in foreground) where horses are seen grazing. Streamside vegetation was largely herbaceous and lacking woody plants. The floodplain morphology is a gentle "C" type channel with ample freeboard for flood waters to spread. A small grove of cottonwoods resided atop an older terrace. (Photo A courtesy of the Sharlot Hall Museum, Prescott, Arizona.)

Figure 2.8—This photo was taken from the Perkinsville Road looking east and shows the homestead on the south side of the river. A stand of young cottonwoods, likely less than 10 years old, can be seen growing along the irrigation ditch. These same cottonwoods are seen in figs. 2.36 to 2.42. (Photo A courtesy of the Sharlot Hall Museum, Prescott, Arizona.)

Neary, Daniel G.; Medina, Alvin L.; Rinne, John N., eds. 2012. **Synthesis of Upper Verde River research and monitoring 1993-2008.** Gen. Tech. Rep. RMRSGTR-291. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 296 p.


Original survey of exteriors June 1902
filed April 14, 1903
T.18.N.,R.2.E.
See T18N R2E
(shown previously)
T17N R2E
T.17.N.,R.2.E.


T17N R2E
T.17N. R.2E.
T.17N. R.3E.
Plat of
HOMESTEAD
ENTRY SURVEY
No. 545
in the
TUSAYAN
NATIONAL FOREST
GILA AND SALT RIVER
BASE AND MERIDIAN
ARIZONA


T17N R3E
Township No 17 North Range No 3 East Gila and Salt River Meridian Arizona
Irrigation ditch
Mountainous – Unsurveyed
66 ft at confluence
with Sycamore Ck
94 ft
120 ft
198 ft
66 ft
94 ft
Irrigating ditch
Fourth Standard Parallel North
T17N R3E

GENERAL DESCRIPTION.

The N. and W. bds. of this Tp. run over land so rough and broken as to be impracticable to survey

The only settlers noted in this township are C. P. Dunham, who has made substantial improvements in the SW¼ of Sec. 33, consisting of good building, irrigation ditch, fences, etc., He occupies and cultivates about 80 acres of land. Arthur G. Wood, in the SW¼ of Sec. 8, has substantial improvements consisting of good dwelling and outhouses, irrigation ditches, fences, etc, and occupies and cultivates about 80 acres of land, part of which is in the SE¼ of Sec. 7, and a part in the NW¼ of sec. 17.

The Sycamore Mine in sec. 7, is the only mine located in the township.

The soil along the Verde river is very fertile, and there is much valuable land lying within the surveyed section, which could be irrigated, from the ample supply of water in the Verde river. The western portion of Tp. is very rough, broken by deep canons and gulches leading to the Verde river, as is also the northeastern portion of Tp.

The geological formation of the country is simple, and consists of mostly stratified limestone, with igneous out-croppings. There is very little signs of mineral formation whatever in this township.

U. S. Deputy Surveyor.

T17N R3E

Irrigated acres
80
80
Total = 160

2 settlers

Sycamore Mine

Monthly statistics for 09510000 for early years

Mean monthly discharge for Dec. 1908 when Federal survey of T17N R3E (previous 2 slides) was made
= 3129 cfs.

This amount of discharge is the 2nd highest mean monthly discharge for the early years at the mouth of the Verde River.

00060, Discharge, cubic feet per second,

YEAR	Monthly mean in ft3/s (Calculation Period: 1904-01-01 -> 1924-01-31) Period-of-record for statistical calculation restricted by user											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1904	236.8	226.3	184.0	118.5	126.3	62.9	729.1	1,625	481.6	188.1	209.6	240.9
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1906	811.8	1,202	5,468	1,029	246.9	149.9	233.8	742.9	210.8	181.3	312.0	[illegible]
1907	2,429	2,619	3,767	838.1	251.3	208.9	217.2	430.3	403.9	614.3	375.2	323.4
1908	306.5	1,973	1,395	301.2	443.3	145.6	462.5	879.9	356.4	264.7	281.5	3,129
1909	1,760	1,459	2,029	1,258	199.9	135.2	379.0	1,255	475.2	160.2	221.1	[illegible]
1913										204.4	338.5	306.5
1914	956.7	3,045	716.5	251.5	153.9	113.6	204.0	234.4	229.8	326.9	269.7	652.1
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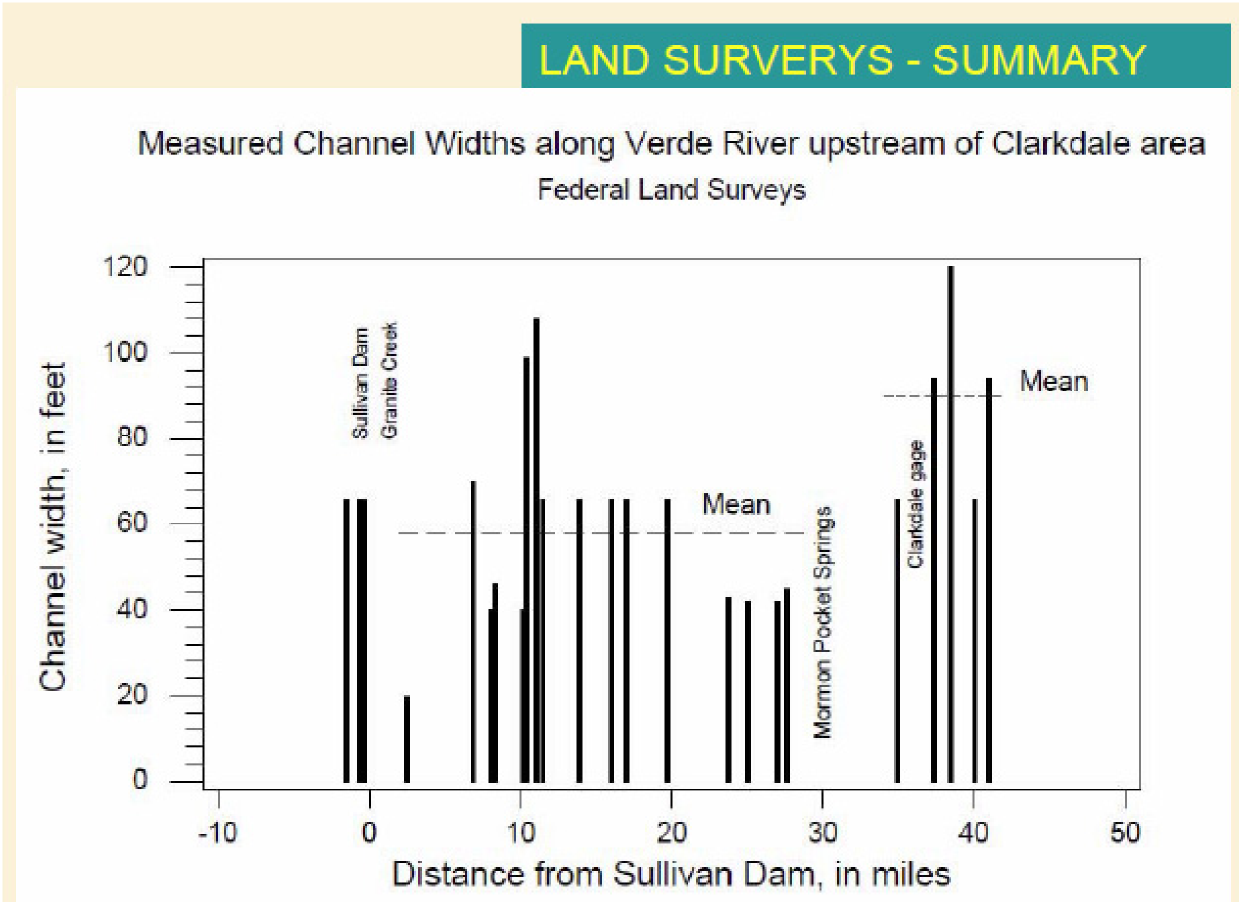
1923	347.3	1,222	2,207	793.6	193.2	115.9	198.7	254.1	1,929	269.7	967.5	3,500
1924	993.8											
Mean of monthly Discharge	1,520	2,570	2,930	1,420	479	160	414	719	517	336	674	1,100

** Incomplete data have been used for statistical calculation



3.-- Recent channel geometry with several photos, channel cross sections, and current meter measurements.

The natural size and shape of the Verde River channel are based on published and unpublished channel geometry relations (cross sections of the river) along the upper river. Current meter measurements and surveyed cross sections that were furnished by U. S. Geological Survey, U. S. Forest Service and the Sierra Club follow. The pre-development width, depth and velocity are estimated using the natural streamflow.

The Manning equation was used to estimate ratings at eleven cross sections where current-meter measurements of discharge were made. Development of the depth versus discharge ratings required relatively minor applications of hydraulic theory.

The equation, written in terms of discharge, is $Q = (1.49/n) AR^{2/3} S^{1/2}$

Where:
Q= discharge,
A=cross-sectional area,
R= hydraulic radius,
S =friction slope, and
n=roughness coefficient.

The roughness coefficient and friction slope were selected using observed channel condition so that the rating curve of maximum depth versus discharge passed through the corresponding current-meter measurement for each cross section. The cross-sections for the low-flow ratings at the cableways of the USGS Paulden and Clarkdale gages were far below the available current-meter measurements that had less influence on the fitting process. The discharge ratings were analyzed by applying some elementary arithmetic and algebraic processes and certain basic concepts of open-channel flow to the available field data.

The Manning equation, written in terms of friction slope and roughness, is

$$S^{1/2}/n = Q/(1.49\ AR^{2/3})$$

As a check of the ratings, that is independent of estimated friction slope and roughness, the slope-roughness term ($S^{1/2}/n$) was computed for the current-meter measurements and then applied to the discharge, area and hydraulic radius for the mean annual flow at nine of the cross sections. Focus was on the maximum depth at each cross section because it was most important for assessment of navigability.

The value of the Manning roughness coefficient (the n value) assigned to a reach of river channel represented by a cross section represent the composite effects of the factors that tend to retard flow. A good method of determining an overall value is by selecting a base value for a given size of bed material and adjusting for supplemental factors. The literature that uses the base "n" method gives different categories of bed material, base "n" values, numbers and sizes of adjustment factors, and limiting values of roughness. Also, the literature typically gives verified values of roughness for high flows (for example Thomsen and Hjalmarson (1991) below) and straight reaches of rather uniform channel material. For low flows along meandering channels like the Upper Verde River the base roughness can be rather small relative to the many heterogeneous factors like isolated boulders, shown in several photographs of this report, that tend to retard flow.

Manning roughness coefficient (n) for the 11 straight reaches represented by the cross sections along the natural meandering channel of the Verde River was determined using established procedures of the USGS. The procedure is based on a selected base roughness for a reach of the river channel where incremental increases of roughness associated with vegetation, obstructions, the degree of channel irregularity and the variation of channel cross section are added to the base value.

The above procedure is discussed in the following four reports. Tables 1 and 2 of the Arcement and Schneider (1989) report are on the following pages.

Arcement, G.J., Jr., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Thomsen, B.W., and Hjalmarson, H.W., 1991, Estimated Manning's roughness coefficient for stream channels, and flood plains in Maricopa County, Arizona: Phoenix, Flood Control District of Maricopa County report, 126p.

Table 1. Base values of Manning's *n*

[Modified from Aldridge and Garrett, 1973, table 1; —, no data]

Bed material	Median size of bed material (in millimeters)	Base *n* value	
		Straight uniform channel[1]	Smooth channel[2]
Sand channels			
Sand[3]	0.2	0.012	—
	.3	.017	—
	.4	.020	—
	.5	.022	—
	.6	.023	—
	.8	.025	—
	1.0	.026	—
Stable channels and flood plains			
Concrete	—	0.012–0.018	0.011
Rock cut	—	—	.025
Firm soil	—	0.025–0.032	.020
Coarse sand	1–2	0.026–0.035	—
Fine gravel	—	—	.024
Gravel	2–64	0.028–0.035	—
Coarse gravel	—	—	.026
Cobble	64–256	0.030–0.050	—
Boulder	>256	0.040–0.070	—

[1] Benson and Dalrymple (1967).
[2] For indicated material, Chow (1959).
[3] Only for upper regime flow where grain roughness is predominant.

Gravel, cobbles and boulders common in upper Verde River.

Probably the best means of computing the maximum depth of flow along the Upper Verde River is the standard step backwater method of computing water-surface profiles using channel geometry data, like that at the 11 cross sections. The method is also used in establishing or extending stage-discharge relations at gaging stations or cross section sites along a stream. A survey of the geometry of many (hundreds) cross sections of the stream channel along the study reach of the Upper Verde River would be needed to produce water level profiles and this clearly is beyond to scope of this analysis for ANSAC. One of the obvious advantages of the step backwater computation is the flow retarding affect of large boulders can be computed. Also, the flow retarding effect of the meandering channel (average m = about 1.2 for the upper Verde River as show below) that typically results in a 10% increase of the depth of flow all along the river is taken into account.

Table 2. Adjustment values for factors that affect the roughness of a channel
[Modified from Aldridge and Garrett, 1973, table 2]

Channel conditions		*n* value adjustment[1]	Example
Degree of irregularity (n_1)	Smooth	0.000	Compares to the smoothest channel attainable in a given bed material.
	Minor	0.001–0.005	Compares to carefully dredged channels in good condition but having slightly eroded or scoured side slopes.
	Moderate	0.006–0.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slopes.
	Severe	0.011–0.020	Badly sloughed or scalloped banks of natural streams; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged, and irregular surfaces of channels in rock.
Variation in channel cross section (n_2)	Gradual	0.000	Size and shape of channel cross sections change gradually.
	Alternating occasionally	0.001–0.005	Large and small cross sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape.
	Alternating frequently	0.010–0.015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.
Effect of obstruction (n_3)	Negligible	0.000–0.004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
	Minor	0.005–0.015	Obstructions occupy less than 15 percent of the cross-sectional area, and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp-edged angular objects.
	Appreciable	0.020–0.030	Obstructions occupy from 15 to 50 percent of the cross-sectional area, or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross section.
	Severe	0.040–0.050	Obstructions occupy more than 50 percent of the cross-sectional area, or the space between obstructions is small enough to cause turbulence across most of the cross section.
Amount of vegetation (n_4)	Small	0.002–0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrowweed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
	Medium	0.010–0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemmy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1- to 2-year-old willow trees in the dormant season, growing along the banks, and no significant vegetation is evident along the channel bottoms where the hydraulic radius exceeds 2 ft.
	Large	0.025–0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8- to 10-year-old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 ft; bushy willows about 1 year old intergrown with some weeds along side slopes (all vegetation in full foliage), and no significant vegetation exists along channel bottoms where the hydraulic radius is greater than 2 ft.
	Very large	0.050–0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; bushy willow trees about 1 year old intergrown with weeds along side slopes (all vegetation in full foliage), or dense cattails growing along channel bottom; trees intergrown with weeds and brush (all vegetation in full foliage).
Degree of meandering[2] (m)	Minor	1.00	Ratio of the channel length to valley length is 1.0 to 1.2.
	Appreciable	1.15	Ratio of the channel length to valley length is 1.2 to 1.5.
	Severe	1.30	Ratio of the channel length to valley length is greater than 1.5.

[1] Adjustments for degree of irregularity, variations in cross section, effect of obstructions, and vegetation are added to the base *n* value (table 1) before multiplying by the adjustment for meander.

[2] Adjustment values apply to flow confined in the channel and do not apply where downvalley flow crosses meanders.

sinuosity of 77% of river about 1.4.
19% of river > 1.2.
3% of river >1.5.

Channel *n* Values 7

The depths and widths of flow shown for the following 11 cross sections that represent rather short-straight reaches are assumed to represent the natural meandering channel of the Upper Verde River. Established procedures of the USGS were used and the resulting maximum depths do not take large obstructions and the degree of meandering into account. Had the large obstructions and degree of meandering been considered, the natural depths would have been at least 10% greater. Thus, the computed flow depths (river stage) that follow are conservatively low.

Mile 3.2

SRP lo flow site

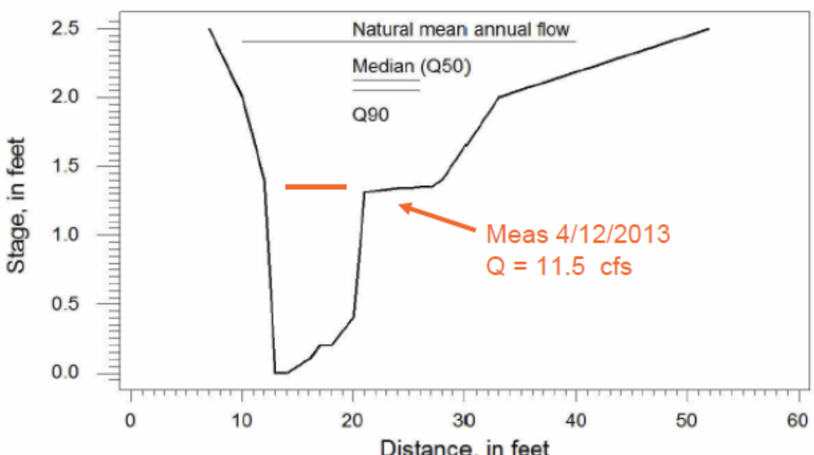
Pawlowski, Steve, 2013, Going With the Flow-A summary of five years of Water Sentinels flow data collection on the Upper Verde River; Sierra Club, 75p.

Figure 10. Campbell Ranch Low-Flow Gage.
Photo credit: Gary Beverly

SRP lo flow site

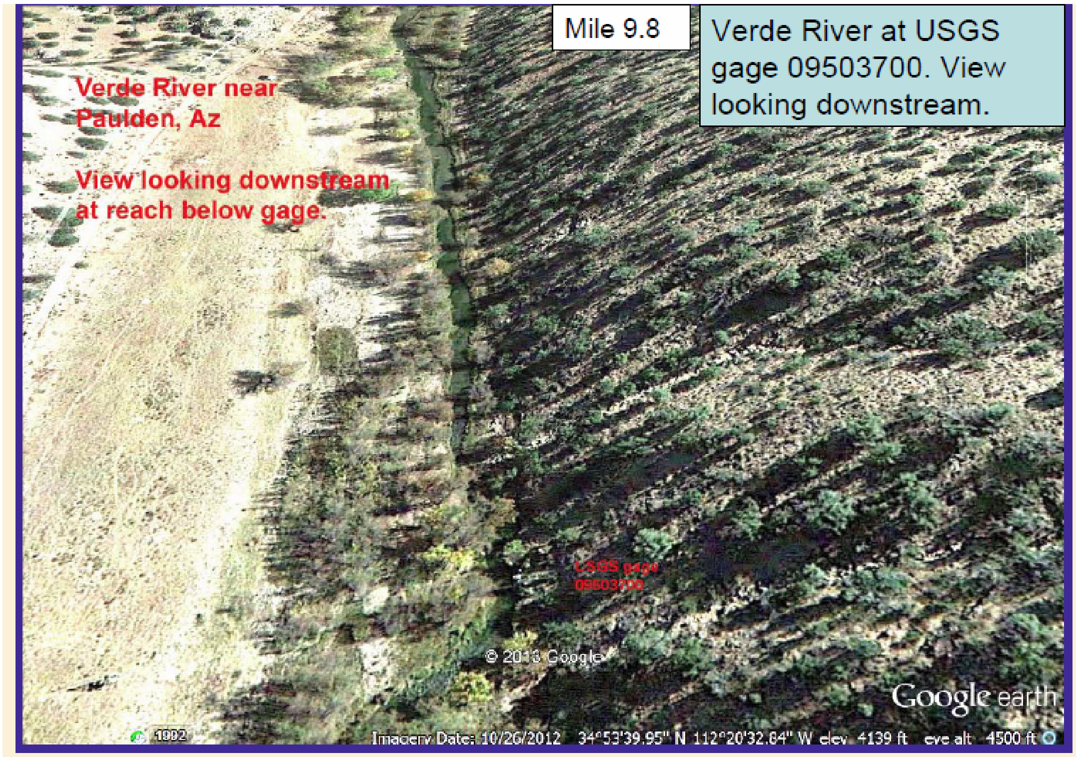
Verde River at SRP lo flow site

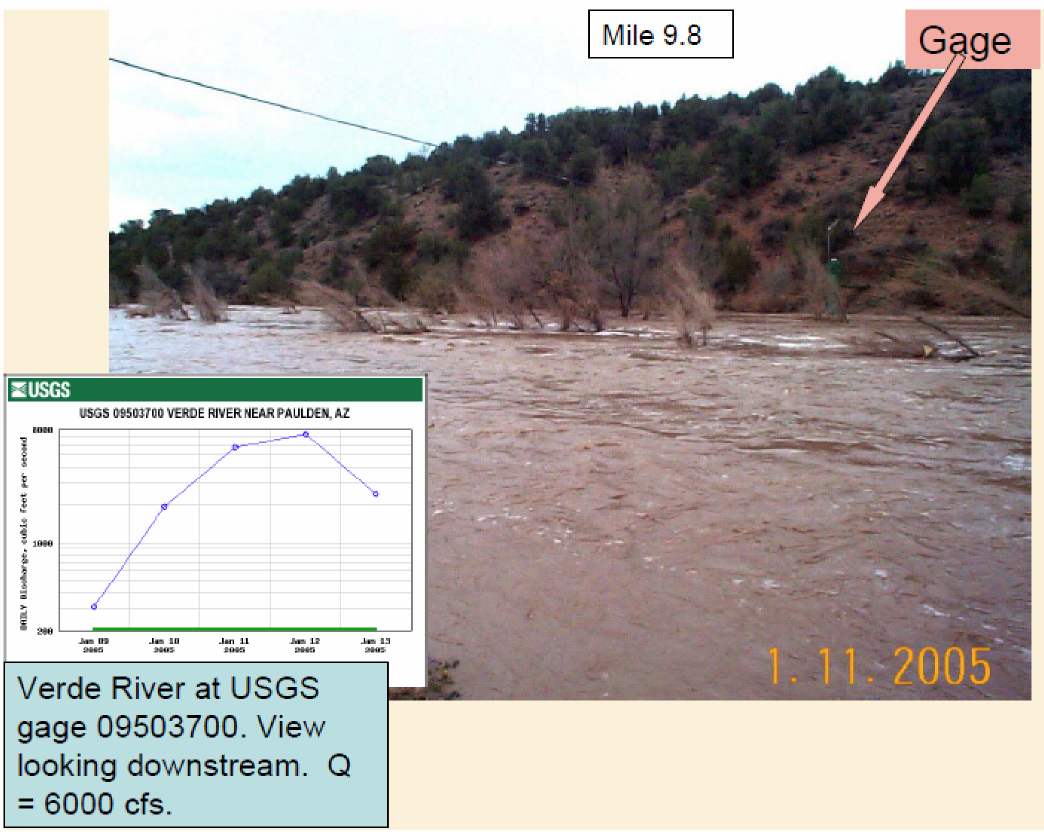
Cross section above gage



Stage ft	Width ft	Area sq ft	Velocity ft/sec	Discharge cfs
0.0	0	0.0	0.0	0.0
1.4	9	10.4	1.06	11.0
1.5	16	11.0	1.05	11.5
2.0	23	22.0	1.32	29.0
2.5	33	36.0	1.39	50.0
3.0	45	60.0	1.50	90.0

Photos of electro fishing. Sillas, Albert USFS [mailto:asillas@fs.fed.us] 2010 **Mile 3.2**

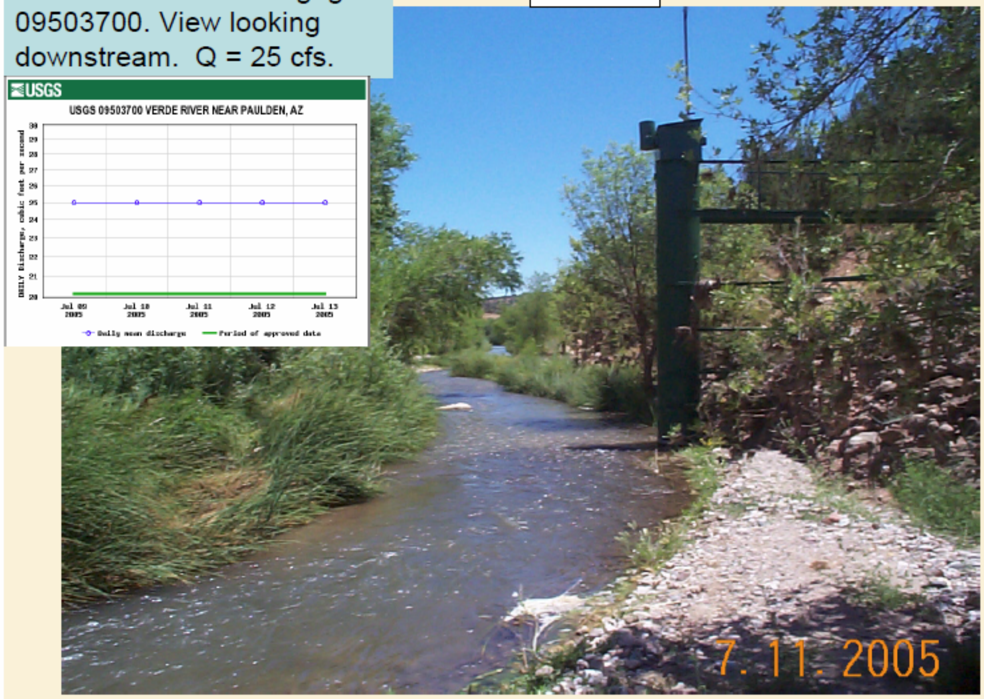

Mile 9.8
Verde River at USGS gage 09503700. View looking downstream.
Verde River near Paulden, Az
View looking downstream at reach below gage.
© 2013 Google
Google earth
Imagery Date: 10/26/2012 34°53'39.95" N 112°20'32.84" W elev 4139 ft eye alt 4500 ft


Mile 9.8
Gage
USGS
USGS 09503700 VERDE RIVER NEAR PAULDEN, AZ
1. 11. 2005
Verde River at USGS gage 09503700. View looking downstream. Q = 6000 cfs.

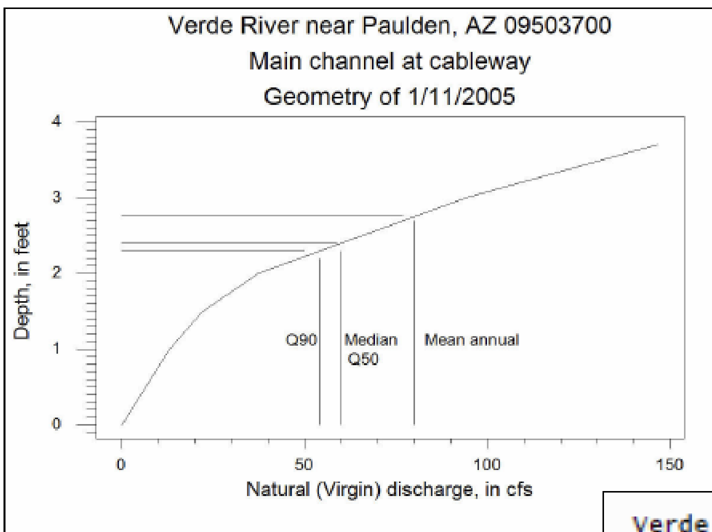
USGS photo

Verde River at USGS gage 09503700. View looking downstream. Q = 25 cfs.

Mile 9.8



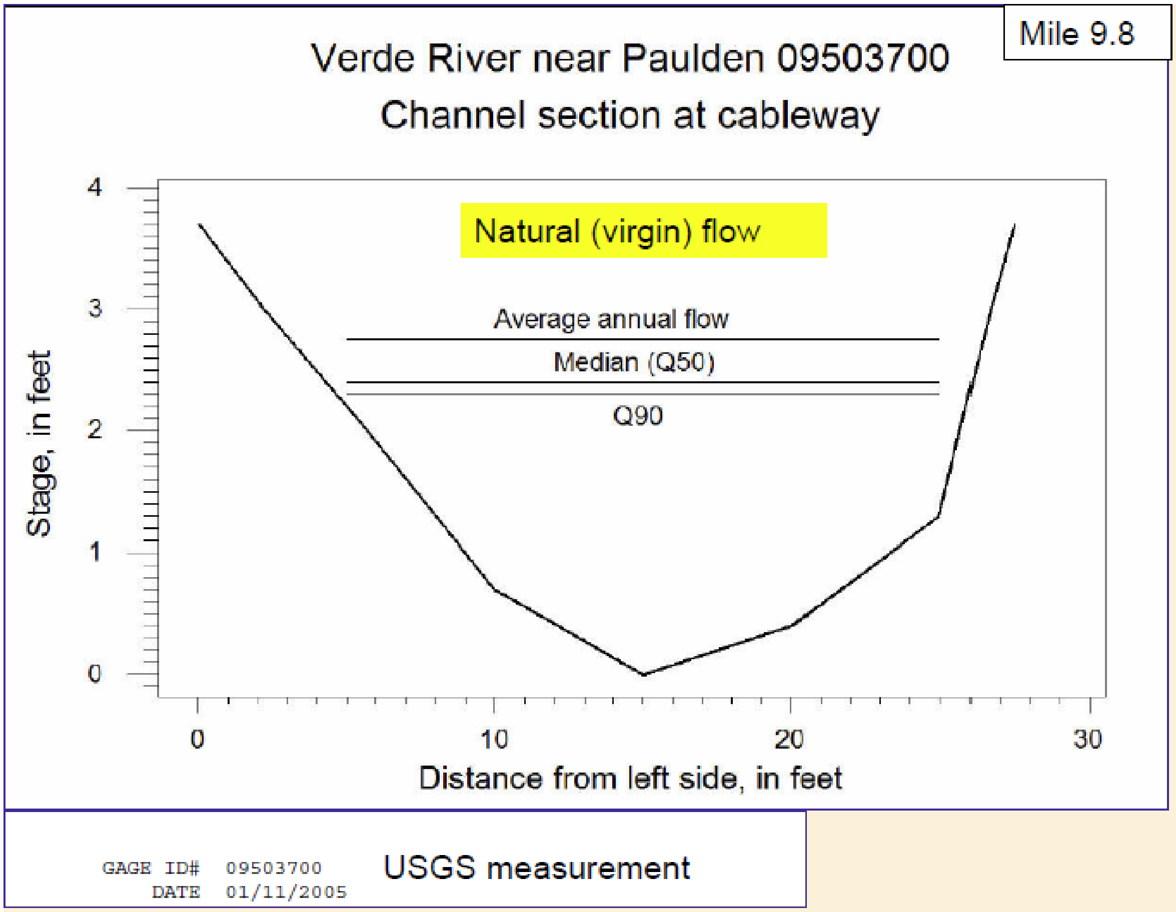
USGS photos

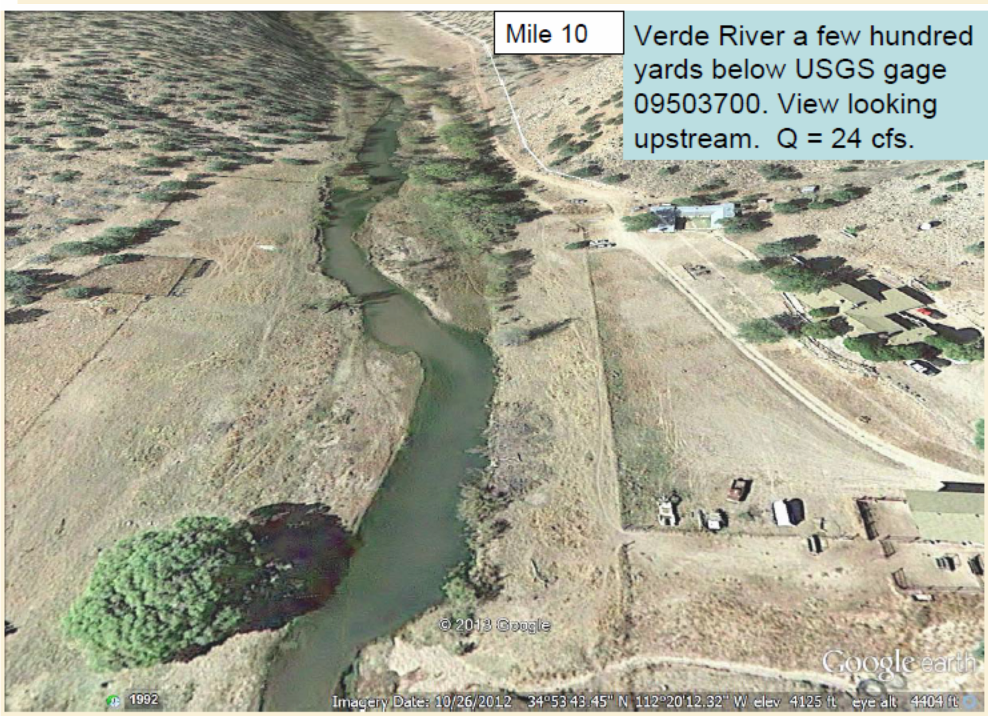


Looking downstream

Verde River near Paulden 09503700
Main Channel at cableway
from USGS meas. on 1/11/2005

Depth ft	Width ft	Velocity ft/s	Discharge cfs
0.0	0.0	0.00000	0.000
2.0	20.0	1.49352	37.338
3.0	24.5	1.96917	94.520
3.7	28.0	2.22281	146.705





Verde River a few hundred yards below USGS gage 09503700. View looking upstream. Q = 24 cfs.

Duff Spring area

Mile 13.9

Figure 5.3—Limestone and siltstone bedrock near Duff Springs in the UVR. (Photo by Alvin L. Medina.)

Neary, Daniel G.; Medina, Alvin L.; Rinne, John N., eds. 2012. **Synthesis of Upper Verde River research and monitoring 1993-2008.** Gen. Tech. Rep. RMRSGTR-291. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 296 p.

Mile 17.9

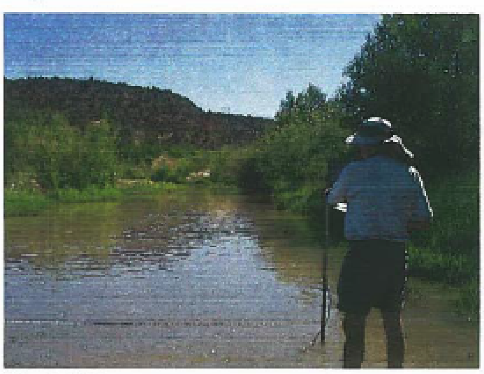
USGS June 2000

P001370

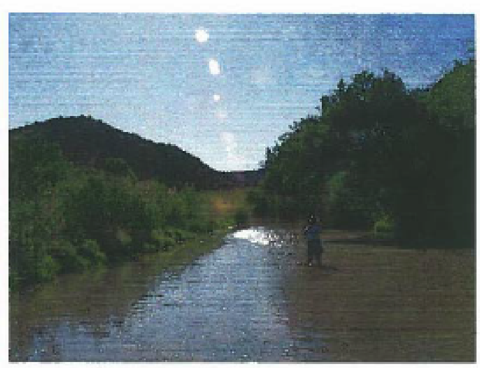
(Verde R. above Hell Canyon Confluence)

P001371

(Verde R. above Hell Canyon Confluence)



P001372



P001373

Mile 19.4 Bear Siding

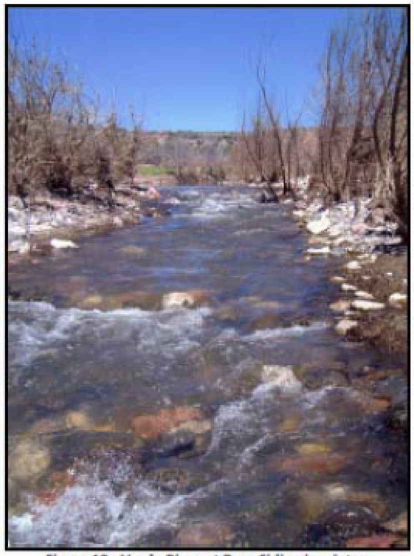


Figure 13. Verde River at Bear Siding in winter.
Photo credit: Tom Slaback

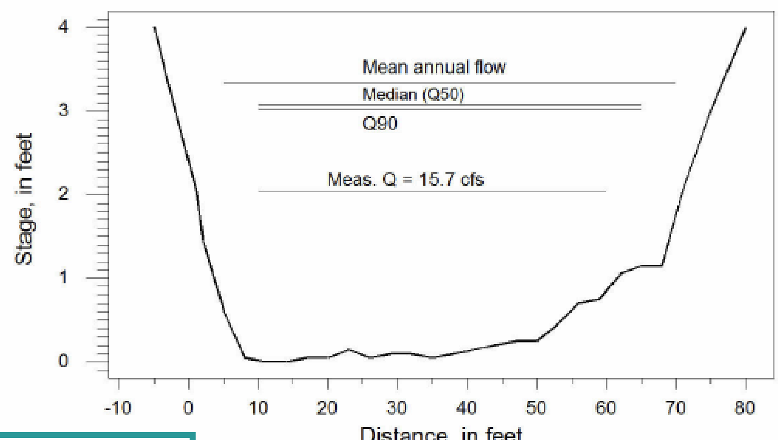
Figure 3. The upper Verde River near Bear Siding
Photo credit: Tom Slaback

Pawlowski, Steve, 2012, The State of the Verde River --A summary of five years of water quality data collection by the Arizona Water Sentinels (December 2006 to December 2011); Water Sentinels, Sierra Club, 129

Bear Siding

Verde River at Bear Siding

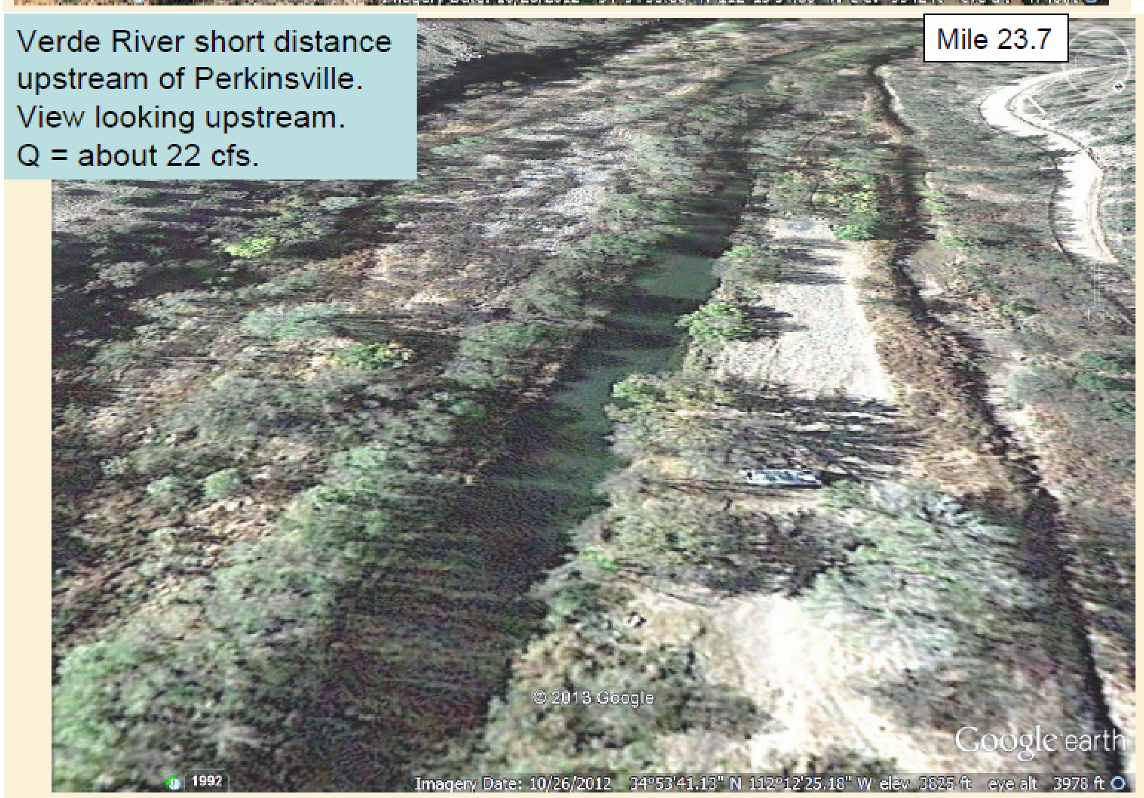
Cross section for Sierra Club meas. in pool



Stage ft	Width ft	Area sq ft	Vel. ft/sec	Q cfs
0.00	0	0	0.00	0.0
1.00	70	60	0.00	0.0
2.05	73	120	0.13	15.7
3.00	79	192	0.26	50
4.00	83	274	0.50	137

Current-meter meas. by Water Sentinels of Sierra Club. Q = 15.7 Dec. 20, 2008


Bear Siding Mile 19.4
U S
Mine
Looking upstream
© 2013 Google
Google earth
1992
Imagery Date: 10/26/2012 34°54'35.66" N 112°15'34.86" W elev 3942 ft eye alt 4710 ft


Verde River short distance
upstream of Perkinsville.
View looking upstream.
Q = about 22 cfs.
Mile 23.7
© 2013 Google
Google earth
1992
Imagery Date: 10/26/2012 34°53'41.13" N 112°12'25.18" W elev 3825 ft eye alt 3978 ft

Stage all	Width	Area	Velocity	Discharge
0.0	0	0.0	0.00000	0
1.6	20	21.0	0.85714	18
2.0	25	30.0	1.20000	36
2.8	36	53.4	1.49813	80
3.0	39	60.0	1.50000	90

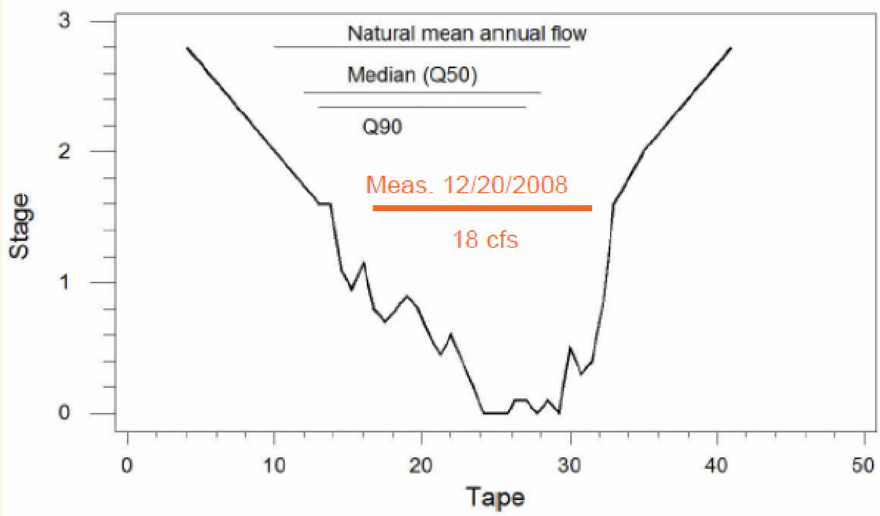
Perkinsville

Perkinsville

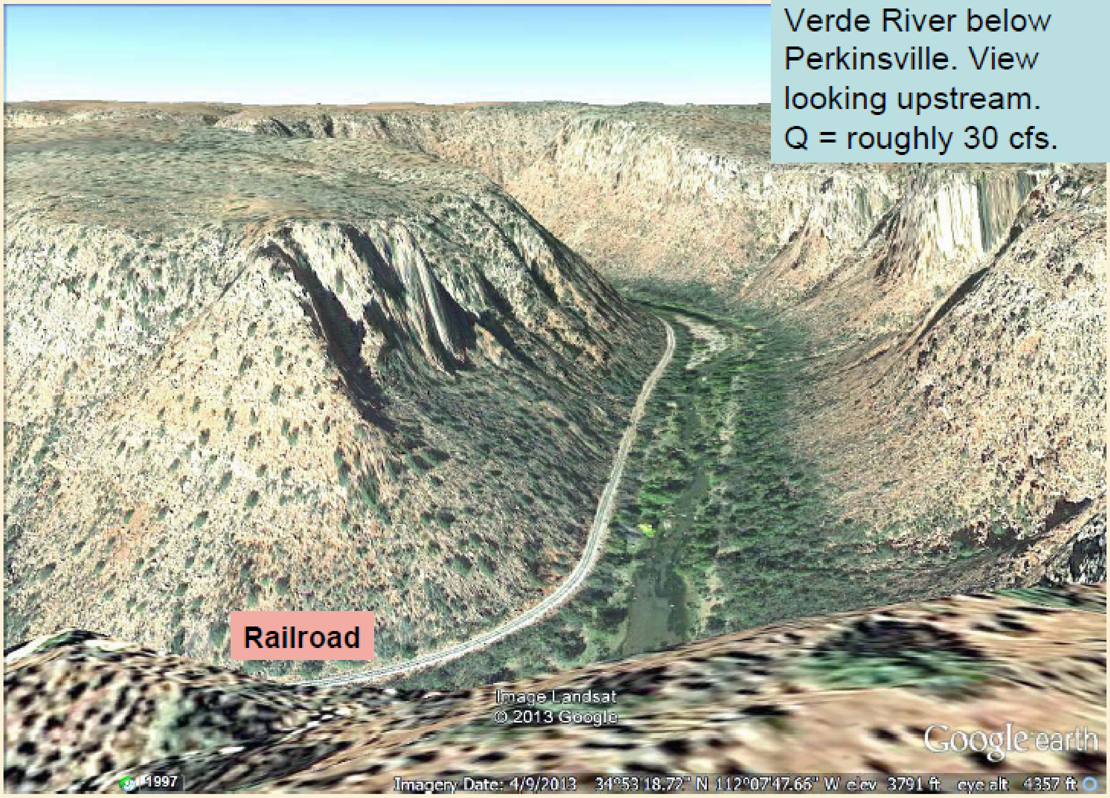
Mile 24

Verde River at Perkinsville

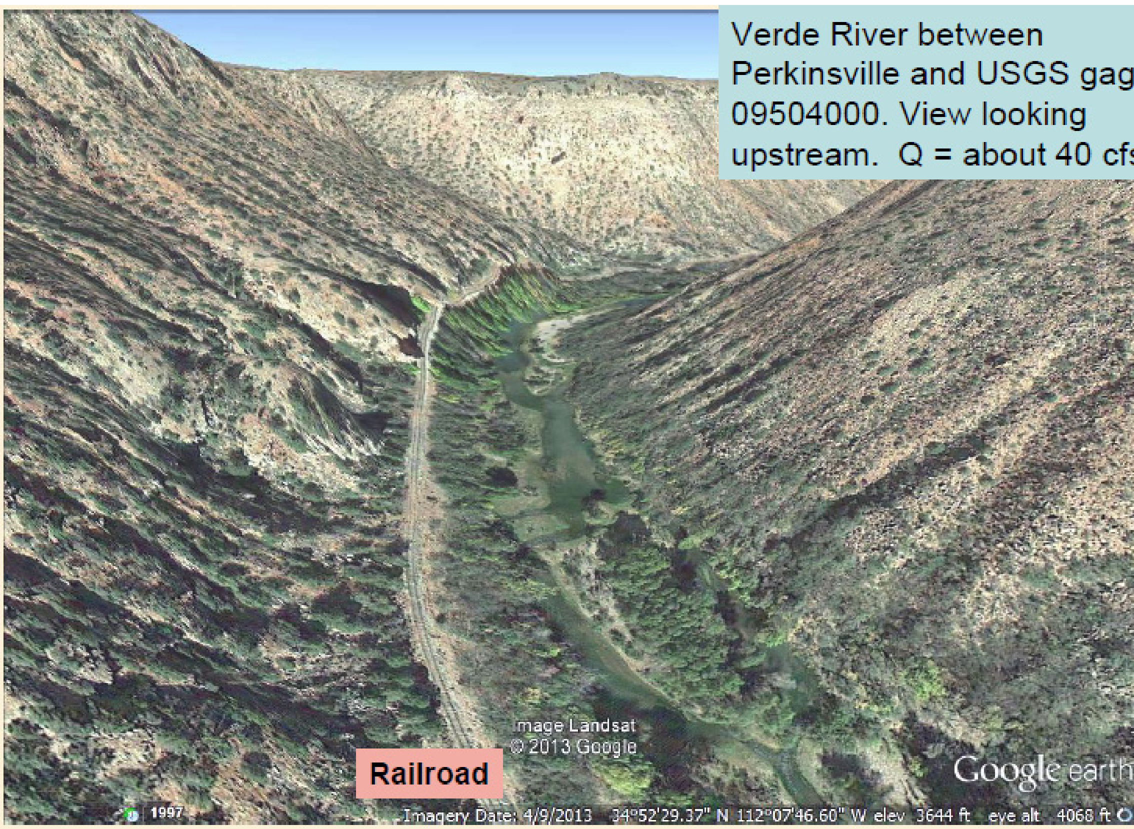
Natural flow conditions



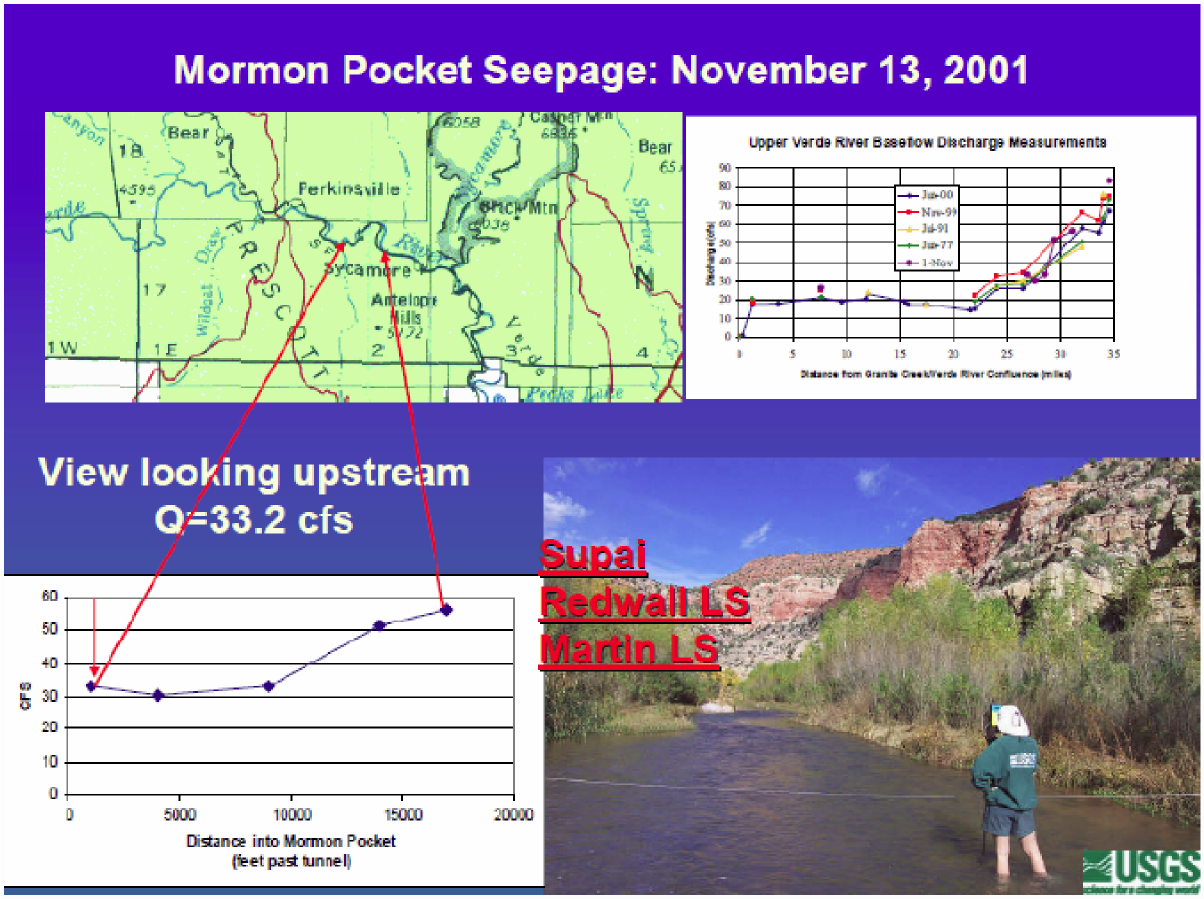
Below Perkinsville



Verde River below Perkinsville. View looking upstream. Q = roughly 30 cfs.

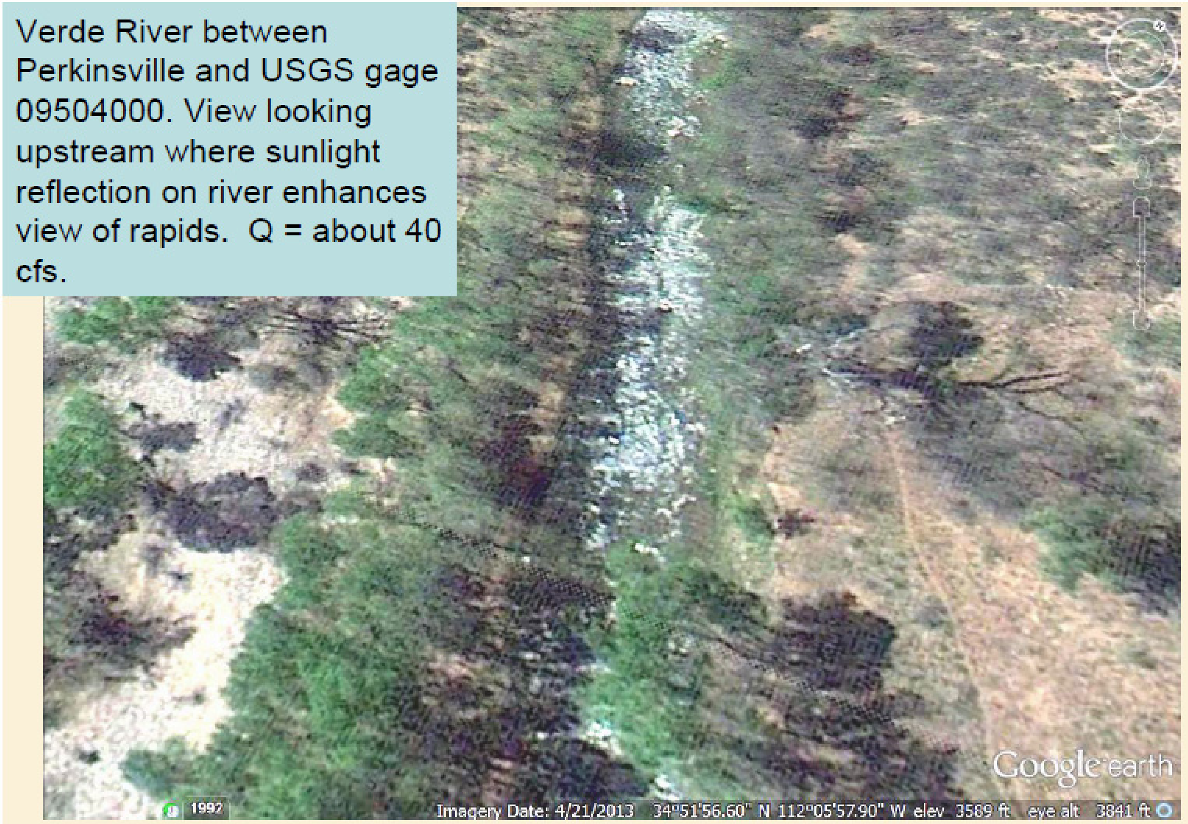


Verde River between Perkinsville and USGS gage 09504000. View looking upstream. Q = about 40 cfs.

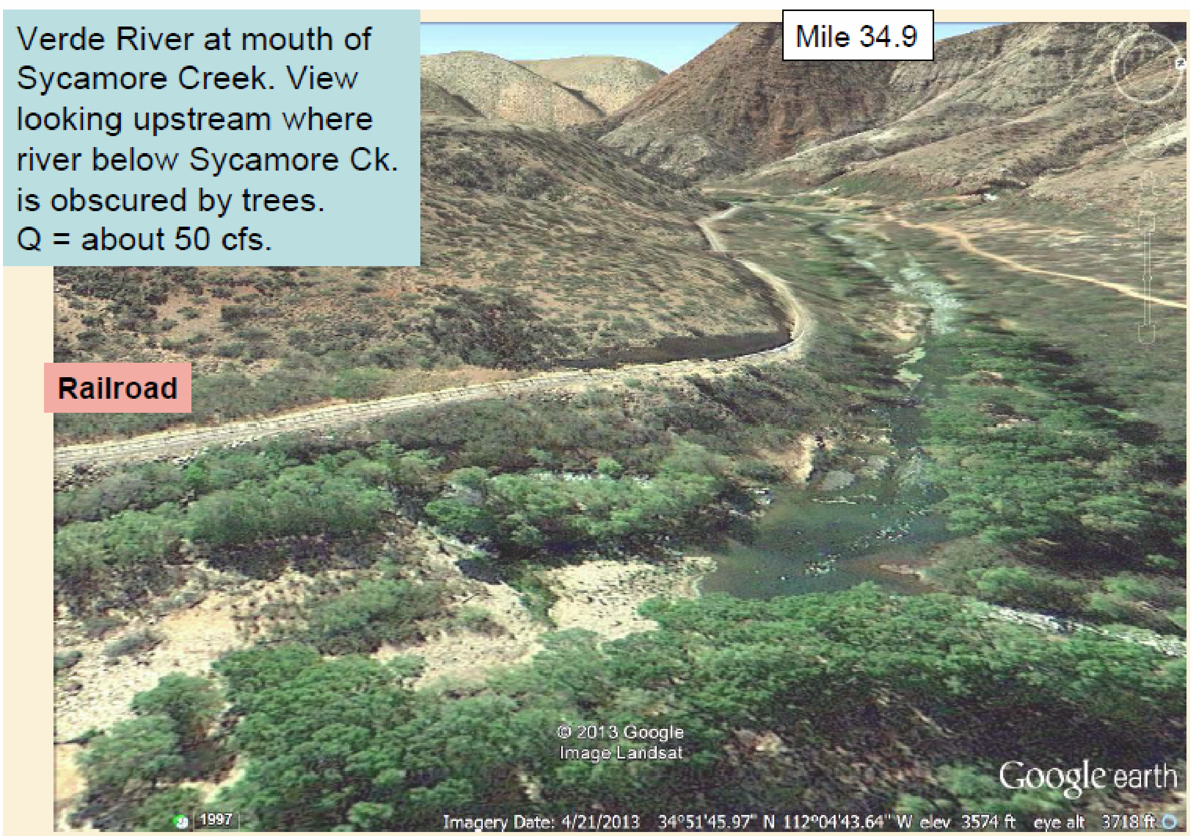


I owned an aluminum canoe for many years and used it on the Dirty Devil, Colorado River, Verde River, etc. I find it interesting that the USGS canoe in this scene appears free of dents. Obviously, even with supplies that include scientific instruments and also collected samples of water for chemical analysis, the draft is only a few inches and the watercraft is stable on the upper Verde River.

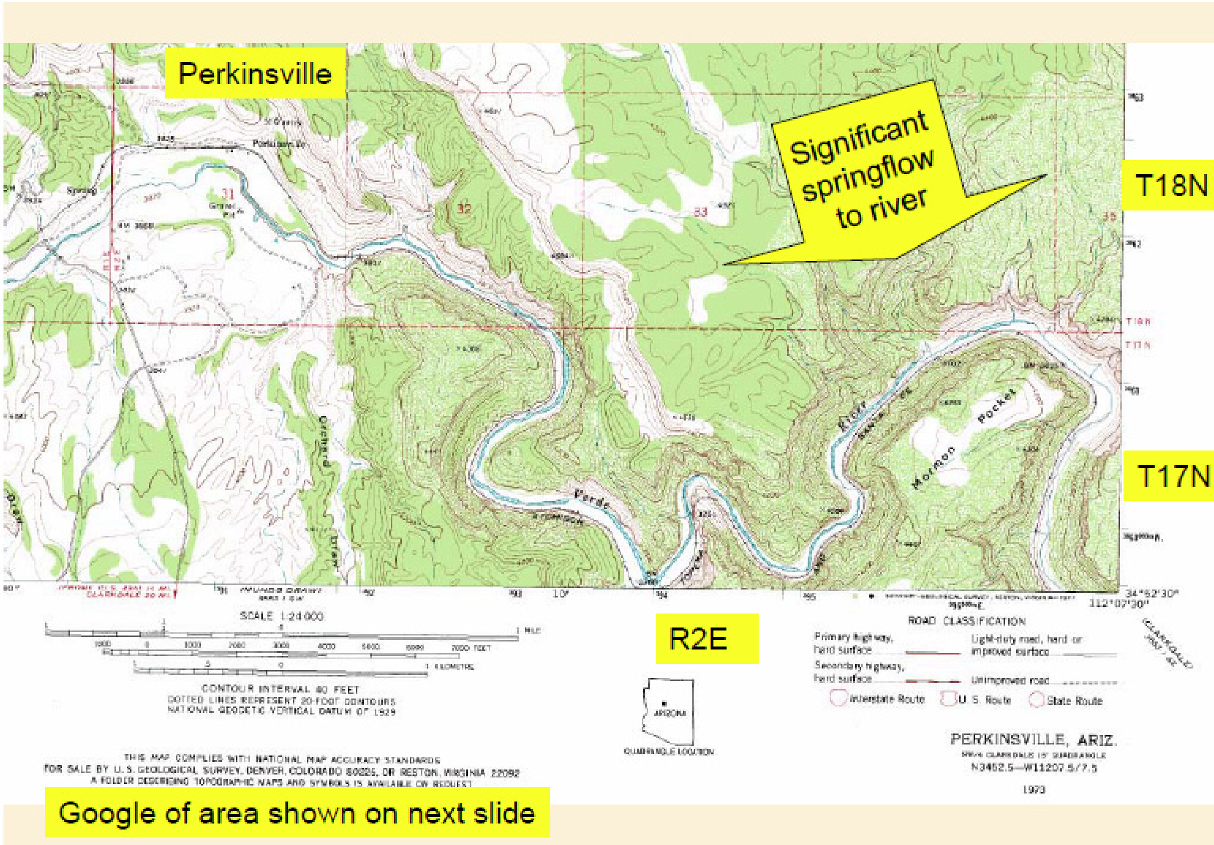
Several canoe/kayak trips along the Upper Verde River have been made by the USGS for scientific purposes. My friend and USGS colleague Lauri Wirt, who was killed while kayaking serious whitewater in Colorado, kayaked the upper Verde River for her scientific studies.



Verde River between Perkinsville and USGS gage 09504000. View looking upstream where sunlight reflection on river enhances view of rapids. Q = about 40 cfs.

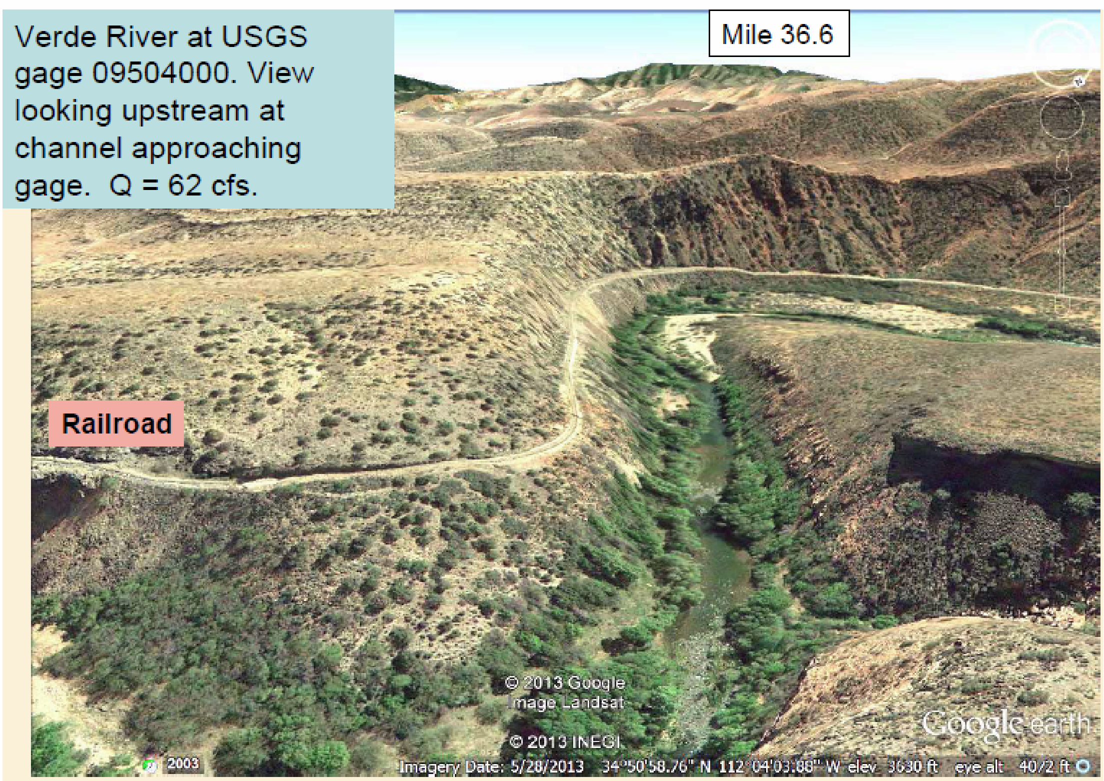


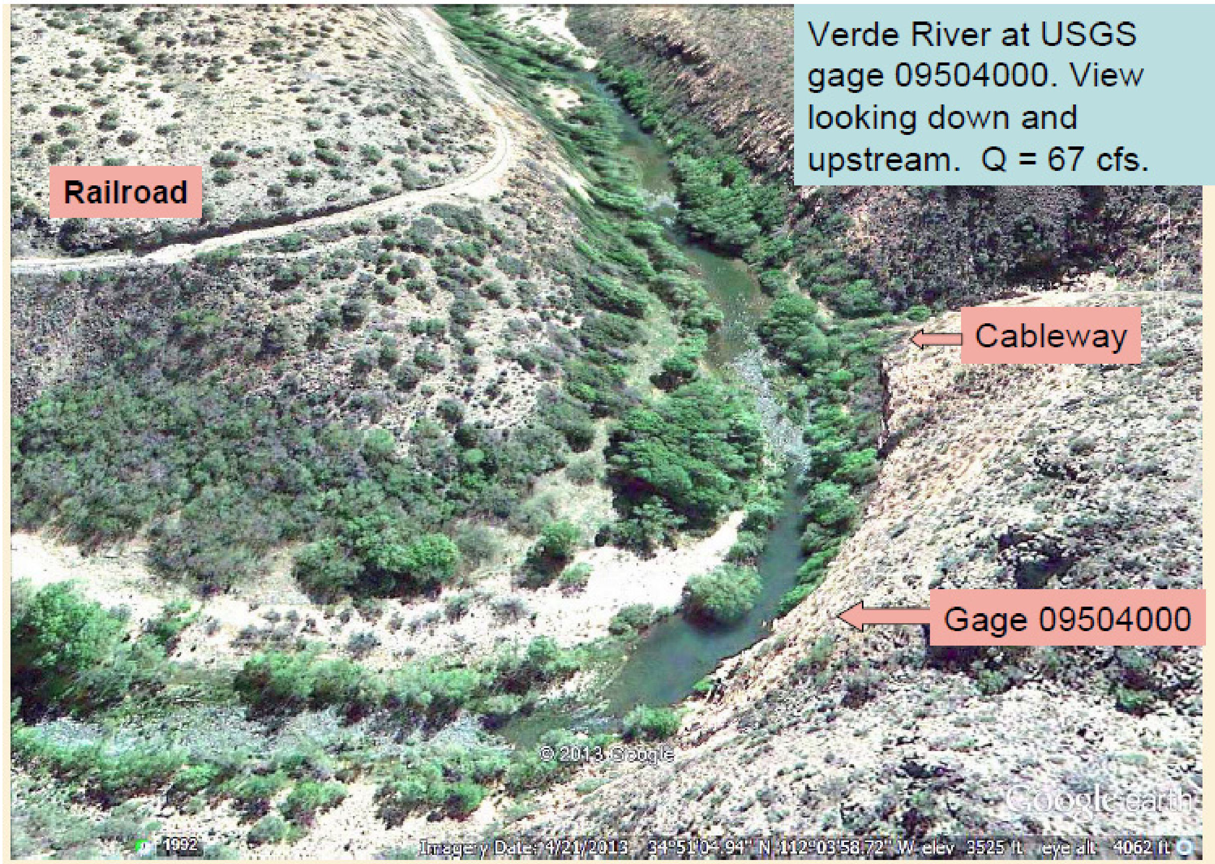
Verde River at mouth of Sycamore Creek. View looking upstream where river below Sycamore Ck. is obscured by trees. Q = about 50 cfs.


Perkinsville
Significant springflow to river
T18N
T17N
R2E
Verde River
Mormon Pocket
SCALE 1:24 000
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929
ROAD CLASSIFICATION
Primary highway, hard surface
Light-duty road, hard or improved surface
Secondary highway, hard surface
Unimproved road
Interstate Route
U. S. Route
State Route
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
PERKINSVILLE, ARIZ.
N3452.5—W11207.5/7.5
1973
Google of area shown on next slide


To Drake
Mile 24
Perkinsville
Significant springflow to river
See next slide
Mormon pocket area
Railroad tunnel
To Jerome
1992
Google earth
Imagery Date: 10/26/2012 34°53'02.16" N 112°09'47.54" W elev 4178 ft eye alt 27580 ft


Verde River between Clarkdale gage and Sycamore Creek. View looking upstream. Q = 67 cfs.
Railroad
© 2013 Google
Image Landsat
Google earth
1997
Imagery Date: 4/21/2013

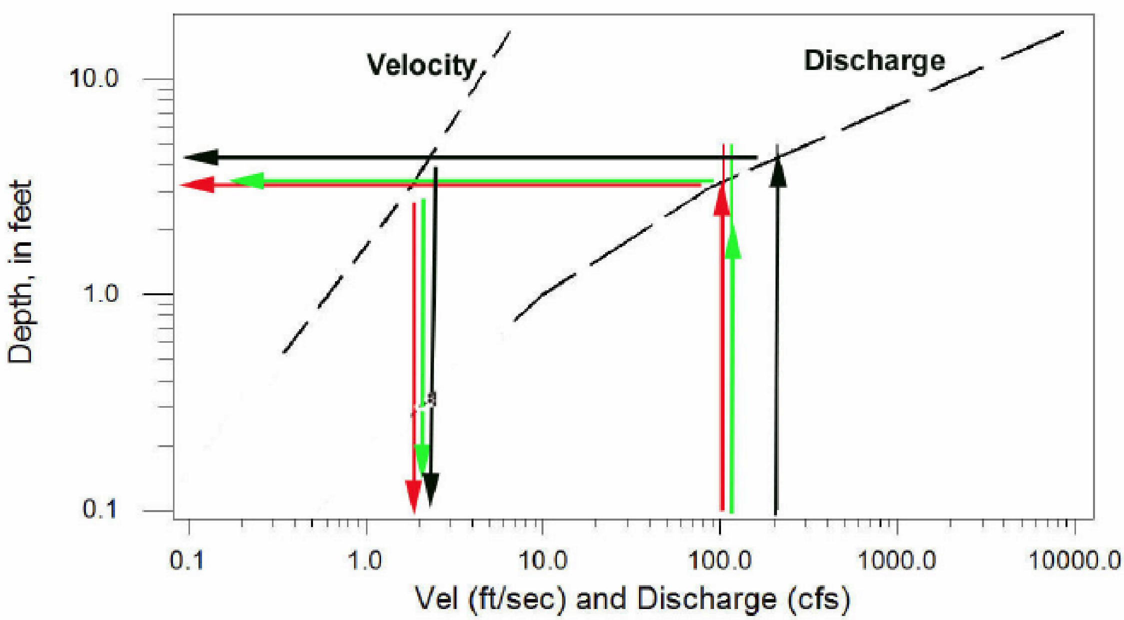

Verde River at USGS gage 09504000. View looking upstream at channel approaching gage. Q = 62 cfs.
Mile 36.6
Railroad
© 2013 Google
Image Landsat
© 2013 INEGI
Google earth
2003
Imagery Date: 5/28/2013

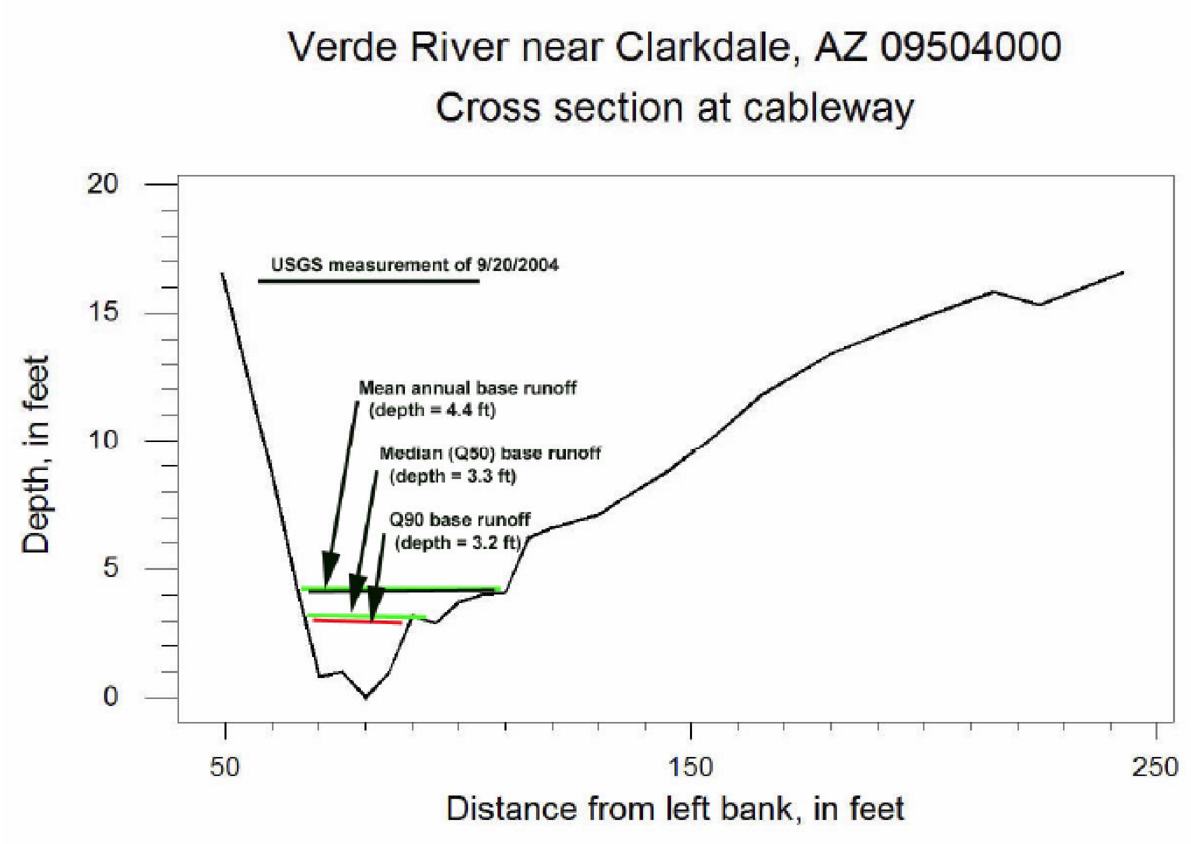


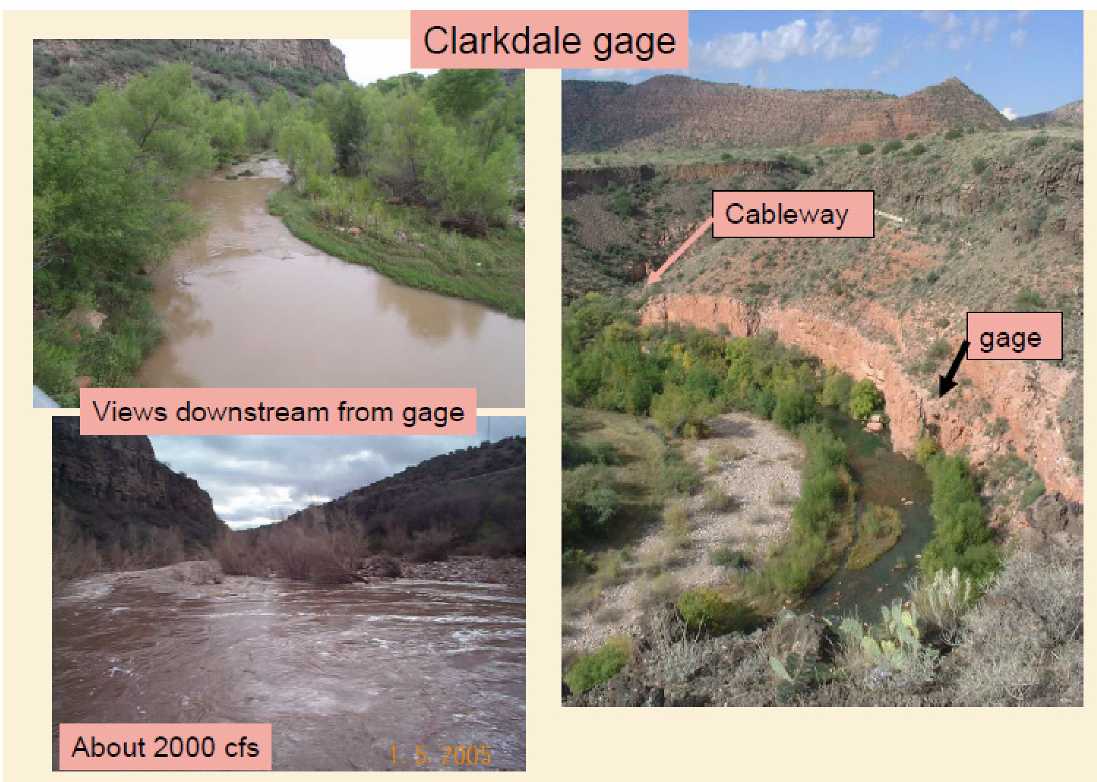
Verde River near Clarkdale, Az 09504000

USGS current meter measurement at cableway

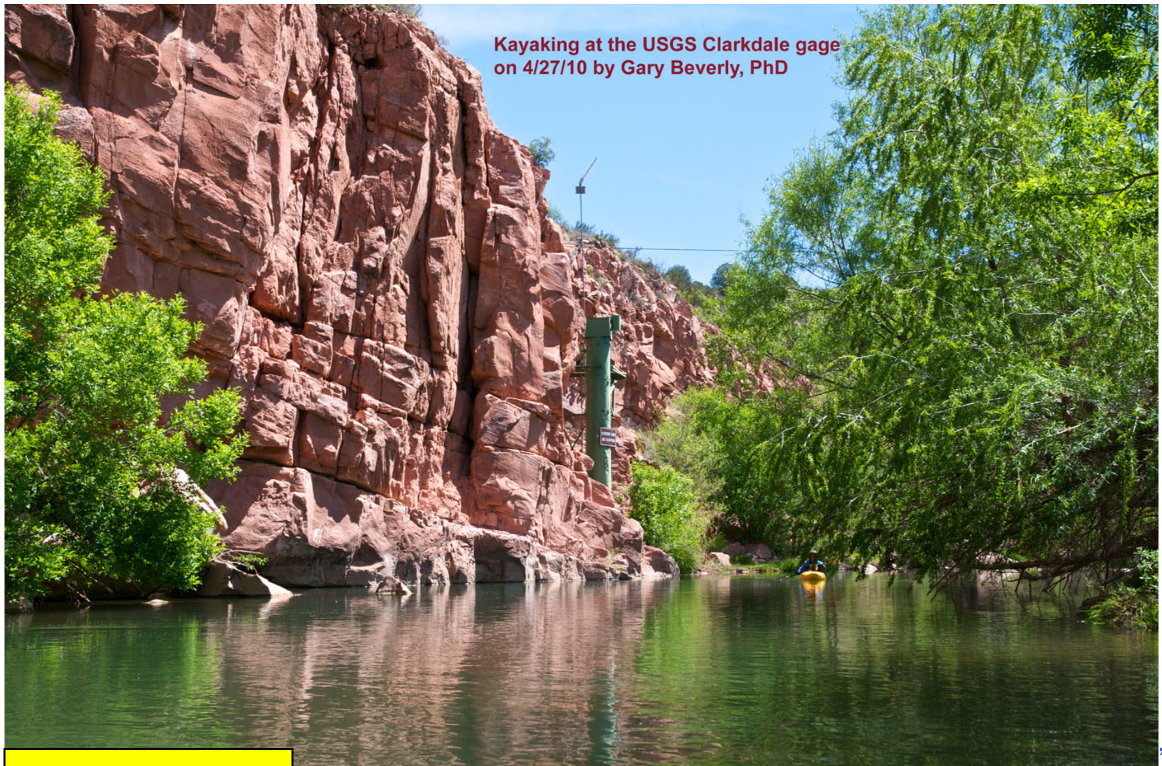
DATE 09/20/2004




Verde River near Clarkdale, AZ 09504000
Cross section at cableway
USGS measurement of 9/20/2004
Mean annual base runoff
(depth = 4.4 ft)
Median (Q50) base runoff
(depth = 3.3 ft)
Q90 base runoff
(depth = 3.2 ft)
Depth, in feet
0
5
10
15
20
50
150
250
Distance from left bank, in feet


Clarkdale gage
Views downstream from gage
About 2000 cfs
Cableway
gage

usgs photos



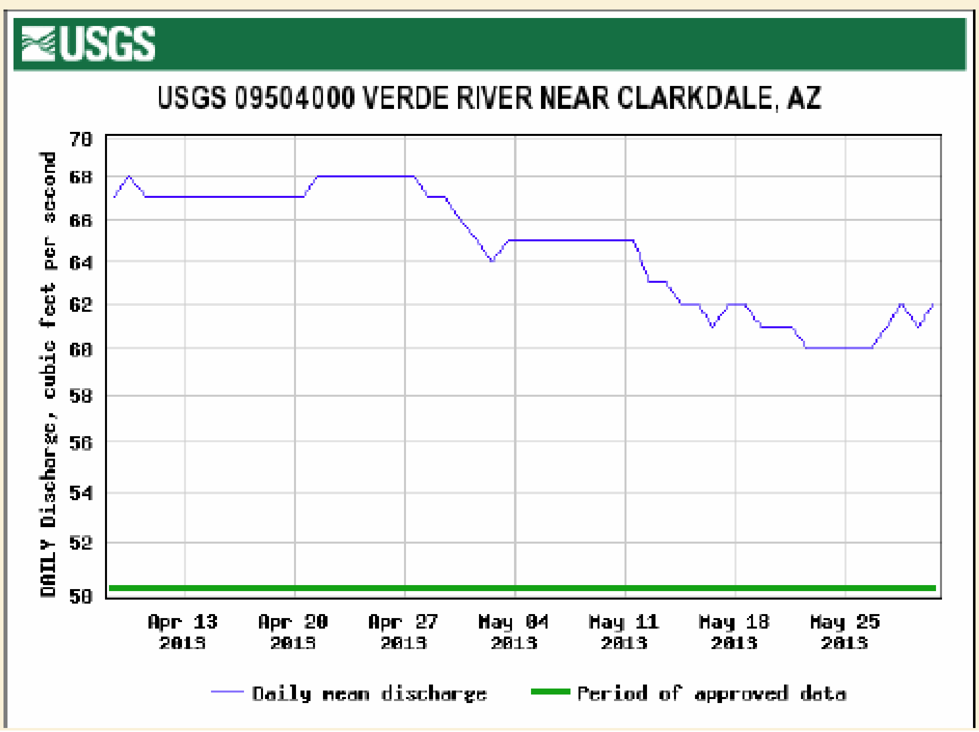
Boating at USGS Clarkdale gage

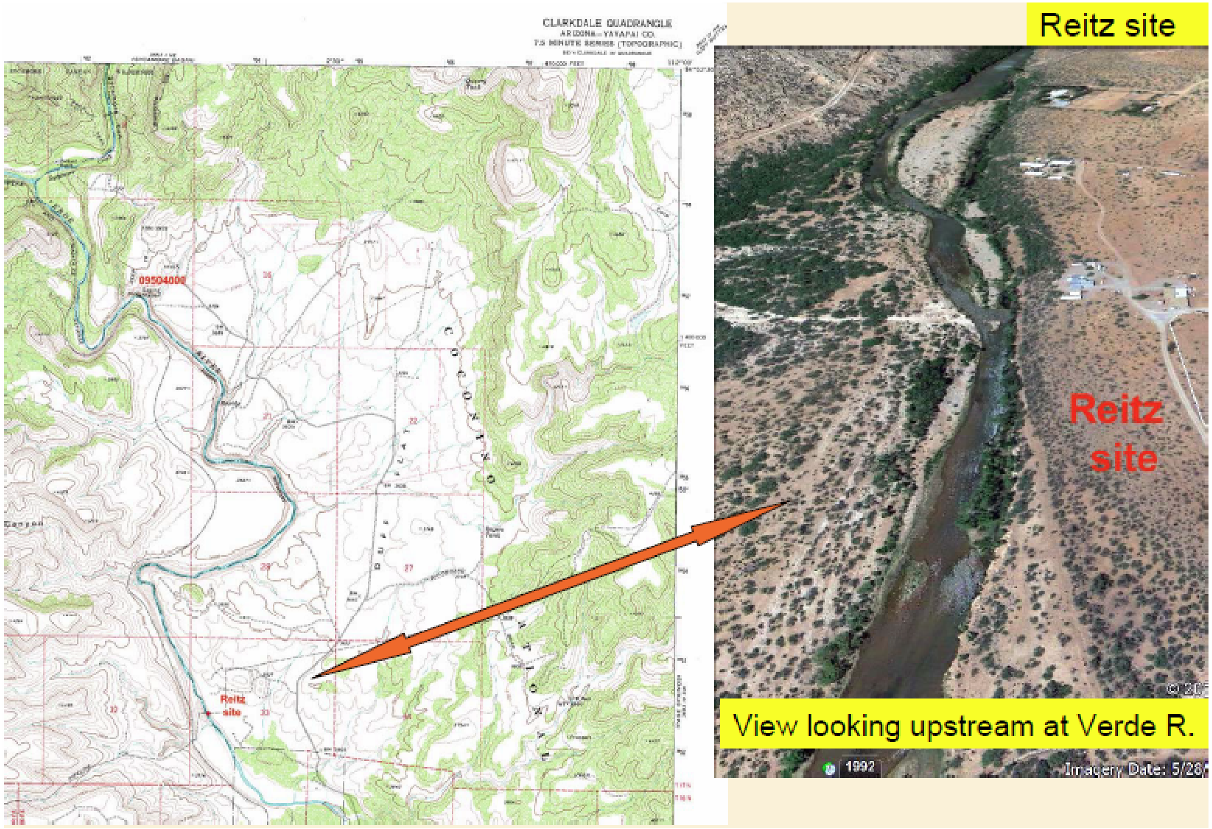
usgs photos

Clarkdale gage

Views downstream from gage

The riffle to the left "drowns out" as discharge increases as shown in the photo below. It's common for riffles and "section controls", where critical velocities exist, to become channel controls with sub-critical flow velocities as stage increases. Thus, I would expect fewer riffles under natural when the base flow was large.





This site is below the study reach and is shown to give the reader a sense of continuity for the entire watershed.

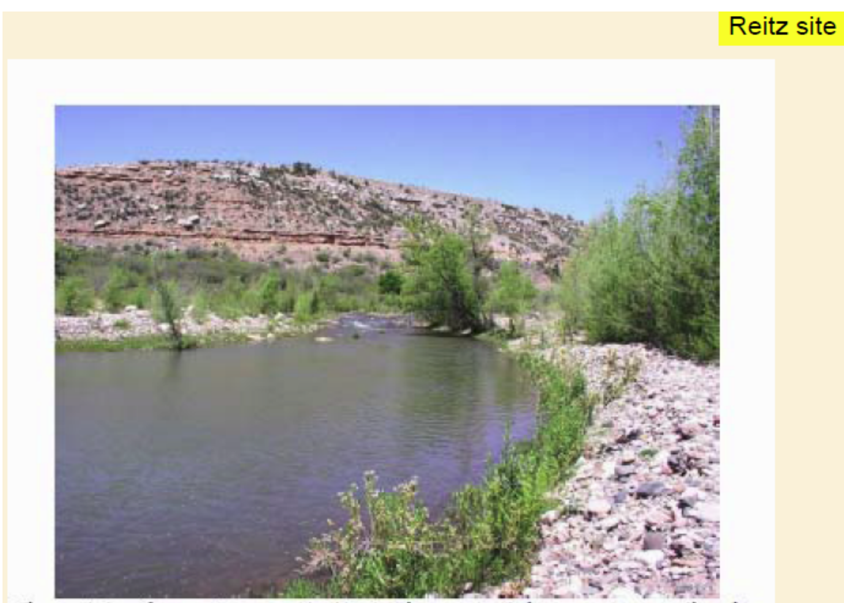
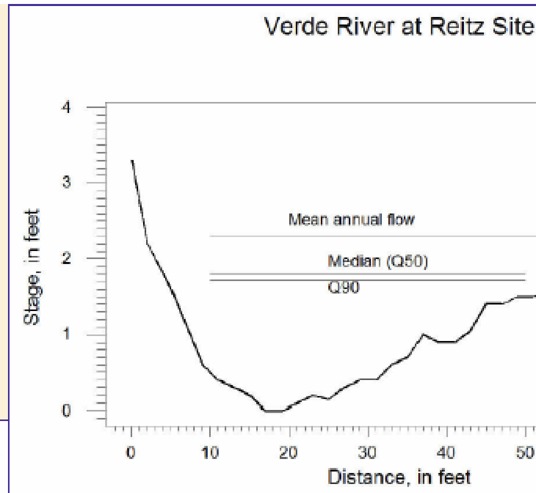
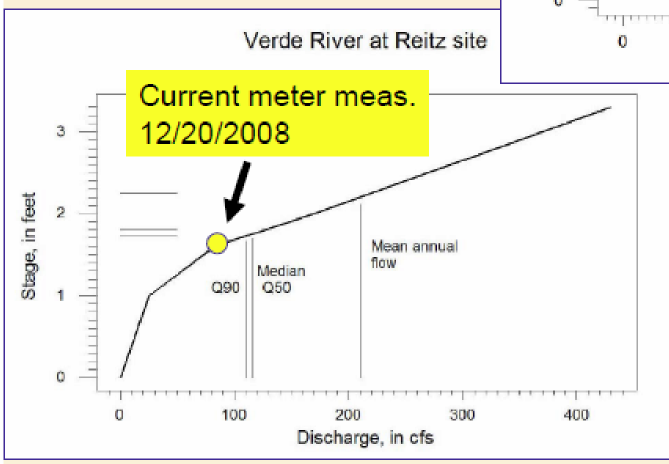


Figure 4. Looking upstream on the Verde River at the Reitz property sampling site
Photo credit: Carole Piszczek-Sheffield

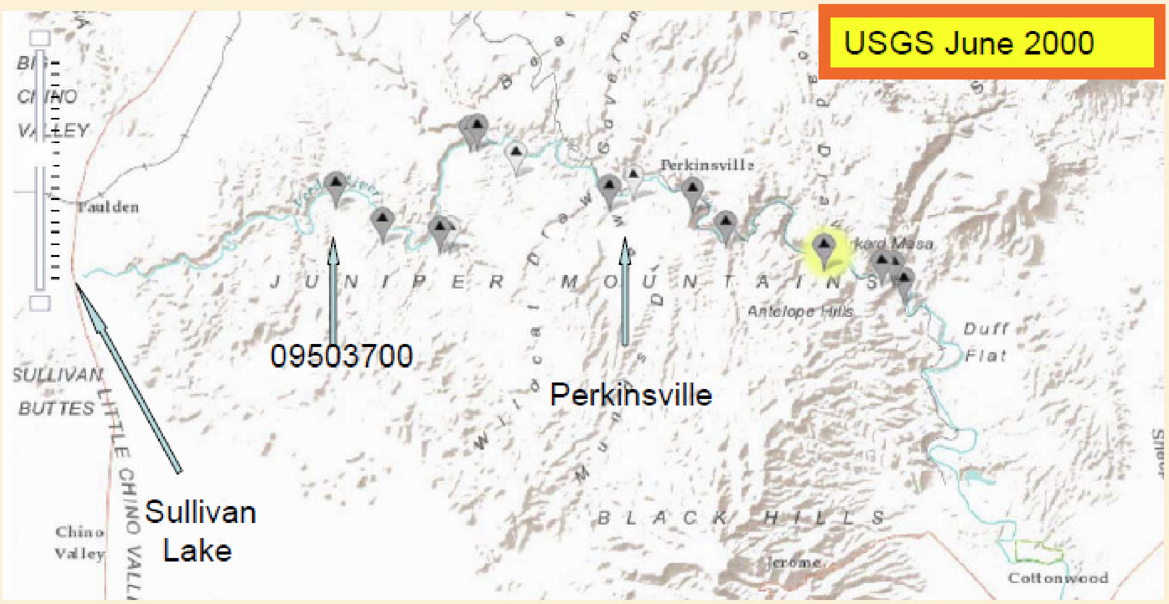
UPPER REACH
(Paulden to Clarkdale)

Reitz site





Stage ft	width ft	area sq ft	Discharge cfs	vel ft/s
0.0	0	0.0	0.0	0.00
1.0	29	19.7	25.0	1.30
1.6	48	43.4	82.4	1.90
2.0	55	64.0	170.0	2.66
3.3	65	131.0	430.0	3.28

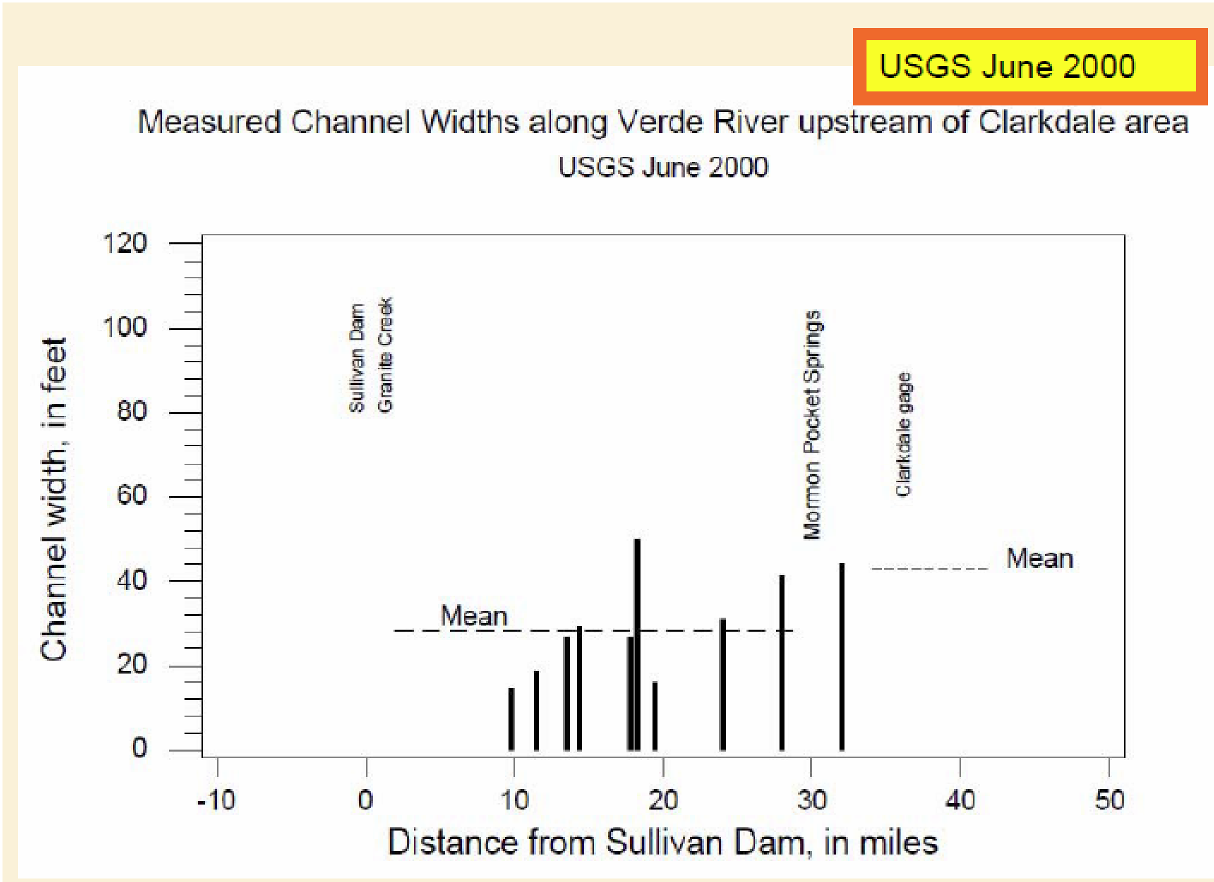


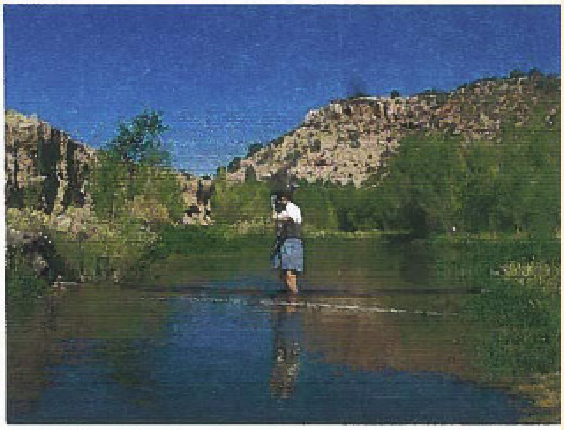
USGS measurement sites of June 13 and 14, 2000.

USGS data for June 13 and 14, 2000

USGS June 2000

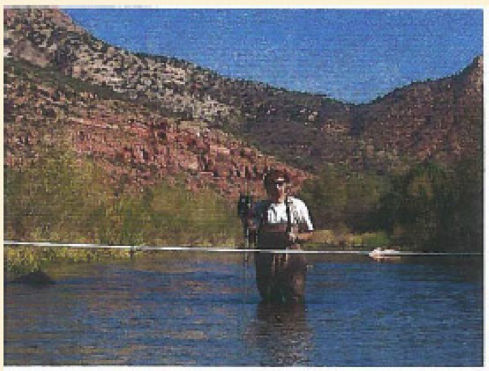
Miles (approx.)	Site name	Discharge cfs	Width ft
0	Sullivan Dam		
9.8	Verde River near Paulden	21.0	14.8
11.5	VERDE RIVER AT BULL BASIN CANYON	19.0	18.7
13.5	VERDE RIVER ABOVE DUFF SPRING	20.0	26.8
14.4	VERDE RIVER BELOW DUFF SPRING 2	23.0	29.2
17.8	VERDE RIVER ABOVE HELL CANYON	19.0	26.6
18.2	VERDE RIVER BELOW HELL CANYON	17.0	50.0
19.4	VERDE RIVER AT US MINE 2	17.0	15.9
23.7	VERDE RIVER ABOVE PERKINSVILLE DIV.	*	*
24	VERDE RIVER NR PERKINSVILLE	15.0	31.0
26	VERDE RIVER BELOW ORCHARD FAULT	*	*
28	VERDE RIVER ABV MORMON POCKET	26.0	41.4
32	VERDE RIVER NEAR BM 1813 (abv Syc. Ck)	58.0	44.2


USGS June 2000
Measured Channel Widths along Verde River upstream of Clarkdale area
USGS June 2000
Channel width, in feet
120
100
80
60
40
20
0
Sullivan Dam
Granite Creek
Mormon Pocket Springs
Clarkdale gage
Mean
Mean
-10
0
10
20
30
40
50
Distance from Sullivan Dam, in miles

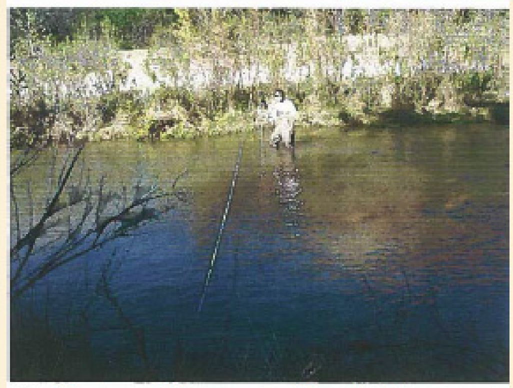


2 miles below Stewart Ranch

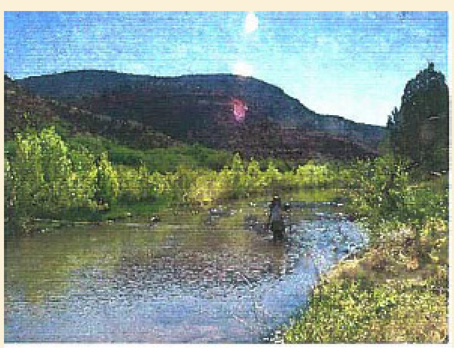
Below Hell Canyon



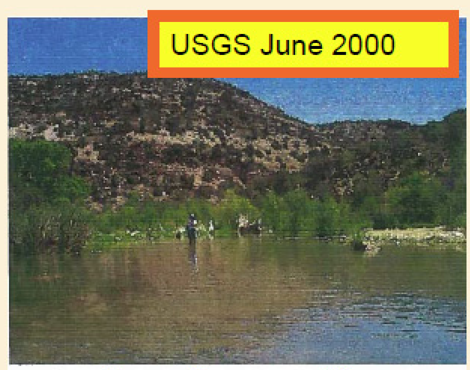
?



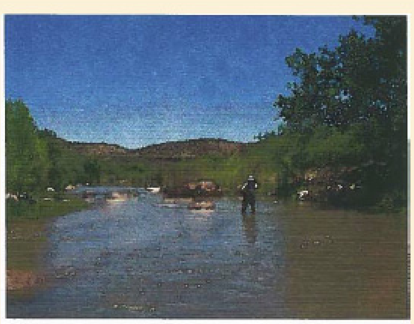
Below Mormon Pocket



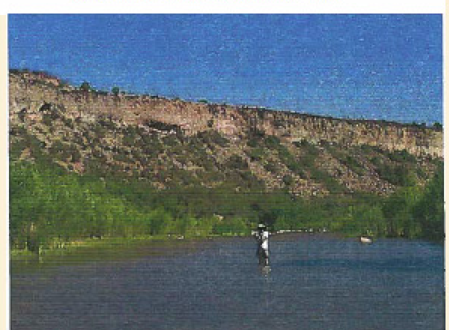
North of BM 1813 abv Sycamore Ck



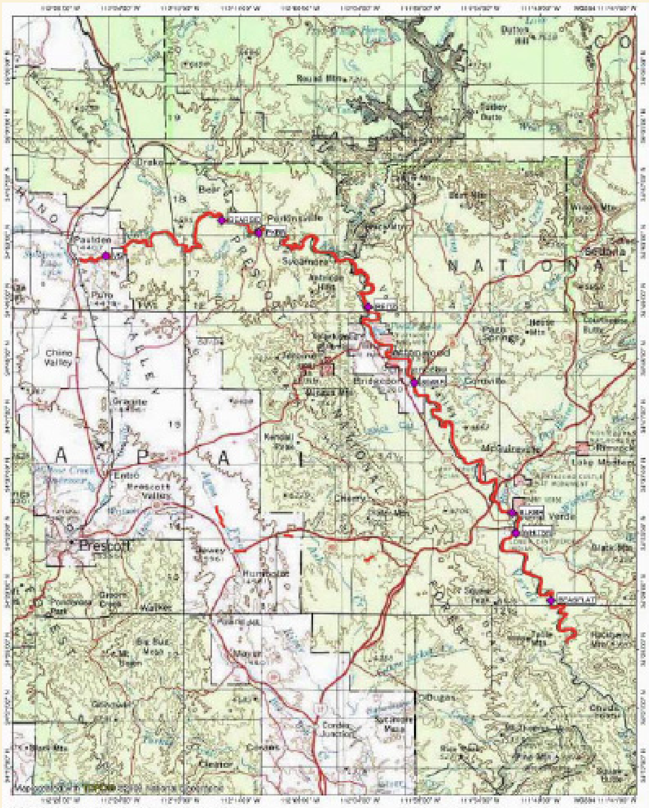
Above Sycamore Ck



1000 ft north of Sycamore Ck



Below Sycamore Ck



Water Sentinels Sampling Sites

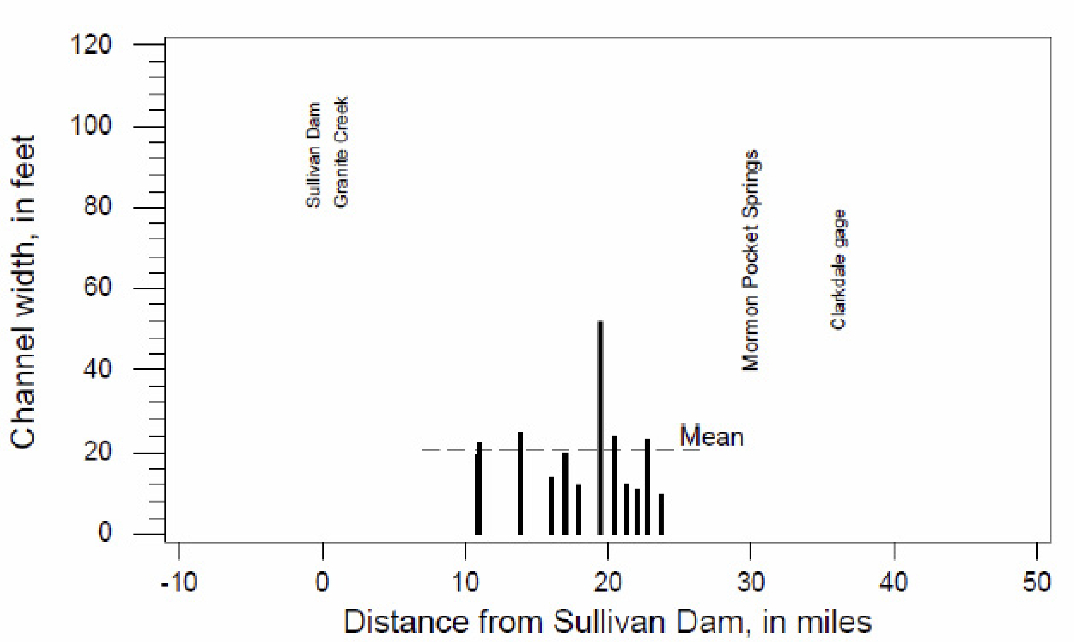
Sierra Club 2013

Miles	Site	Q cfs	W ft
9.8	Paulden gage		*
10.2			*
10.4			*
10.8	SR01	17.46	19.7
11.0	SR02	16.35	22.4
11.5	SR03	*	*
13.0	SR04	18.27	25.0
16.0	SR05	16.00	14.0
17.0	SR06	14.42	20.0
18.0	SR07	16.49	12.0
19.4			52.0
19.7	SR08	11.85	*
20.5	SR09	11.59	24.0
21.3	SR09A	11.86	12.5
22.0	SR10	11.42	11.0
22.8	SR11	12.8	23.0
23.7	SR12	13.9	9.8

Sierra Club 2013

Measured Channel Widths along Verde River upstream of Clarkdale area

Sierra Club June 2013



Following 6 cross sections surveyed by USFS during April-May 2009 furnished by Daniel Neary.

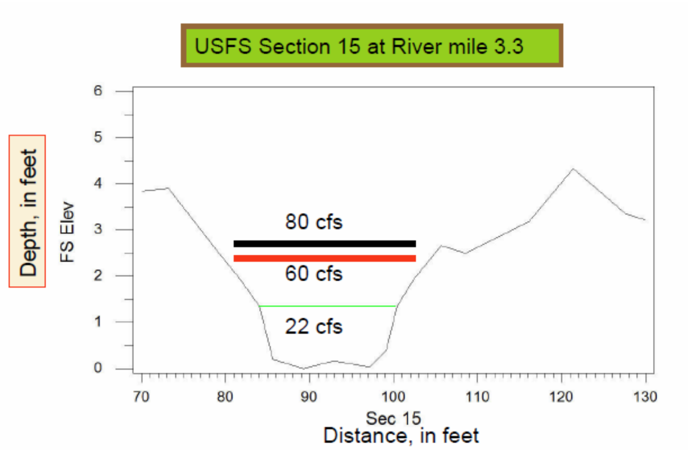
Neary, Daniel G.; Medina, Alvin L.; Rinne, John N., eds. 2012. **Synthesis of Upper Verde River research and monitoring 1993-2008.** Gen. Tech. Rep. RMRSGTR-291. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 296 p.

Rocky Mountain Research Station
2500 South Pine Knoll Drive,
Flagstaff, AZ 86001
USA

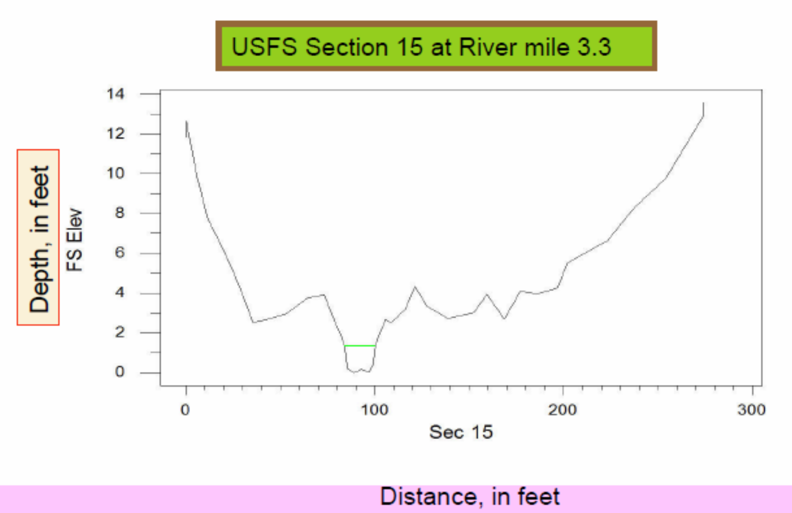
Dan Neary
PhD, CPSS, FSSSA, FASA, McMaster Fellow, OECD Fellow

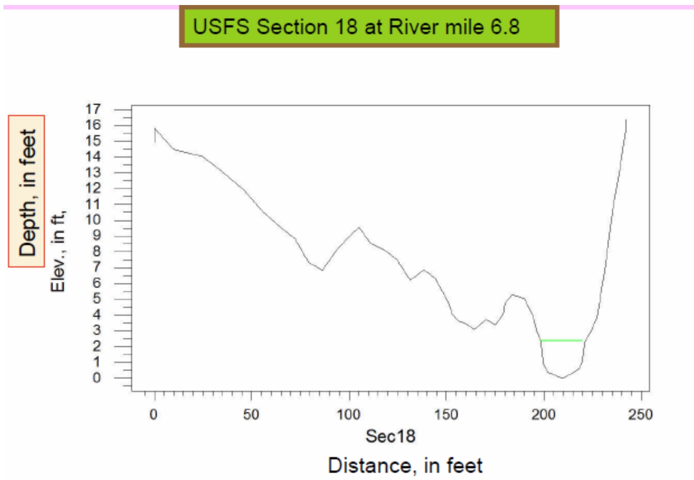
Rocky Mountain Research Station

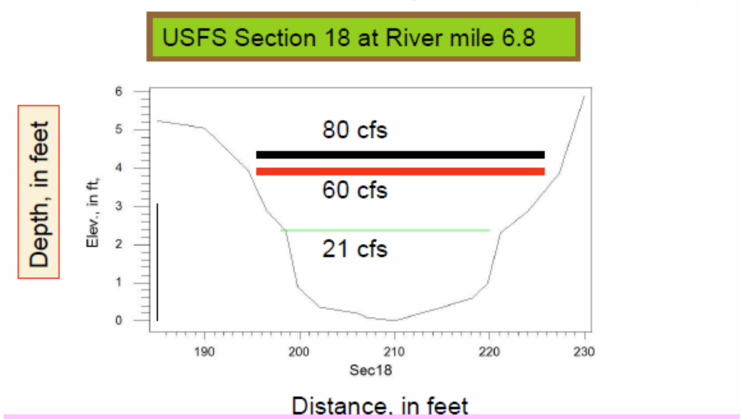
NOTE: The USFS has surveyed 108 stream cross-sections in the upper Verde River. Because this large number would overwhelm my ability to produce a navigability analysis for ANSAC in a reasonable amount of time, I asked Dan Neary, PhD to furnish a few representative cross sections. Mr. Neary graciously furnished the cross sections and current meter measurements that follow.

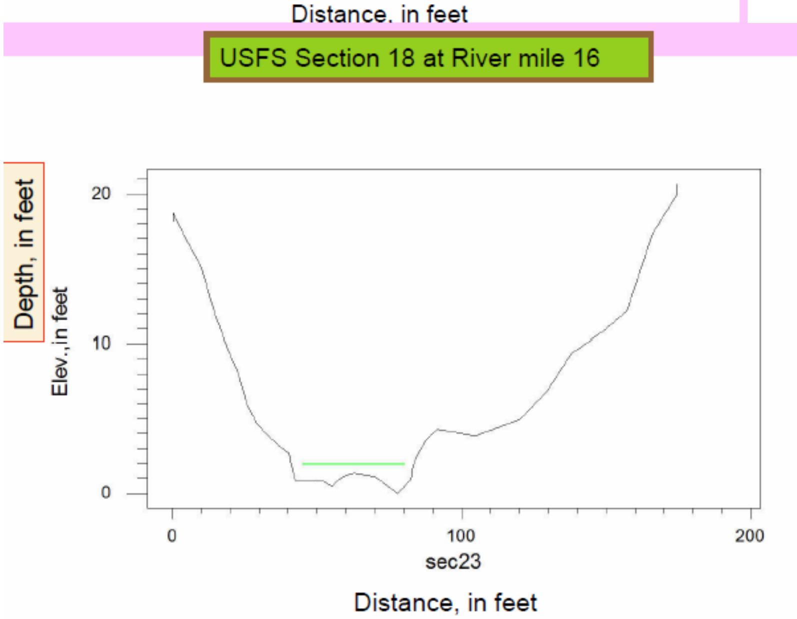


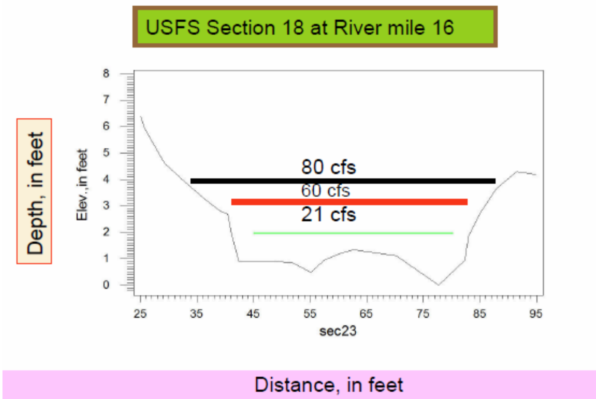
Black line is average annual discharge and red line is Q50 (median). Typical.

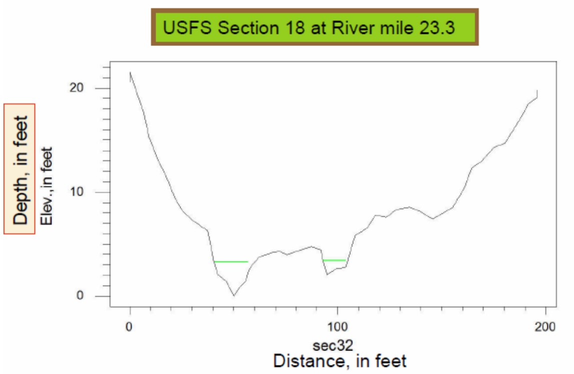


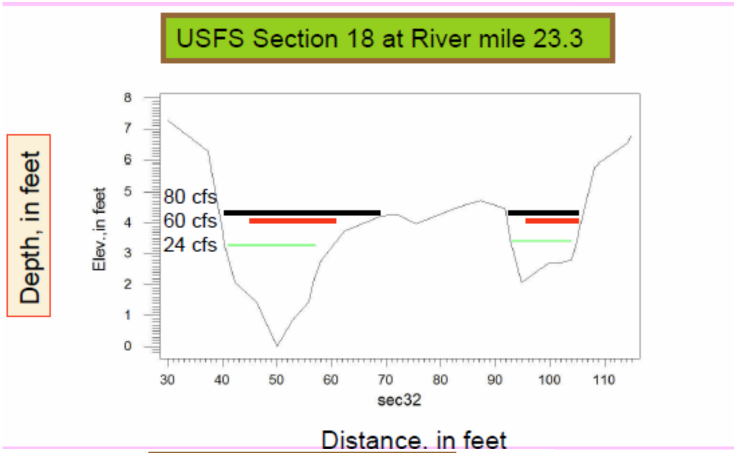

USFS Section 18 at River mile 6.8
Depth, in feet
Elev., in ft,
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
0
50
100
150
200
250
Sec18
Distance, in feet

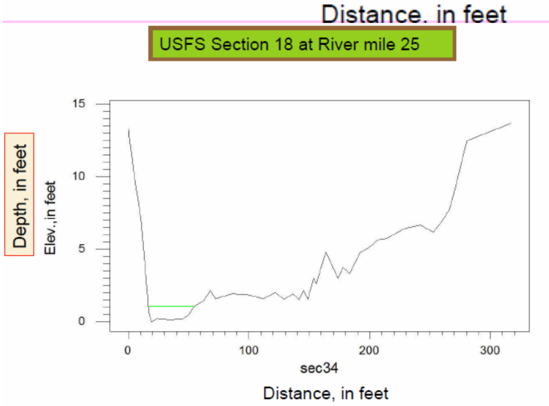

USFS Section 18 at River mile 6.8
Depth, in feet
Elev., in ft,
80 cfs
60 cfs
21 cfs
0
1
2
3
4
5
6
190
200
210
220
230
Sec18
Distance, in feet

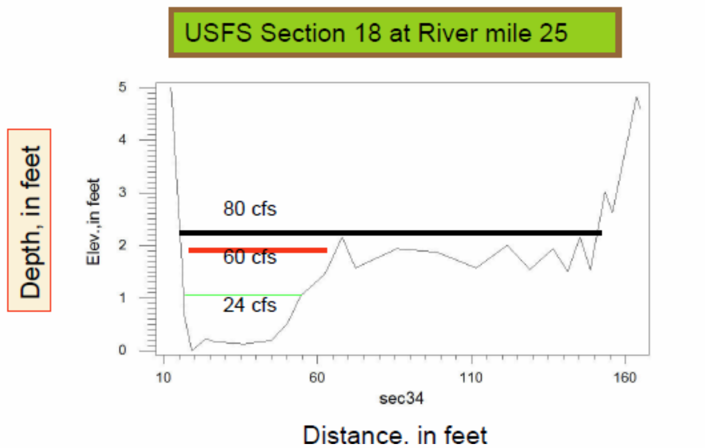

USFS Section 18 at River mile 16
Depth, in feet
Elev.,in feet
0
10
20
0
100
200
sec23
Distance, in feet

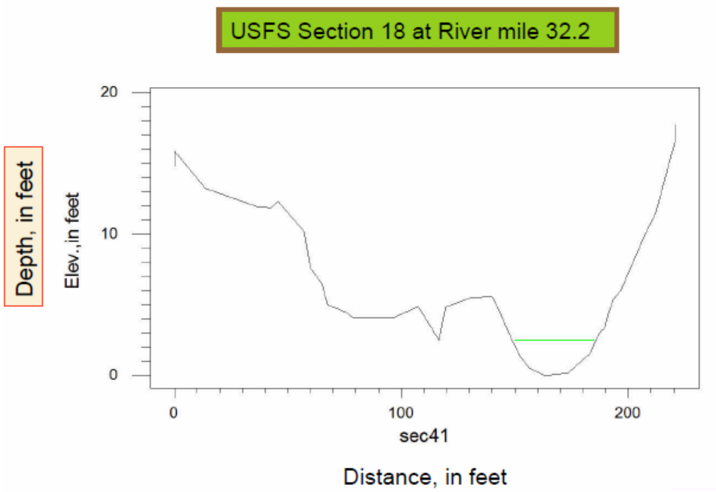

USFS Section 18 at River mile 16
Depth, in feet
Elev.,in feet
80 cfs
60 cfs
21 cfs
sec23
Distance, in feet

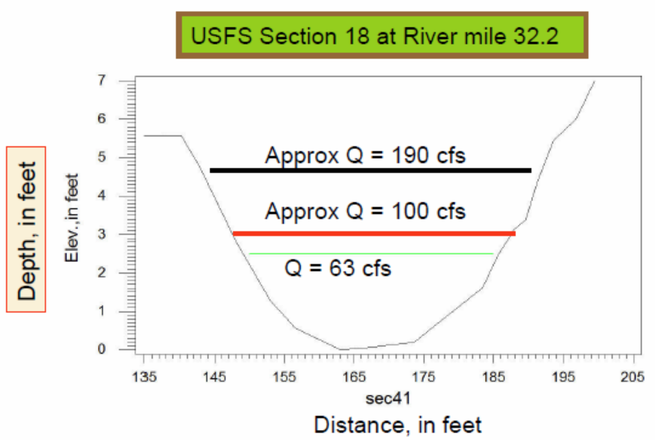

USFS Section 18 at River mile 23.3
Depth, in feet
Elev.,in feet
sec32
Distance, in feet

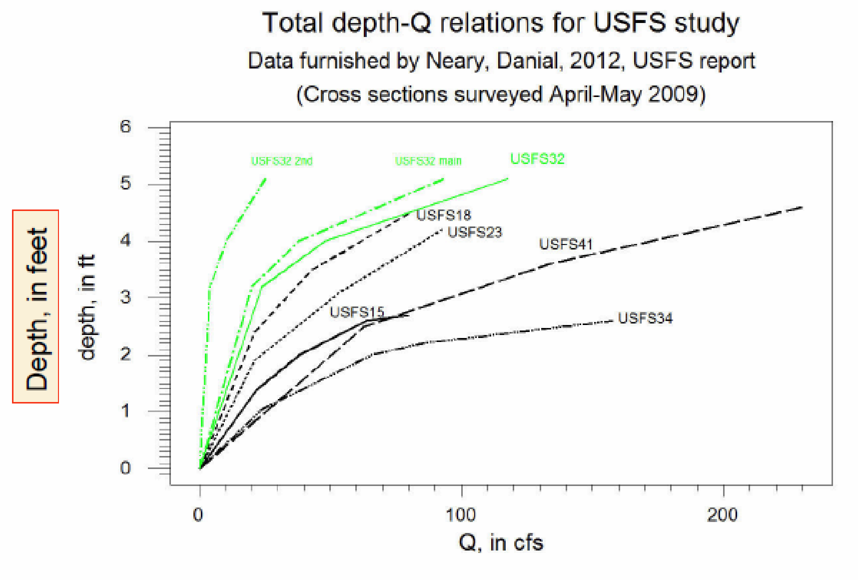

USFS Section 18 at River mile 23.3
Depth, in feet
Elev.,in feet
80 cfs
60 cfs
24 cfs
sec32
Distance, in feet


USFS Section 18 at River mile 25
Depth, in feet
Elev.,in feet
sec34
Distance, in feet


USFS Section 18 at River mile 25
Depth, in feet
Elev.,in feet
80 cfs
60 cfs
24 cfs
5
4
3
2
1
0
10
60
110
160
sec34
Distance. in feet


USFS Section 18 at River mile 32.2
Depth, in feet
Elev.,in feet
20
10
0
0
100
200
sec41
Distance, in feet

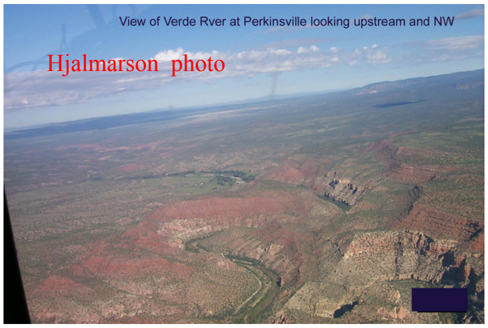

USFS Section 18 at River mile 32.2
Depth, in feet
Elev.,in feet
Approx Q = 190 cfs
Approx Q = 100 cfs
Q = 63 cfs
7
6
5
4
3
2
1
0
135
145
155
165
175
185
195
205
sec41
Distance, in feet



4.-- Energy and morphology considerations

Notes on hydraulics, hydrology, geomorphology and energy
along the Upper Verde River

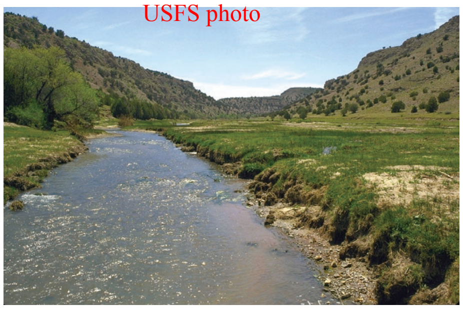
Like any other semi-arid watershed a little more water falls as precipitation than is lost by evaporation and transpiration from the land surface to the atmosphere. Thus there is a small excess of water that escapes ET which flows down the Verde River. The very upper part of the Verde River is atypical because a relatively large percentage of the precipitation is infiltrated into the ground and flows underground to the Upper Verde River springs located mostly between Granite Creek and the USGS gage near Paulden. This provides a form of storage or regulation that sustains the flow of the river during dry periods. This groundwater underflow (See diagram of groundwater-base runoff in Figure 3) becomes what is called base flow and for the Upper Verde River it is a relatively large portion of the total river flow.



The Verde River channel has been formed (evolved through geologic time) within an ancient meandering channel carved in bedrock and forming the canyon. The forces involved in shaping and maintaining the present channel in the sediment and rock debris appear to be much different from the fluid flow and forces that formed the canyon. In a sense the Verde River is a sinuous river that resides in a sinuous canyon formed during ancient time.

The transport of sediment debris by rivers like the Verde River is common knowledge. The forces (eg.-shear forces) involved in shaping and maintaining the channel are related to both the amount and duration of water flow. As flow (energy) in this scene increases, the silt and sand can become suspended in the flow and the gravel, cobbles and small boulders can be moved by pushing, rolling and skipping. The rate of sediment transport is much less for base flow than flood flow but the duration of base flow is considerably longer.

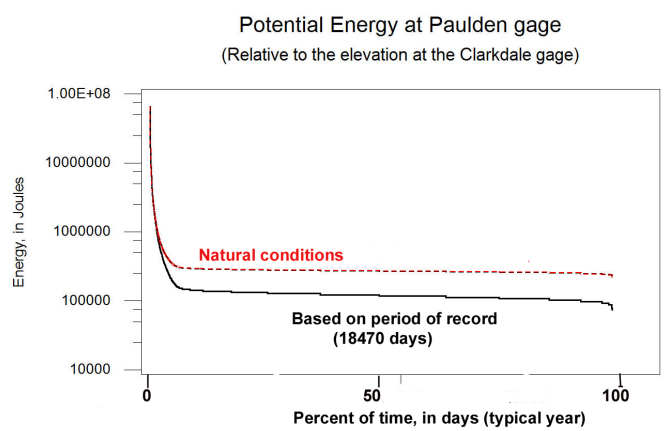
Photo above of cobbles near Sycamore Canyon. (Photo by James Cowlin USFS).



If the shearing force on the channel banks is sufficient to overcome the cohesion of the bank materials, erosion takes place, and the eroded particles are swept away from their original position and become a part of the bed materials, there either to be moved or temporarily lodged.

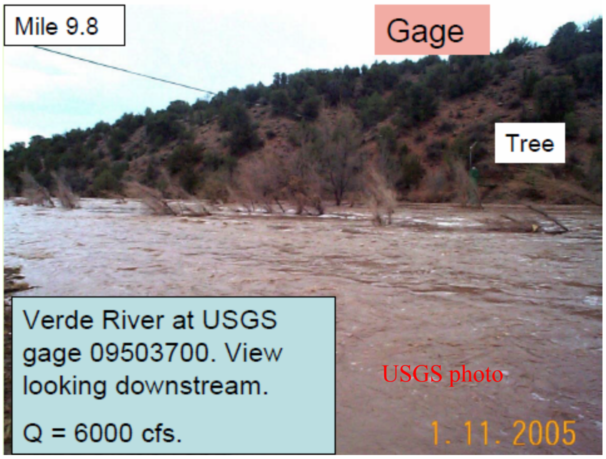
The total potential energy of the streamflow at the Paulden gage is shown to the right. This energy was available to overcome turbulence and friction along the channel and to the form the channel down to the Clarkdale gage. (Elevation drop = 617 ft.)

20% of the natural energy for the period of record is during the 1% of days with greatest flow.



The total energy of the 18470 days of record was 58% of the total natural energy. The difference between the two relations is the energy lost along the Verde River because of human effects.

There is not a linear relation between total potential energy and (1) the sediment transport and (2) the forming of the river channel. However, the energy diagram shown here is an index of such a much more complex non-linear relation.



Scour of the channel bed occurs primarily during high discharges (high kinetic energy flow). Trees are uprooted and large debris (e.g. cobbles and boulders) is mobilized.

On the stream bed, scour takes place when the shear exceeds some critical value, and this occurs during relatively high flow. At low flow it is usual for the shearing forces on the bed to be sufficiently small that relatively few bed materials move. Scour, then, occurs primarily during high discharges. The relatively long time periods represented by modest and low flow are periods of relatively little movement of bed material—especially the larger material.

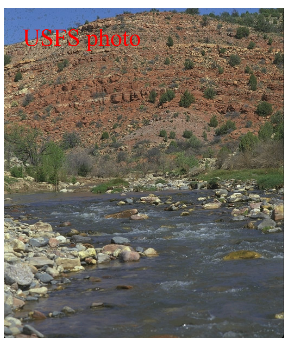


Photo of a USFS fish study site at Bear Siding in May 1979. Note the vegetation, water color, channel substrates, and stream bank conditions. The aquatic habitat is characterized as a typical C-3 type channel with interspersed riffles throughout the reach. (Photo by James Cowlin.)

An example of boulder debris shed from upstream side slopes and transported/deposited by larger flows. Deposits of boulder debris commonly form riffles along the Verde River.

An example of channel bed scour during high flow on Colorado River. The bed scours during high discharges and fills as discharge lessens.

Leopold, Luna B., 1960, Rivers, in American Scientist, v.50, no.4 (December), p.511-537.

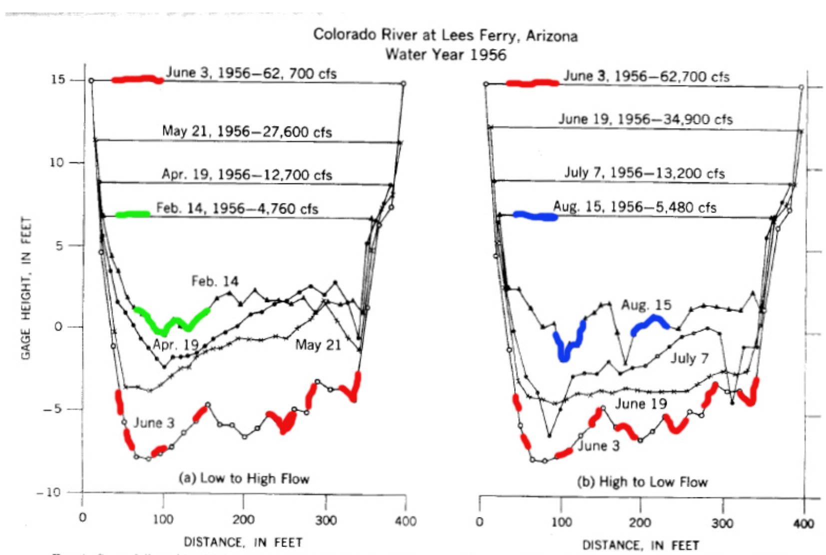
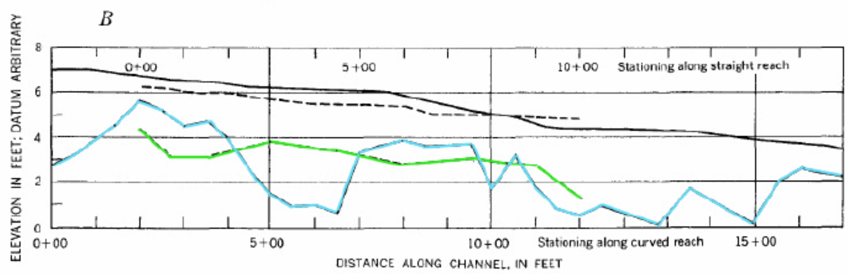


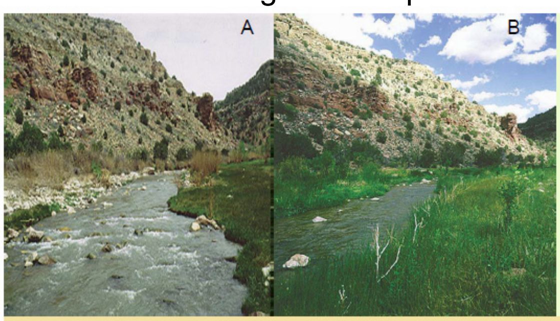
FIG. 4. Scour followed by fill during the passage of flood during snowmelt season, Colorado River at Lees Ferry, Arizona, 1956.

The beds of meandering segments of rivers have a more uniform gradient (smoother appearance and fewer/smaller riffles) than the beds of straight segments.



Langbein, W. B., and Leopold, Luna, 1966, River Meanders-theory of minimum variance; USGS Professional Paper 422-H, 15p.

Thus, meandering segments typically are smoother than straight segments. This typically small decrease of channel roughness is accompanied by an overall increase of Manning roughness coefficient requiring an adjustment for degree of meandering. (Jarrett, R., 1985, Determination of roughness coefficients for streams in Colorado, USGS Water-Resources Investigations Report 85-4004, 54p, page 17). Thus, meandering enhances navigability with a smoother channel bottom, lesser slope of the water surface and greater depth of flow.



UVR vegetation recovery and channel narrowing and deepening at a second site a decade before (A: 1979) and after (B: 2003) the 1993 floods, Verde River Ranch. (Photos by James Cowlin and Alvin L. Medina.)

An example of slope processes where debris is shed toward and into the river channel. Large debris (boulders) will remain as obstructions to navigation until moving downstream by continuous and high energy river flow.

Large debris (boulders) from side slopes. Obviously only very large, or high, (kinetic) energy flow will move such large obstructions. Also, energy is lost (with a corresponding decrease of velocity and increase in depth) as streamflow encounters this rough channel material.

The “Otter Rock” in the Upper Verde River channel in the Horseshoe Allotment in 1998, five years after the large 1993 flood. (Photos by Alvin L. Medina, USFS).

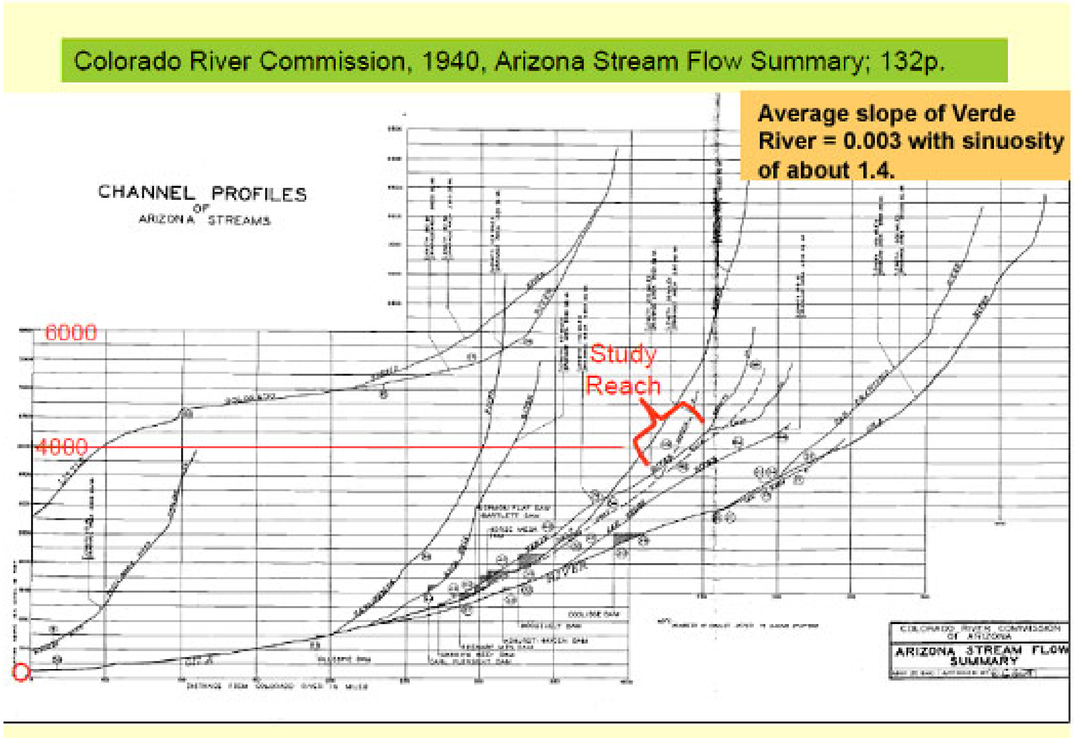
Where forces and shear stresses generated by base flow and/or frequent (small floods) events are incompetent to transport available materials, less frequent flows of greater magnitude are obviously required. Again, this non-linear effect of energy in streamflow is not considered in this general energy analysis. Otter Rock in this scene has been photographed by the USFS since 1993 and its unknown how long “Otter Rock” has been in the channel.

Photo to right is an aerial view of the Verde River Ranch headquarters 0.3 mile below the U.S. Geological Survey’s Paulden gauge in March 1997. The wetlands, intact for many decades, provide a valuable reference of wetland habitats of time past. (Photos by Alvin L. Medina.)

Many rivers are competent to erode both bed and banks during moderate flows. Observations of natural channels suggest that the channel shape as well as the dimensions of meandering rivers appear to be associated with flows at or near the bankfull stage. The fact that the bankfull stage recurs on the average once every year or two years indicates that these features of many alluvial rivers are controlled by these more frequent flows rather than by the rarer events of catastrophic magnitude.

The distribution of energy in a geomorphic system like the Verde River is one way of expressing the relative elevation of particles of water and of sediment which gradually will, in the process of landscape evolution, move downhill toward base level. The longitudinal profile of the Verde River, for example, is a statement of the spatial distribution of stream-bed materials with regard to their elevation and, thus, with regard to their potential energy.

The profile of the Verde and other rivers is shown below.



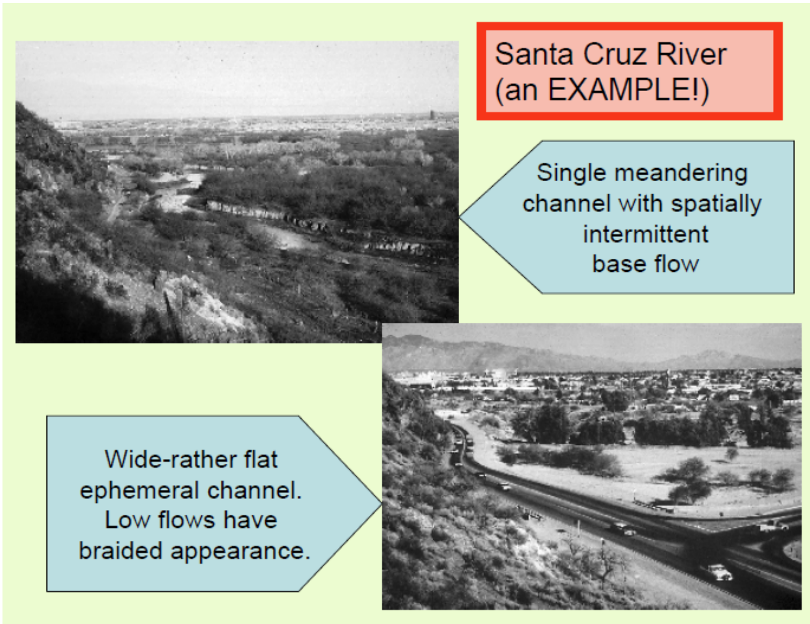
Systems in geomorphology, like heat energy based thermodynamic systems, also have a base datum with regard to the distribution of energy. For rivers the base datum is elevation, in many cases represented by mean sea level.

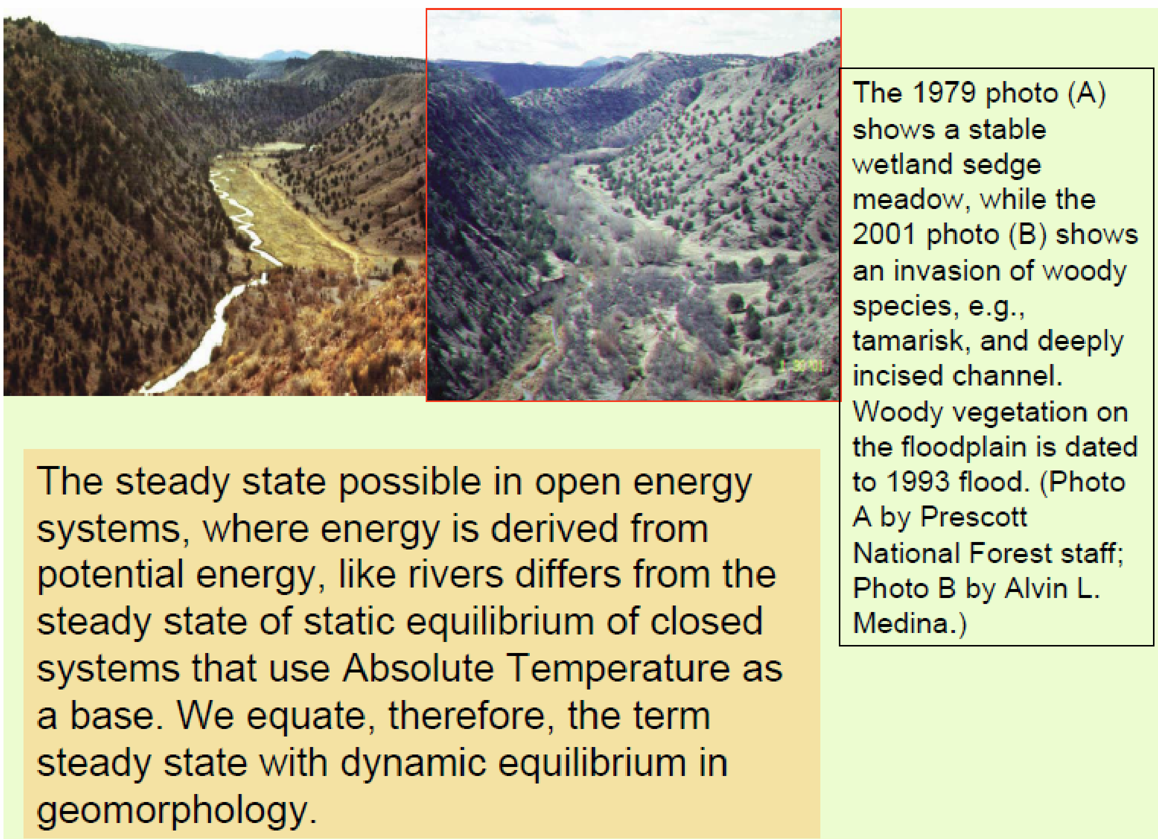
A river system, then, we consider to be an example of an open system, defining the system as the water and the debris in the river channel that travels for an elevation to a lower elevation.

As the water flows down the channel it gives up potential energy which is converted first to kinetic energy of the flowing water and which in the process of flow is dissipated into heat along the channel margins. Precipitation brings increments of energy into the system because water enters at various elevations and thus with various amounts of potential energy. Heat is lost by convection, conduction, or radiation, yet the channel may be considered in dynamic equilibrium.

In other words, when settlers consumed water in tributary streams some of the energy that formed the Verde River channel was removed. When all of the base flow is removed from rivers like the Verde, the rivers become ephemeral and the natural river channel is lost. The channels of many rivers in Arizona, for example the lower Gila, San

Pedro, Santa Cruz, etc., have become braided and normally dry because base flow has been removed by humans. An example for the Santa Cruz River is shown below.





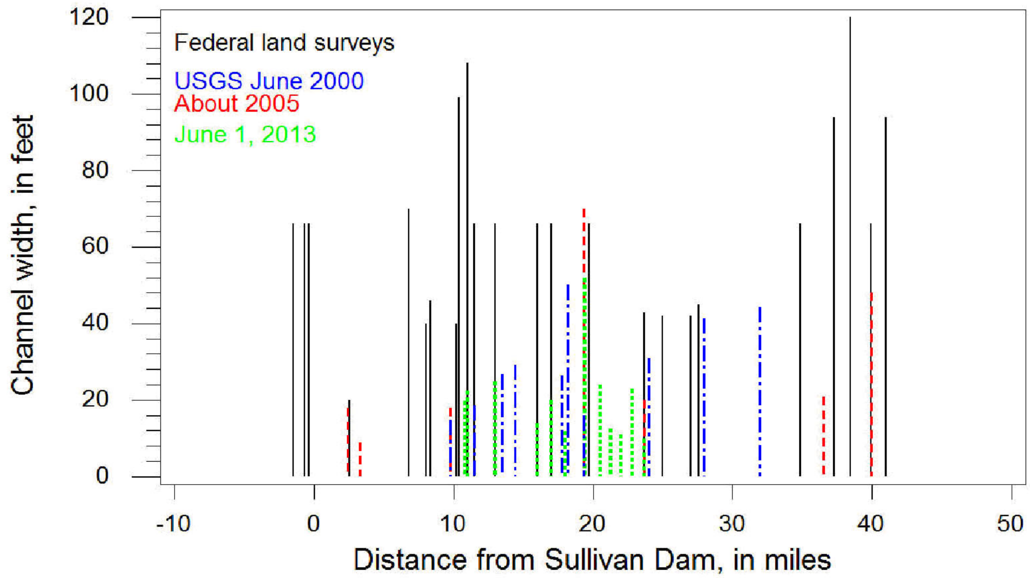
A relatively stable low-flow channel is described by Pearthree (1996, p.7). "During the past several million years, the Verde River has downcut hundreds of feet, occasionally leaving terrace deposits behind as a record of former valley floors. Because of this long-term downcutting, the Verde River is confined within a steep, narrow valley along much of its length. In these confined reaches, the floodplain is limited in extent, and the potential for changes in channel positions is also limited." (Pearthree, P. A., 1996, Historical Geomorphology of the Verde River, Arizona Geological Survey Open-File Report 96-13, 29p.). There is a series of pools (deep water areas) and riffles (shallow water areas typically dominated by cobbles and small boulders) throughout the Upper Verde River. While there is potential for changes in channel morphology and shifts in channel position during large floods the recent alluvium is stabilized by cobble and boulder deposits, largely from tributaries, and vegetation along the river banks.

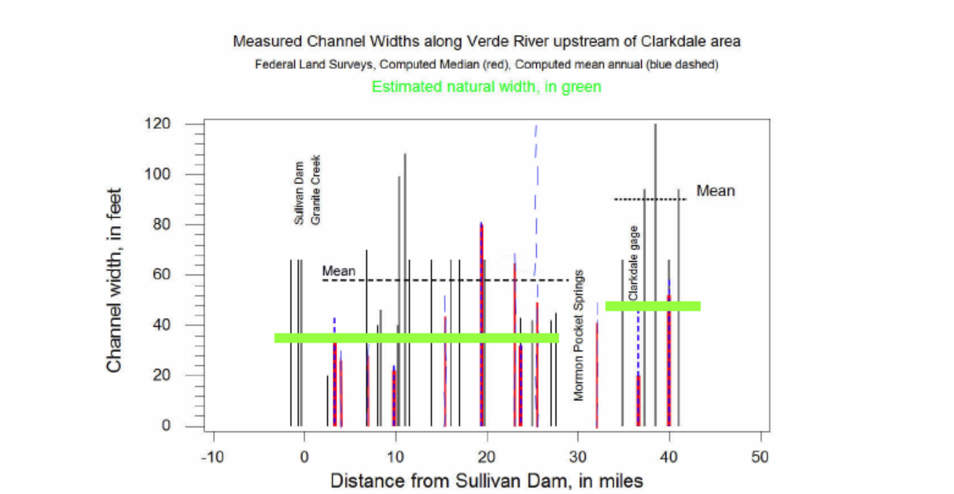
Based on observations of the river channel, the cross-sectional geometry (size and shape), there is no obvious change resulting from the human depletion of base flow. Perhaps the present base flow has been sufficient to maintain the main channel. The channel conditions at the Campbell Ranch and Perkinsville Ranch irrigation diversion sites appear unchanged. Also, the computed natural mean annual flow for this study typically is within the banks of the present main channel of the Verde River. In fact, at several cross sections (See prior section 3.-- Recent channel geometry with several photos, channel cross sections, and current meter measurements.) the natural mean annual flow is at the top of the banks of the main channel suggesting it is the channel forming discharge. I've recently discussed this issue with Dan Neary (PhD, USFS) and there are reasons, such as impoundment of tributary sediment at the many reservoirs and stock ponds, to expect a change in the natural channel of the Upper Verde River. However, because any possible change of the morphology of the Upper Verde River appears to be small, probably associated with the long-term channel downcutting (Pearthree, 1996, p.7), in this assessment, the present river channel is assumed to be like the natural channel before human impact. Also, many of the riffles along the entire Verde River are formed at the mouths of tributaries where sediment debris is dumped into the main channel.

5.-- A summary, additional comments with comparison of channel condition for recent and Federal Survey conditions.

Surveyed channel widths of the original land surveys are considerably greater than measured widths. There was close agreement only at two sites (near miles 20 and 27). Thus, a considerably greater natural base flow before more recent human activity is strongly suggested as determined in the hydrology section of this report.

Measured Channel Widths along Verde River upstream of Clarkdale area





Estimated natural channel width is for typical channel and gradual riffles and does not include pooled areas where hydraulic backwater conditions exist.

The computed depths for natural flow along the upper Verde River are shown below. These depths are for the surveyed and measured cross sections previously shown in the Hydraulics section of this report. The cross sections typically are for a single channel except one section includes a secondary channel with flow and another section includes a wide overflow area. Because the cross sections are for measurements of river discharge where deep pools are avoided, the depths are less than depths of the numerous pools along the Upper Verde River. Also, the shallow depths represent the riffle condition for the relatively short reaches of the pool and riffle channel system of the Upper Verde River. Aside from this limitation (bias), the cross sections, along with the numerous photographs previously shown, are a depiction/estimate of natural channel conditions in the study reach.

Location	Mean annual		Median		Q90	
	Q cfs	Max. Depth ft	Q cfs	Max. Depth ft	Q cfs	Max. Depth ft
mile 0						
mile 3.3	80	2.7	60	2.4	54	2.3
Srp	80	2.9	60	2.6	54	2.5
mil 6.8	80	4.4	60	3.9	54	3.8
Paulden	80	2.8	60	2.4	54	2.4
mile 16	80	3.9	60	3.3	54	3.2
Bear Siding#	80	3.4	60	3.1	54	3.0
mile 23.3	80	4.4	60	4.2	54	4.1
Perkinsville	80	2.8	60	2.5	54	2.5
mile 25	80	2.2	60	1.9	54	1.9
mile 32.2	190	4.2	100	3.0	94	2.9
Clarkdale	211	4.3	116	3.1	110	3.0

The depths represent the expected range that would have been encountered along the natural pool-riffle channel for normal conditions. It's important to keep in mind that most of the Upper Verde River is pools and that riffles occupy a much smaller portion of the river. Thus, typical depths for natural conditions along the reach from mile 3.3 downstream to the USGS Clarkdale gage are at least 3.5 ft (mean annual), 3.0 ft (median, Q50) and 2.9 ft. (Q90). Also, the depths closely represent depths along a potential navigation lane (or corridor) used for small water craft.

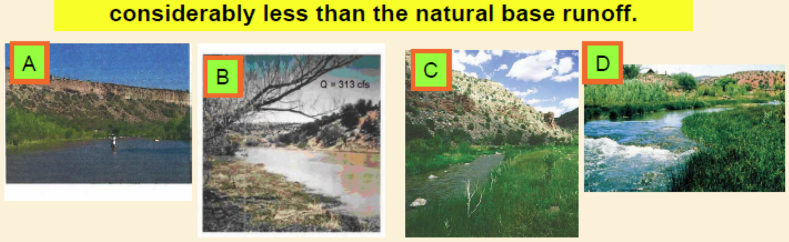
Velocities of natural base runoff typically are less than 3 ft/sec. (A below)

For discharge less than 500 cfs the velocities typically are less than 4-5 ft/sec. (B)

Flow velocities typically are subcritical except along the main thread of flow at a few rapids. (C)

There are few cobble/boulder "falls" that are small but where velocities of flow are critical. (D)

Note: Flow shown in photos A, C and D is considerably less than the natural base runoff.



There are alternating pools and riffles along the Verde River and many of the riffles are located at the mouths of tributaries that dump flood debris into the Verde River. Most of the channel bed is gravel and cobbles with sand and boulders. These conditions are typical of nearly all perennial gravel bed streams and streams where the bed material is larger than coarse sand.

NAVIGABILITY

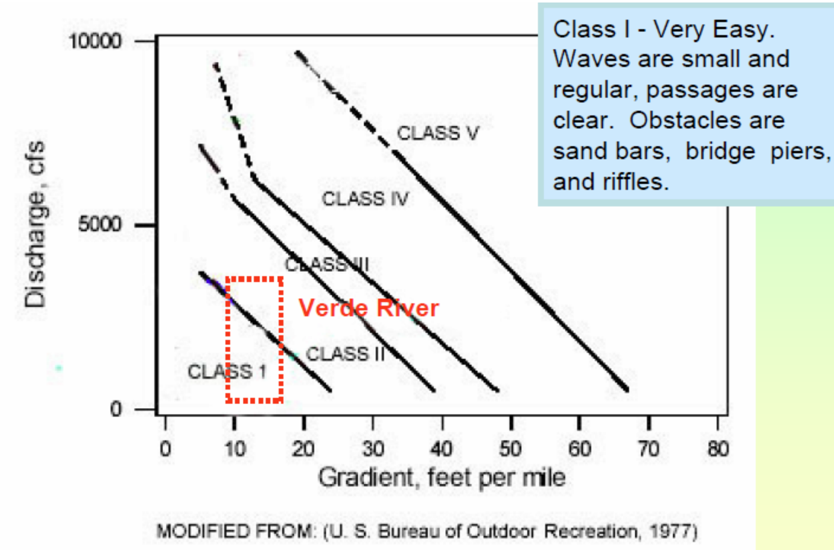
The following assessment of navigability is unaffected by channel sinuosity and curvature at meander bends that do not adversely affect channel width and alignment along potential navigable lanes. The channel widths typically are 35 ft for the reach above Mormon Pocket Springs and 50 ft in the reach near the USGS gage near Clarkdale, Az. The depths along the thalwag (potential navigation lanes) average at least 2.9 ft for the median flow. There are numerous pools where depths are greater than the average of 2.9 ft. There are occasional small-steep riffles where portage is unnecessary except possibly for novice boaters.

Navigability along the Upper Verde River is evaluated using the natural hydrology, eleven measured cross sections and many measured channel widths in the study reach area.

The Upper Verde River is evaluated as a single segment while recognizing an increase in base runoff at Mormon Pocket Springs. Two convenient methods of assessing the sufficiency of instream flows are used. The two relatively simple methods were developed by the U.S. Department of the Interior mostly for modern recreational boating.

Bureau of Outdoor Recreation Method

The first method is a rule of thumb rating of navigation difficulty by Jason M. Cortell and Associates Inc. of Waltham Mass. for Bureau of Outdoor Recreation. (U. S. Bureau of Outdoor Recreation, 1977). The use of small watercraft, that includes canoes, kayaks drift boats and rafts, is rated in terms of flow criteria based on an International River Classification scale. A minimum stream flow condition is used to rate the difficulty of using these watercraft in rivers. Six classes of white water are used and Class I is the easiest for navigability. The discharge and gradient of the study reach is well within Class I and the use of watercraft is considered very easy (Following figure).

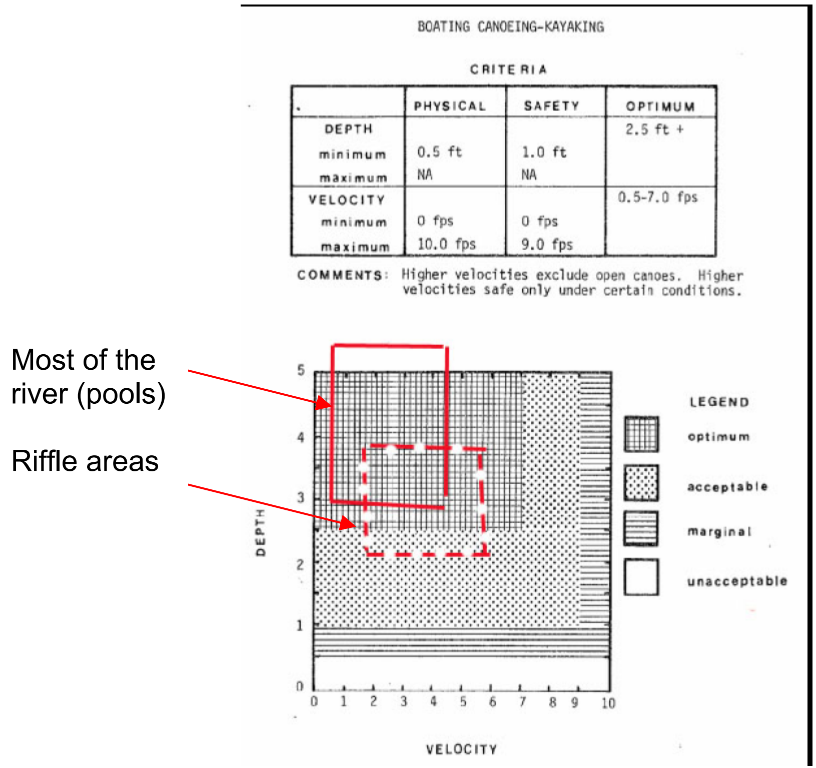


Hyra (1978) presents minimum depth and width requirements for canoes, kayaks, drift boats and row boats and power boats (See table below). At riffles the boating conditions are acceptable and optimal. However, the width, depth and velocity requirements typically are optimal for canoes, kayaks, drift and row boats along nearly all of the Upper Verde River.

Fish and Wildlife Service Method

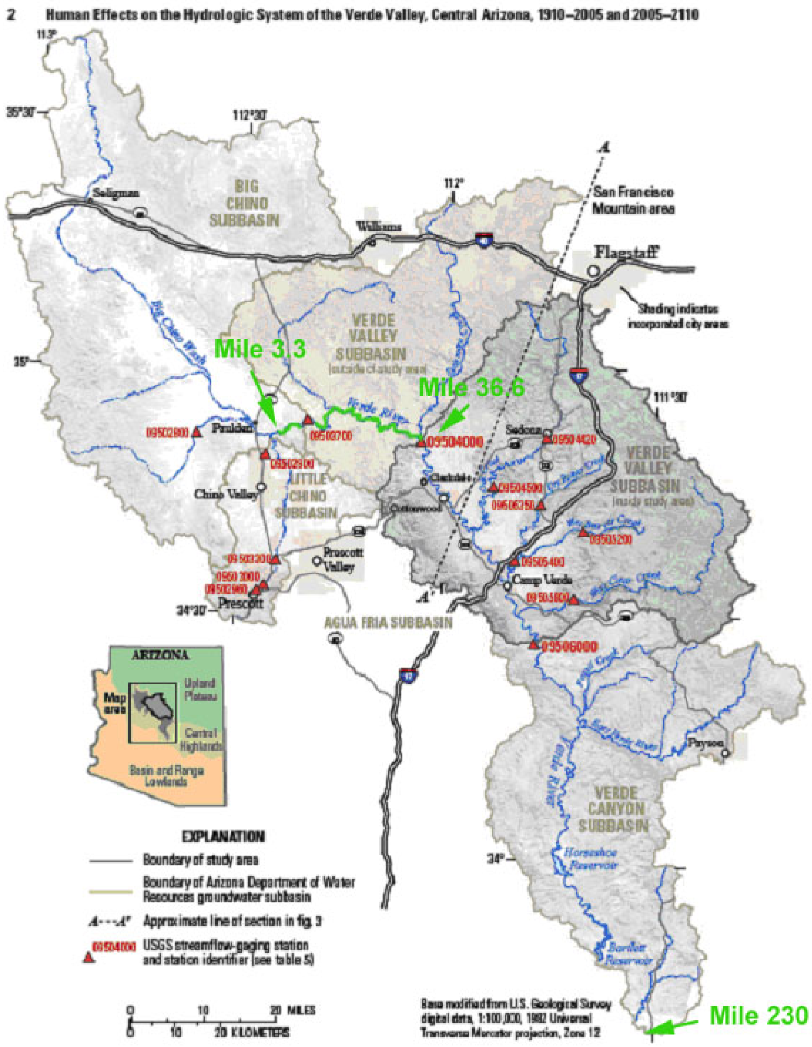
The second method is also easy to use and is based on hydraulics of a single channel cross section that is representative of channel conditions. These navigation requirements (*Instream Flow Information No. 6*) were developed by R. Hyra (1978) for the Fish and Wildlife Service of the Dept. of the Interior. Channel depth and width requirements are defined for types of watercraft such as rafts and rowboats. The U.S. Fish and Wildlife Service (Hyra, 1978) developed a method of assessing streamflow suitability for recreation that is applied to the upper Verde River. The single cross section technique is very simple to use and results in an assessment of the minimum flow recommended for a particular watercraft activity.

The characteristics of the eleven surveyed sections for the Upper Verde River are used. Hyra (1978) presents minimum depth and width requirements for canoes, kayaks and other small watercraft. As shown in the figure below, minimum width and depth and velocity requirements are easily met for canoes and kayaks along the Upper Verde River from mile 3.3 at the old Campbell Ranch area to 36.6 at the USGS stream gage near Clarkdale, AZ.



SUMMARY AND CONCLUSION

The two Federal methods show that in its ordinary and natural condition, the Upper Verde River along the study reach from the Stewart Ranch area (mile 3.3) to the USGS stream gage near Clarkdale (mile 36.6) was navigable (Following Figure).



.
Assessment of whether the natural channel of the middle and lower Verde River was navigable involved using published/known hydrologic, hydraulic and geomorphic information and relationships from the present and projecting this information into the past. Standard civil engineering and hydrologic and hydraulic methods were used to accomplish the assessment using three basic steps (See sectionG4 of Appendix G). Also, a considerable amount of time was devoted to examining plats and field notes of original Federal Land Surveys throughout the watershed.

The following factors formed the basis of the conclusions for this assessment of the entire Verde River:

A. There was excellent agreement among the three independent estimates of natural runoff to the upper Verde River. These techniques use published information of the USBR, USGS, USFS, Salt River Project, local historic newspapers and Federal Land Surveys. Also, surveyed channel widths of the original land surveys, that were considerably greater than recent measured widths, support the estimated amount of natural runoff. Base runoff along the entire river conforms to the amount of virgin flow (USBR, 1952) at the mouth.

B. Channel geometry and flow width and depths, especially depth of base discharge, was defined for many locations along the entire river. This modern channel geometry that included rating curves, along with channel widths and several depths from Federal Surveys, were sufficient to support the conclusion that typical natural flow depths from mile 3.3 at the old Campbell Ranch area to the mouth at the Salt River were at least 3 ft 90% of the time.

C. Human impacts on the river started in the 1860s. Also, navigating the entire river using canoes and kayaks has been a popular activity for about the past 25 years. Because successful boating on the river is greatly dependent on the amount of base flow in the river, predevelopment navigability on the natural river likely would have been improved simply because of the greater amount of natural base flow.

D. Available geomorphic information shows the general cross-sectional size and shape of the main channel has remained rather uniform. In other words, there is enough width and depth for small watercraft. Most of the river is pools, formed behind boulder riffles, that act as small sediment traps that partially fill during small discharges and are flushed during large discharges.

E. The base runoff and channels of both the Verde and John Day (an Oregon river) Rivers are similar and the John Day River has been found navigable by the state of Oregon. Also, the depths of base flow along the entire Verde River are several times larger than the drafts needed for canoes and kayaks used at the time of statehood and relied upon by Oregon for the assessment of the John Day River.

F. The U. S. Fish and Wildlife Service Method showed the natural condition of the Verde River was optimal for navigability from river mile 3.3 (distance downstream of Sullivan Lake dam) to the mouth.

It is my opinion the Verde River, using the assessment based on the high standard associated with the optimum conditions defined by the Fish and Wildlife Service of the Dept. of the Interior (Hyra, 1978), from river mile 3.3 in the Stewart (Campbell) Ranch area to the mouth at the Salt River (mile 230) was susceptible to navigation at the time of statehood (February 14, 1912) in its natural condition. However, if ANSAC finds a lesser standard is more appropriate then segmentation probably would not be needed and the entire Verde River could be consider susceptible to navigation. During ordinary years the river was susceptible to navigation more than 90% of the time. Evidence relied upon to form this opinion is in this report, the attached appendices, and in the references cited throughout this report.

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Verde River Facebook Page, permission granted by Doug Von Gausig, 630 Cliffside Drive, Clarkdale, AZ 86324, email of Sept. 23, 2014.

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GLOSSARY
(Mostly from Langbein and Iseri, HTML Version 1995)

HYDROLOGIC DEFINITIONS FOR THIS STUDY OF NAVIGABILITY

Acre-foot. A unit for measuring the volume of water, is equal to the quantity of water required to cover 1 acre to a depth of 1 foot and is equal to 43,560 cubic feet or 325,851 gallons. The term is commonly used in measuring volumes of water used or stored.

Alluvium (alluvial, adj.) A general term for clay, silt, sand, gravel, or similar unconsolidated detrital material, deposited during comparatively recent geologic time by a stream or other body of running water.

Aquifer Rock and (or) sediment in a formation, a group of formations, or part of a formation that is sufficiently permeable to store and transmit economic quantities of water to wells and springs.

Aquifer, confined An aquifer that lies between layers of less permeable rock (lower hydraulic conductivity) and in which ground water is confined under pressure significantly greater than atmospheric pressure. Static water levels in wells that penetrate a confined aquifer are higher than the top of the aquifer. Synonym: *artesian aquifer*.

Aquifer, perched An aquifer containing *perched ground water*.

Aquifer, unconfined An aquifer in which there are no confining beds between the zone of saturation and the ground surface. There is a water table in an unconfined aquifer. Synonym: *water-table aquifer*.

Average discharge. In the annual series of the Geological Survey's reports on surface-water supply—the arithmetic average of all complete water years of record whether or not they are consecutive. Average discharge is not published for less than 5 years of record. The term "average" is generally reserved for average of record and "mean" is used for averages of shorter periods, namely, daily mean discharge.

Bank. The margins of a channel. Banks are called right or left as viewed facing in the direction of flow.

Base flow. The water in a stream that comes from ground water as seepage or spring water. This water sustains the stream during periods of no precipitation. See Base runoff.

Base-flow recession The declining rate of discharge of a stream fed only by base flow for an extended period. Typically, a base-flow recession will be exponential

Base runoff. Sustained or fair weather runoff. In most streams, base runoff is composed largely of groundwater effluent. (Langbein and others, 1947, p. 6.) The term base flow is often used in the same sense as base runoff. However, the distinction is the same as that between streamflow and runoff. When the concept in the terms base flow and base runoff is that of the natural flow in a stream, base runoff is the logical term. (See also Ground-water runoff and Direct runoff.)

Braiding of river channels. Successive division and rejoining (of river flow) with accompanying islands is the important characteristic denoted by the synonymous terms, braided or anatomizing stream. A braided stream is composed of anabranches.

Channel (watercourse). An open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. River, creek, run, branch, anabranch, and tributary are some of the terms used to describe natural channels. Natural channels may be single or braided (see Braiding of river channels) Canal and floodway are some of the terms used to describe artificial channels.

Direct runoff. The runoff entering stream channels promptly after rainfall or snowmelt. Superposed on base runoff, it forms the bulk of the hydrograph of a flood.

Discharge. In its simplest concept discharge means outflow; therefore, the use of this term is not restricted as to course or location, and it can be applied to describe the flow of water from a pipe or from a drainage basin. If the discharge occurs in some course or channel, it is correct to speak of the discharge of a canal or of a river. It is also correct to speak of the discharge of a canal or stream into a lake, a stream, or an ocean. (See also Streamflow and Runoff.)

Drainage basin. A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Drainage divide. The rim of a drainage basin. (See Watershed.)

Ephemeral stream. A stream which flows only at certain times of the year when the channel receives water exclusively from surface-water sources, such as rainfall and snowmelt. See *intermittent streams* and *perennial streams*.

Evaporation. The process by which water is changed from the liquid or the solid state into the vapor state. In hydrology, evaporation is vaporization that takes place at a temperature below the boiling point.

Evapotranspiration. Water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration. The sum of *evaporation* and *transpiration*.

Evapotranspiration, actual. The evapotranspiration that actually occurs under given climatic and soil-moisture conditions.

Flow-duration curve. A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded. (See Searcy, 1959.) Also--A graph showing the percentage of time that the given flows of a stream were equaled or exceeded. Typcally, it is based on a statistical study of historical streamflow records.

Gaging station. A particular site on a stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained. (See also Stream-gaging station.)

Ground water. Water in the ground that is in the zone of saturation, from which wells, springs, and ground-water runoff are supplied. (After Meinzer, 1949, p. 385.)

Groundwater runoff. That part of the runoff which has passed into the ground, has become ground water, and has been discharged into a stream channel as spring or seepage water. See also Base runoff and Direct runoff.

Hydrologic budget. An accounting of the inflow to, outflow from, and storage in, a hydrologic unit, such as a drainage basin, aquifer, soil zone, lake, reservoir, or irrigation project.

Hydrologic cycle. A convenient term to denote the circulation of water from the sea, through the atmosphere, to the land; and thence, with many delays, back to the sea by overland and subterranean routes, and in part by way of the atmosphere; also the many short circuits of the water that is returned to the atmosphere without reaching the sea.

Hydrology. The science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground. The science that relates to the water of the earth.

Infiltration. The flow of a fluid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word percolation, which connotes flow through a porous substance.

Irrigation. The controlled application of water to arable lands to supply water requirements.

Intermittent stream. A stream which flows only at certain times of the year when the channel receives water from a ground-water source and surface-water sources. See *ephemeral streams* and *perennial streams*. See Stream.

Meander. The winding of a stream channel.

Overland flow. The flow of rainwater or snowmelt over the land surface toward stream channels. After it enters a stream, it becomes runoff.

Perennial stream. A stream that flows continuously. See Stream.

Percolation. The movement, under hydrostatic pressure, of water through the interstices of a rock or soil, except the movement through large openings such as caves

Precipitation. As used in hydrology, precipitation is the discharge of water, in liquid or solid state, out of the atmosphere, generally upon a land or water surface.

Reservoir. A pond, lake, or basin, either natural or artificial, for the storage, regulation, and control of water.

Return flow. That part of irrigation water that is not consumed by evapotranspiration and that returns to its source or another body of water. The term is also applied to the water that is discharged from industrial plants. Also called return water.

Riparian. Pertaining to the banks of a stream.

Runoff. That part of the precipitation that appears in surface streams. It is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels.

Stream. A general term for a body of flowing water. In hydrology the term is generally applied to the water flowing in a natural channel as distinct from a canal. More generally as in the term stream gaging, it is applied to the water flowing in any channel, natural or artificial. Streams in natural channels may be classified as follows:

- Relation to time.
  - Perennial. One which flows continuously.
  - Intermittent or seasonal. One which flows only at certain times of the year when it receives water from springs or from some surface source such as melting snow in mountainous areas.
  - Ephemeral. One that flows only in direct response to precipitation, and whose channel is at all times above the water table.
- Relation to space.
  - Continuous. One that does not have interruptions in space.
  - Interrupted. One which contains alternating reaches, that are either perennial, intermittent, or ephemeral.
- Relation to ground water.
  - Gaining. A stream or reach of a stream that receives water from the zone of saturation.
  - Losing. A stream or reach of a stream that contributes water to the zone of saturation.
  - Insulated. A stream or reach of a stream that neither contributes water to the zone of saturation nor receives water from it. It is separated from the zones of saturation an impermeable bed.
  - Perched. A perched stream is either a losing stream or an insulated stream that is separated from the underlying ground water by a zone of aeration.

Stream, gaining A stream or reach of a stream, where flow increases because of an influx of ground water. See Stream.

Stream, losing A stream or reach of a stream that loses water by seepage into the ground. See Stream.

Streamflow. The discharge that occurs in a natural channel. Although the term discharge can be applied to the flow of a canal, the word streamflow uniquely describes the discharge in a surface stream course. The term “streamflow” is more general than runoff, as streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

Transpiration. The quantity of water absorbed and transpired and used directly in the building of plant tissue, in a specified time. It does not include soil evaporation.

Underflow. The downstream flow of water through the permeable deposits that underlie a stream and that are more or less limited by rocks of low permeability.

Watershed. The divide separating one drainage basin from another and in the past has been generally used to convey this meaning. Drainage divide, or just divide, is used to denote the boundary between one drainage area and another. Used alone, the term “watershed” is ambiguous and should not be used unless the intended meaning is made clear. As used in this report, watershed refers to the entire drainage of the Santa Cruz River and basins refers to internal areas of the “watershed”.

Water table. The upper surface of a zone of saturation. No water table exists where that surface is formed by an impermeable body.