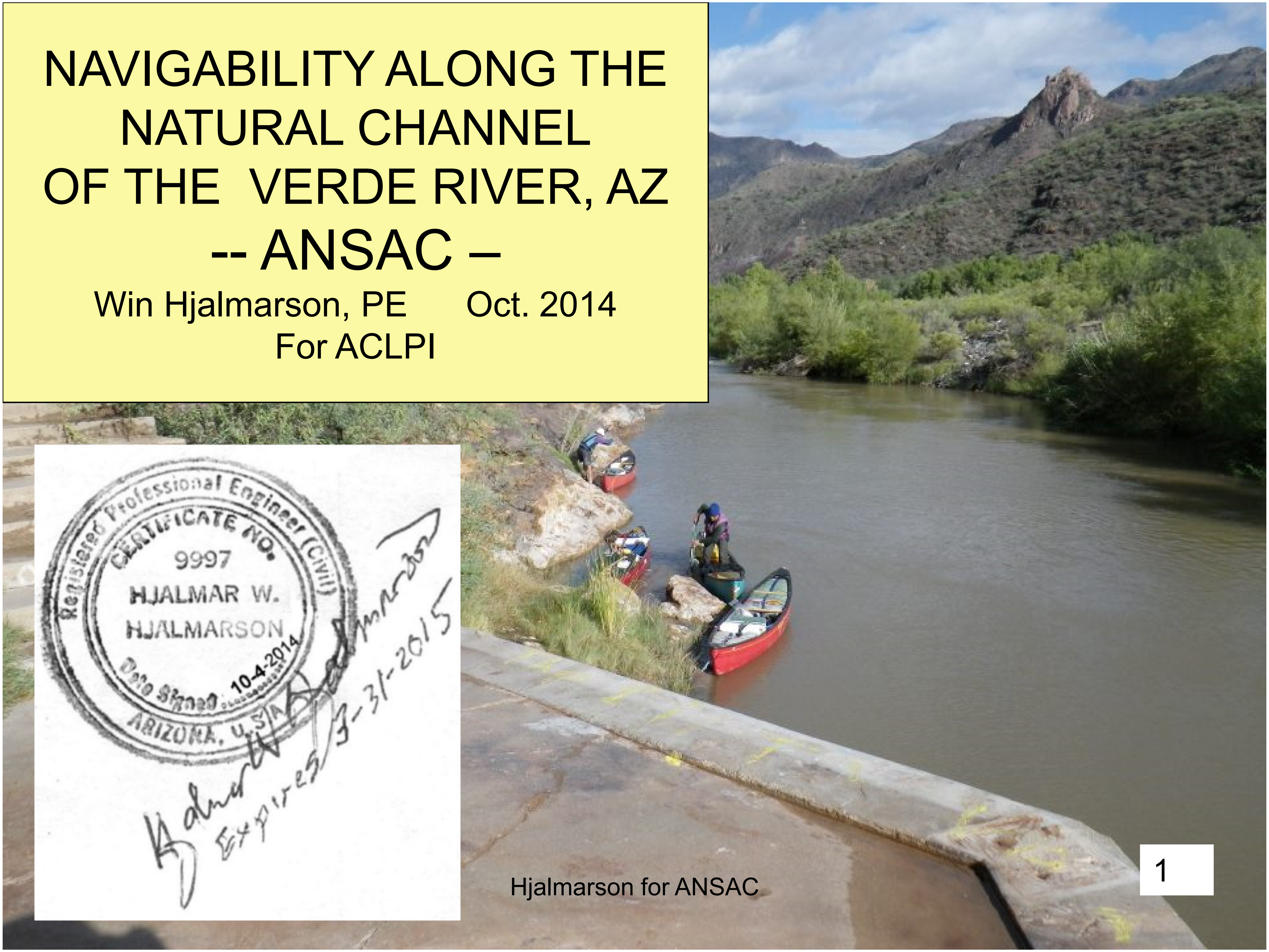
NAVIGABILITY ALONG THE NATURAL CHANNEL OF THE VERDE RIVER, AZ

-- ANSAC –

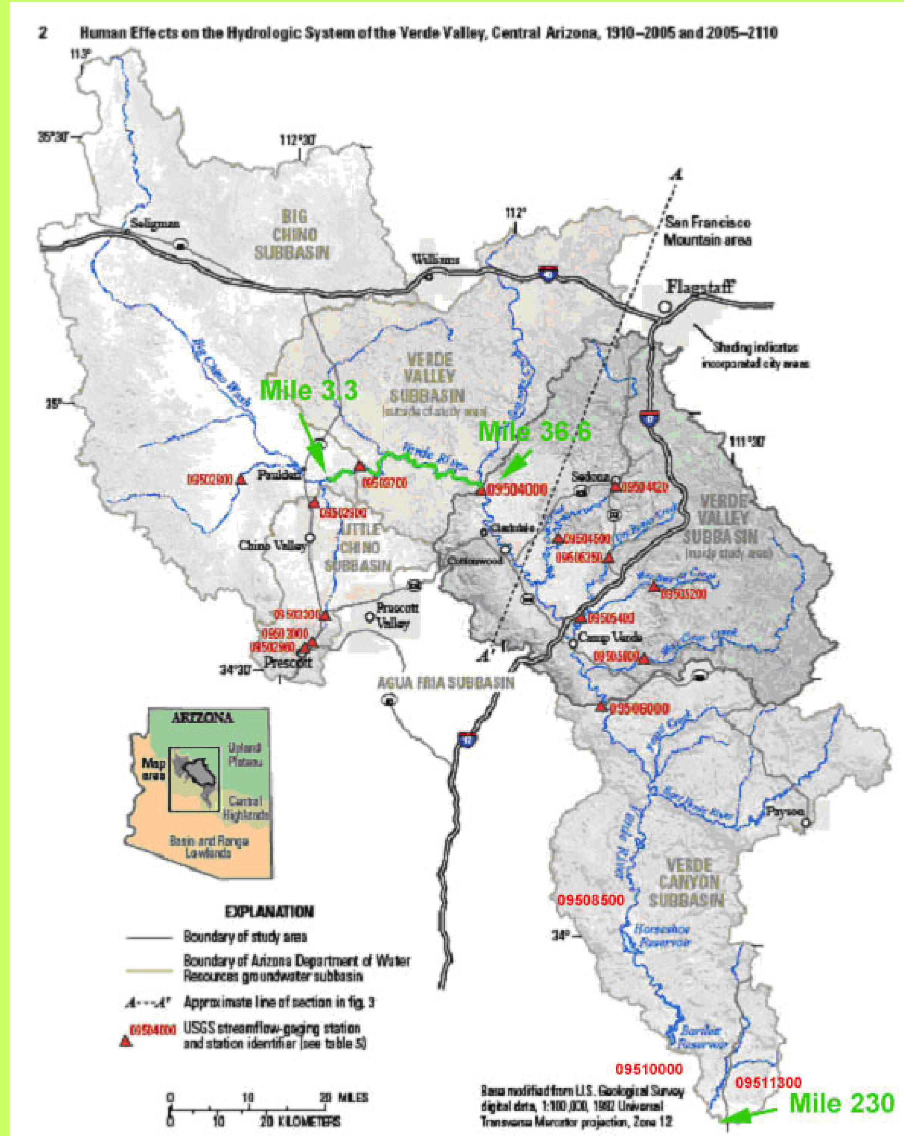
Win Hjalmarson, PE Oct. 2014

For ACLPI



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

General analysis from Clarkdale gage to mouth.



UNITED STATES
DEPARTMENT OF THE INTERIOR
Julius A. Krug, Secretary

BUREAU OF RECLAMATION
Michael W. Straus, Commissioner

E. A. Moritz, Regional Director, Region III

CHINO VALLEY PROJECT
ARIZONA

PROJECT PLANNING REPORT NO. 3-8b.9-0
APPENDIXES

APRIL 1946

Verde River: Throughout its entire length the Verde is a perennial continuous stream. The head of the Verde formed by the junction of Chino Creek and Williamson Valley Wash is fed by permanent ground water. Throughout its course, the Verde is alternately influent and effluent with respect to ground water, but under natural conditions there is no point on the main river channel which is normally dry. Spring and summer floods occur on the

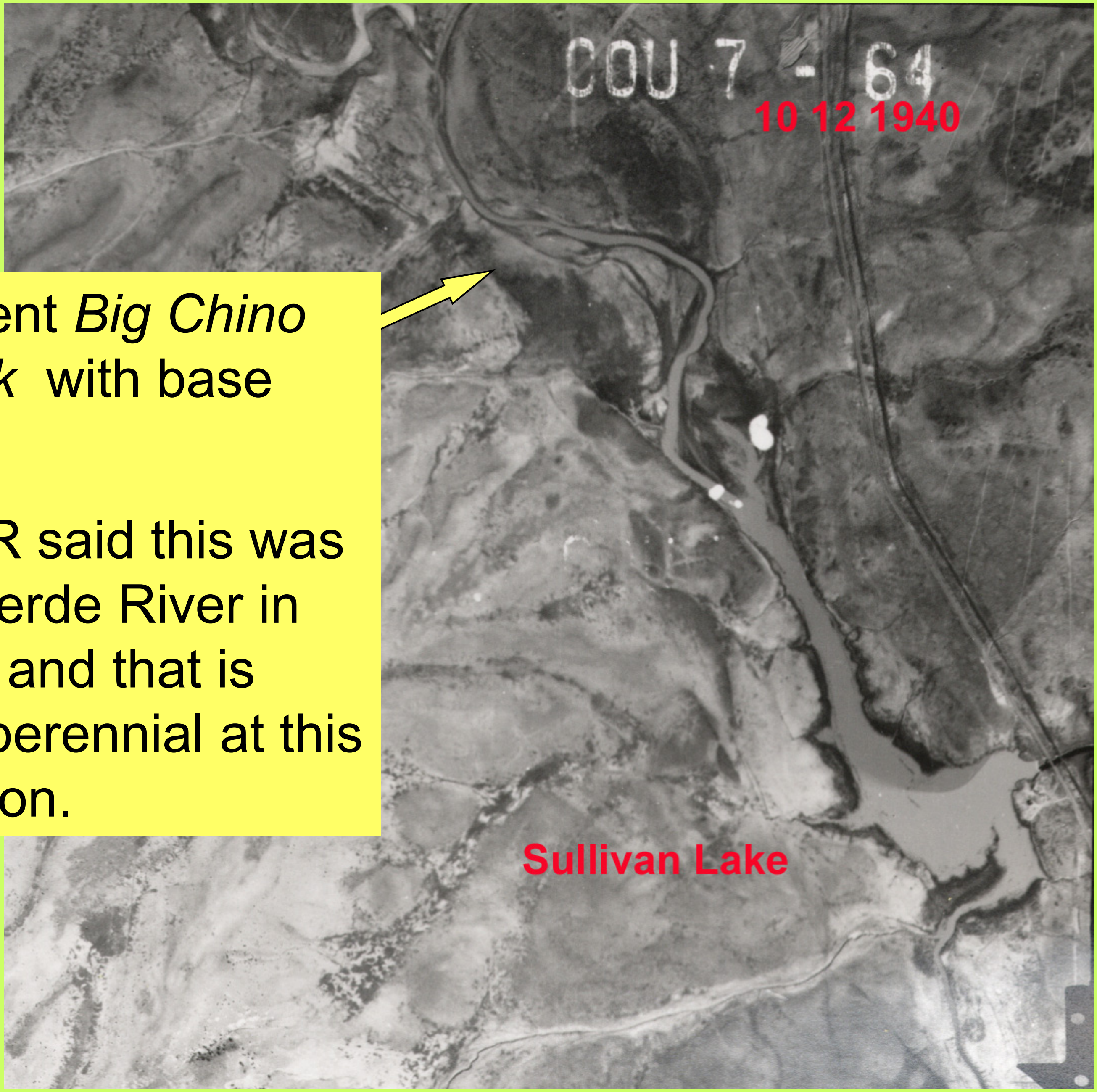
Page 7 of U. S. Bureau of Reclamation, 1946, Chino Valley Project, Project planning report no. 3-8b.9-0, 115p.

"Verde River: Throughout its entire length the Verde is a perennial continuous stream. The head of the Verde formed by the junction of Chino Creek and Williamson Valley Wash is fed by permanent ground water. Throughout its course, the Verde is alternately influent and effluent with respect to ground water, but under natural conditions there is no point on the main channel which is dry. "

Handout
121

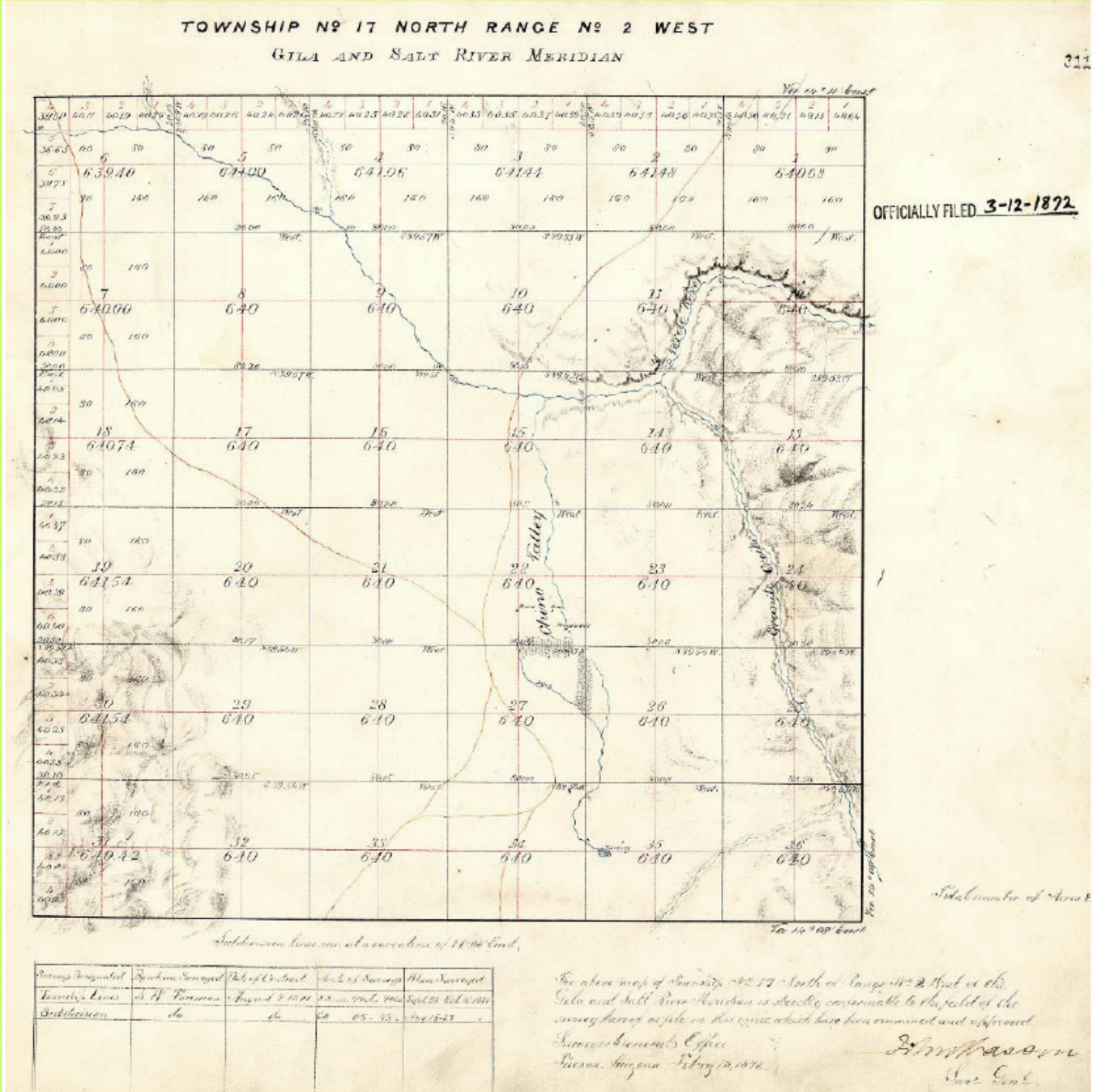
Present *Big Chino Creek* with base flow.

USBR said this was the Verde River in 1946 and that is was perennial at this location.



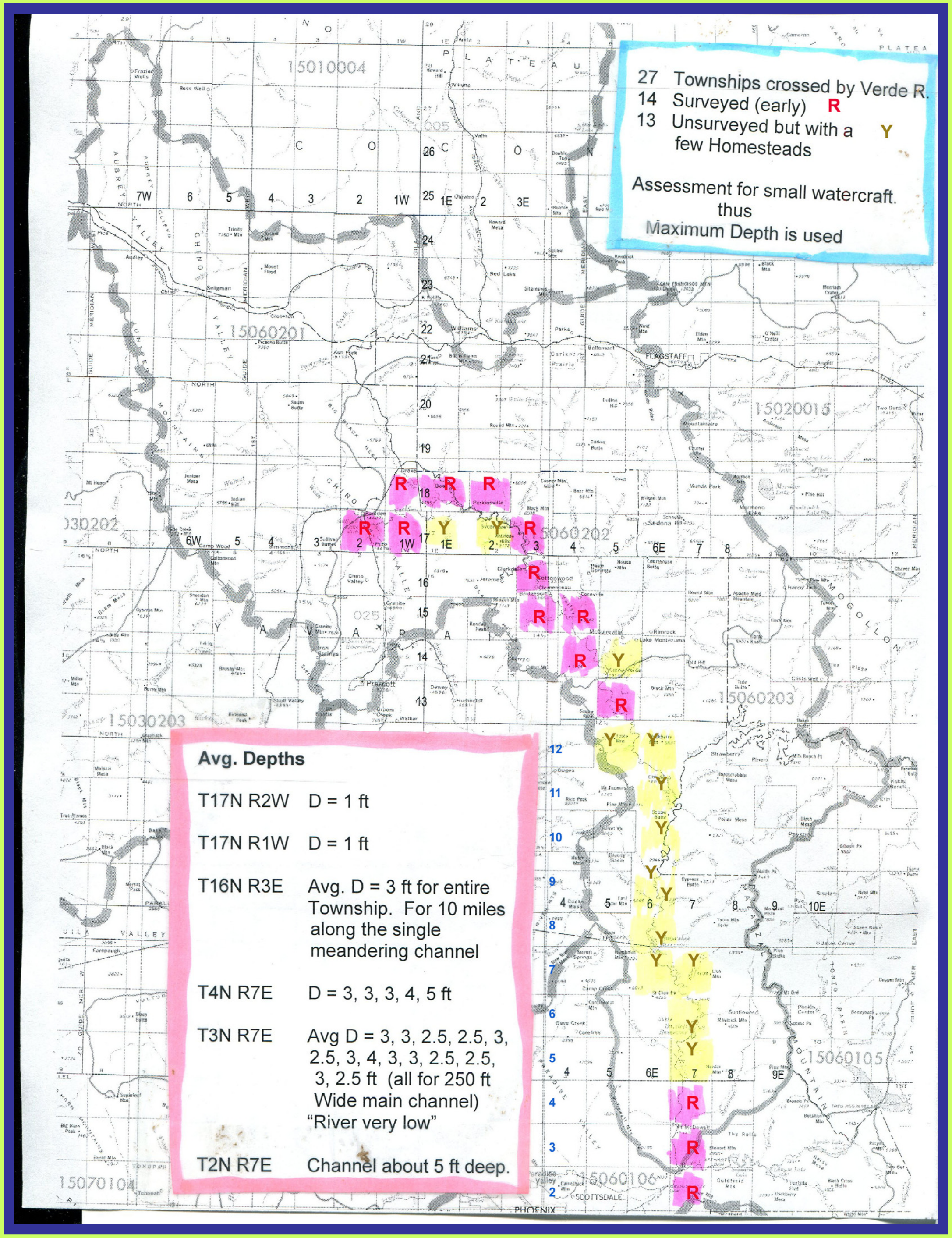
Handout

122


TOWNSHIP No 17 NORTH RANGE No 2 WEST
GILA AND SALT RIVER MERIDIAN
OFFICIALLY FILED 3-12-1872

Handout

123



Townships crossed by the Verde River

R surveyed

Y unsurveyed

Handout at meeting

Handout

124

An assessment based on

- Federal GLO surveys
- historic evidence
- hydrology
- hydraulics
- morphology
- technical reports
- modern navigation
- personal experience

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 watershed – especially the upper watershed .

The question:

Was the Verde River susceptible to navigation at the time of Arizona statehood (February 14, 1912) in its ordinary and natural condition ?

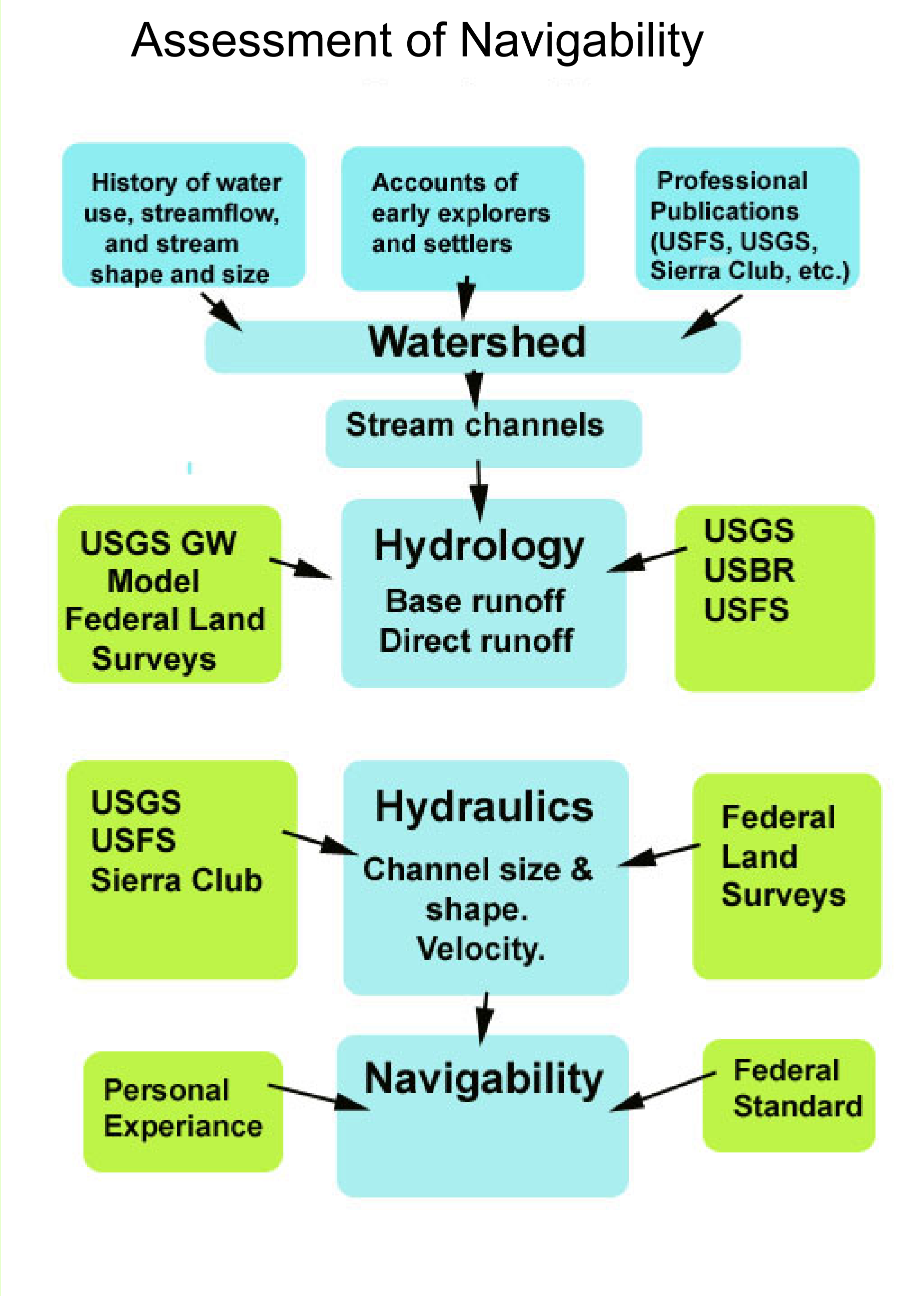
The test for determining navigability used in this analysis is from *Defenders of Wildlife v. Hull*, 199 Ariz. 411,426, 18 P.3d 722 (App. 2001):

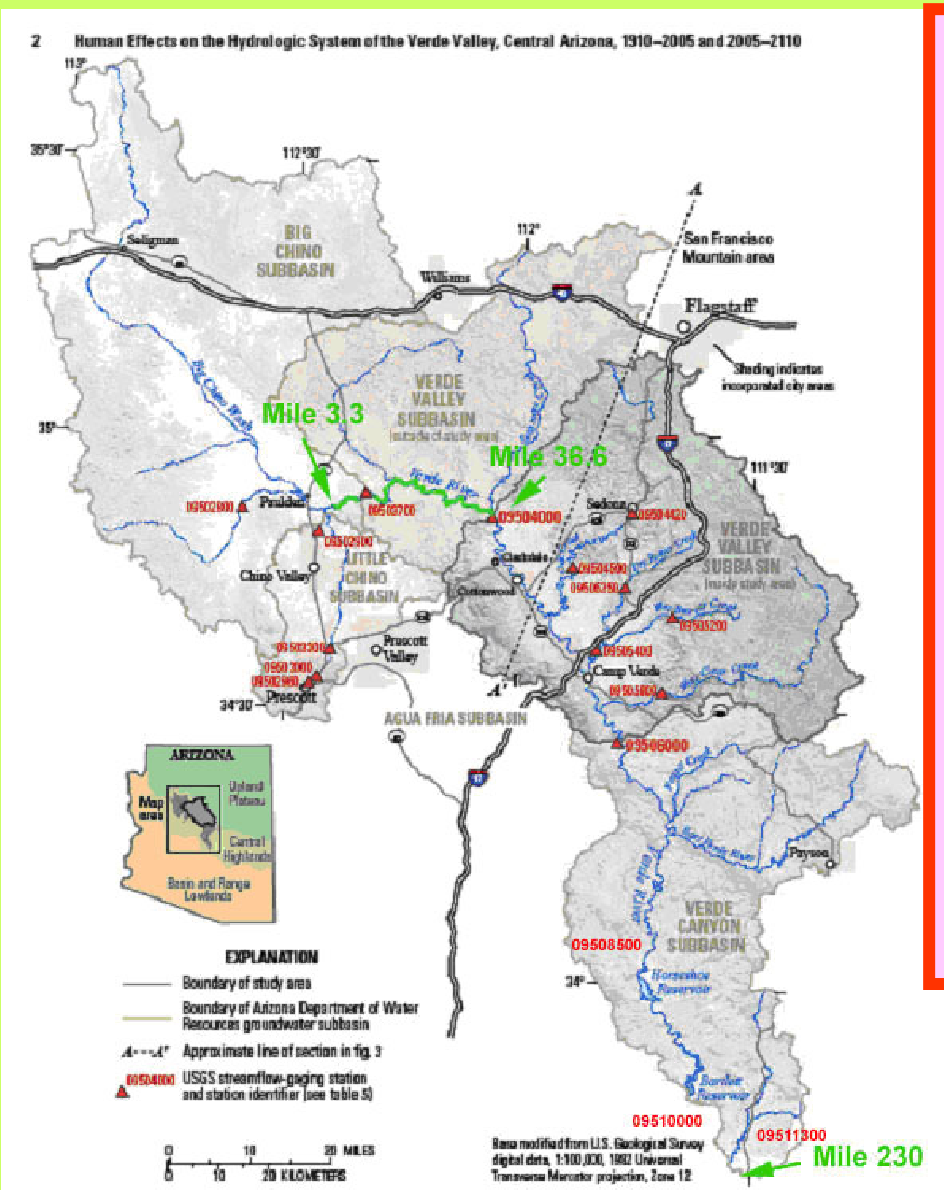
Also, physical evidence is presented on two issues: (1) navigability or non-navigability of the Verde River in its "ordinary and natural condition" at the State of Arizona's admission to the United States on February 14, 1912, consistent with the Arizona Court of Appeals decision in *State v. Arizona 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).

PART 1

PART 2

PART 3

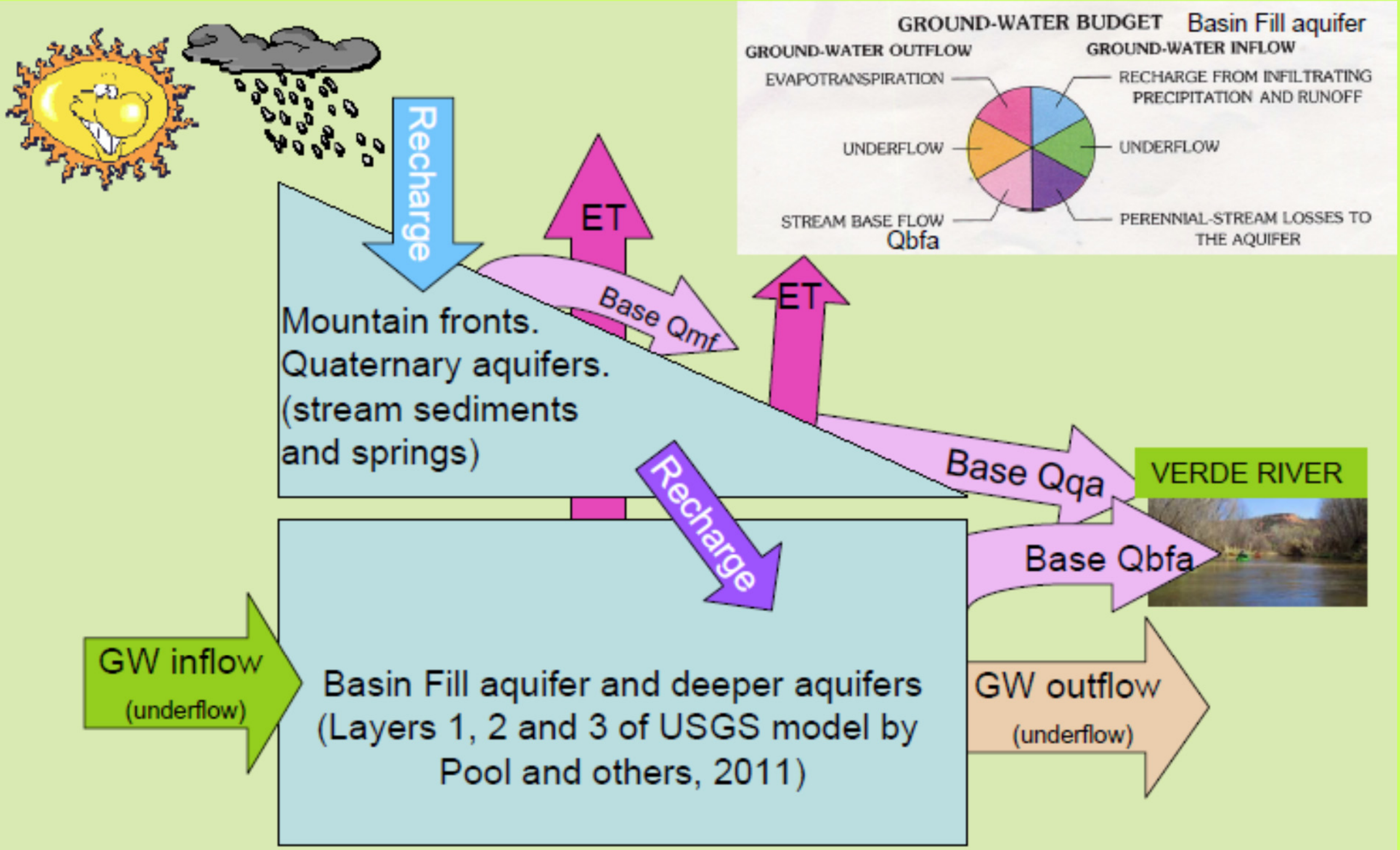




Site	Area mi.^{2}	Distance miles
Sullivan Lake	2170	0
Clarkdale gage	3503	36.6
Mouth at Salt R.	6188	230

Hjalmarson for ANSAC

Conceptual model for ANSAC study



Modified from: 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.

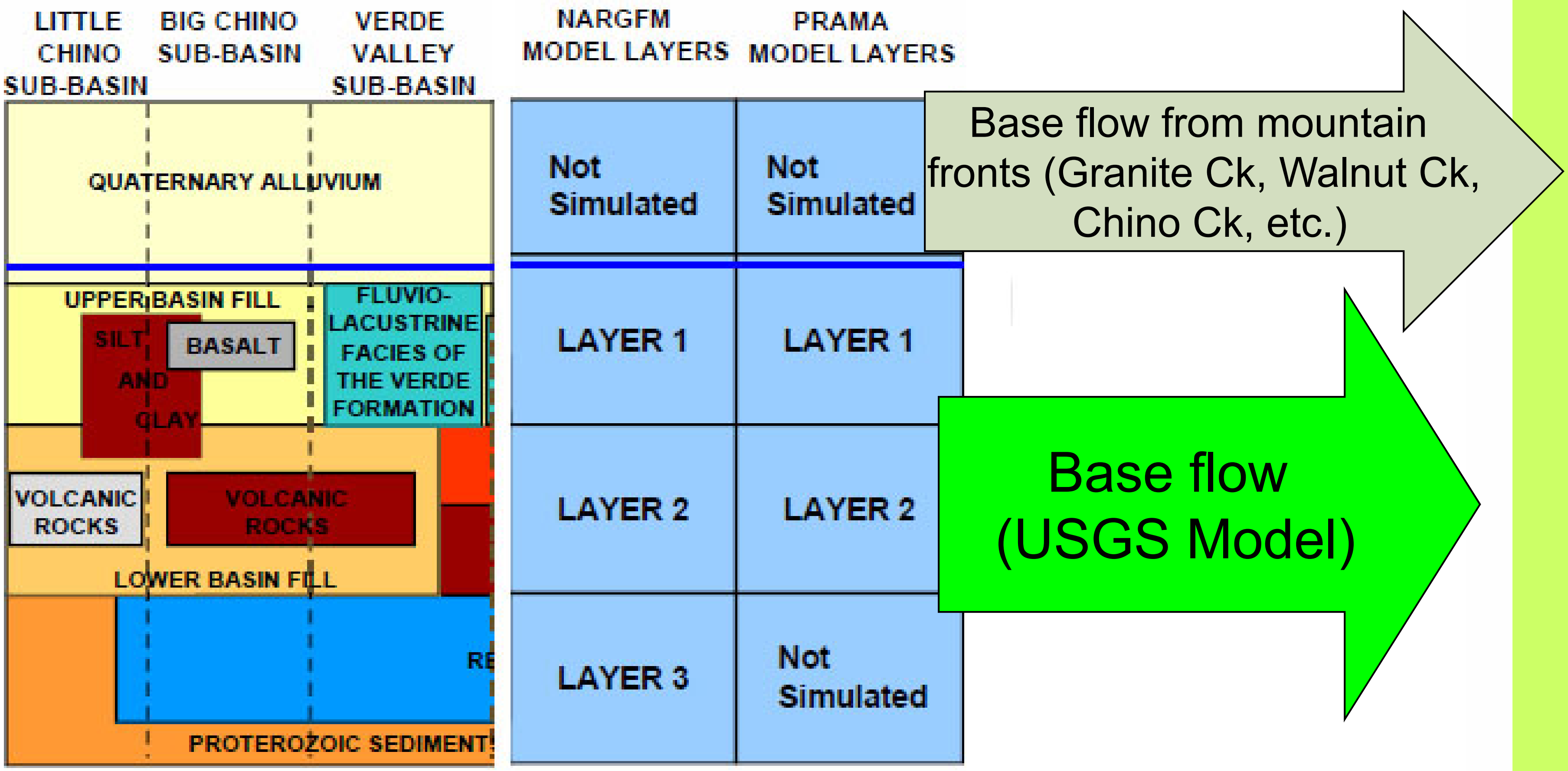
The conceptual model is largely based on recent USGS studies.

The USGS did not model the Quaternary aquifers or the mountain front springs

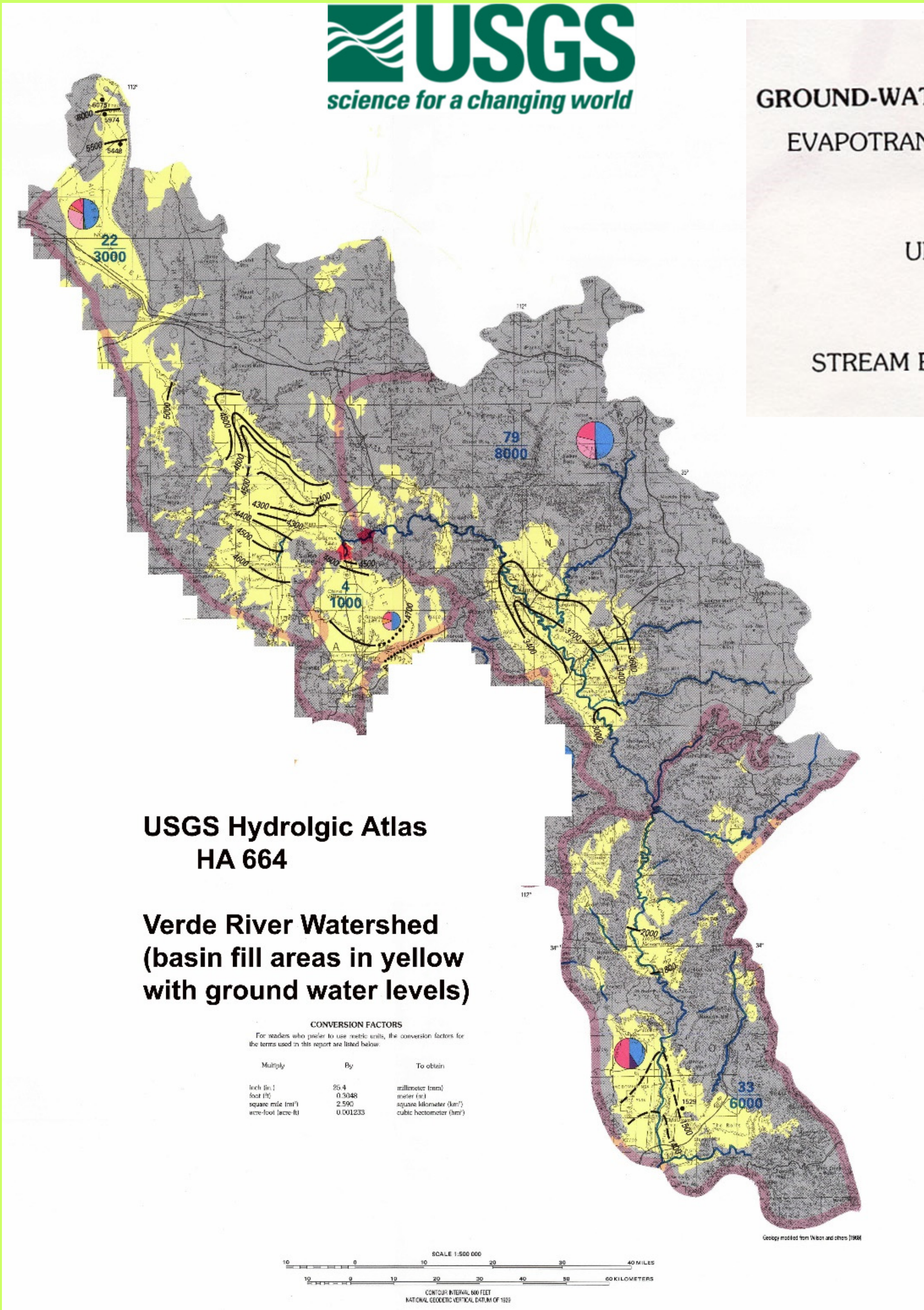
Base runoff of the Quaternary aquifers and the mountain front springs is estimated for the study.

4th report

Conceptualized relations among major hydrogeologic units and Northern Arizona Regional Groundwater-Flow Model layers.

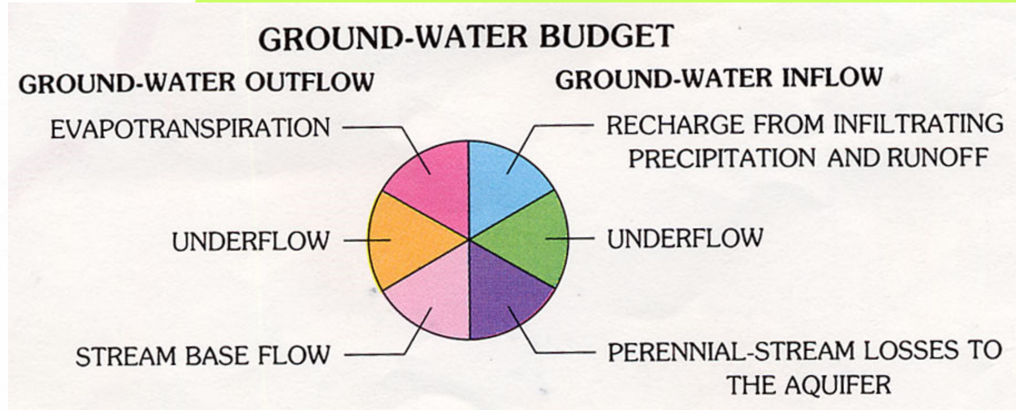


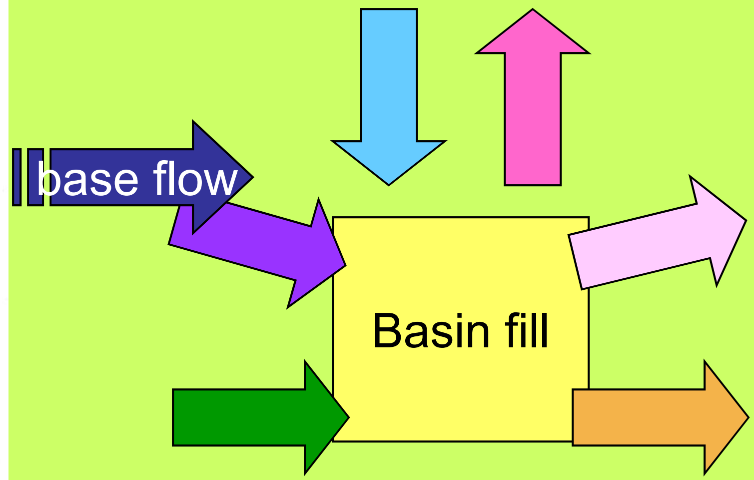
Modified from: Pool, D.R., Blasch, K.W., Callegary, J.B., Leake, S.A., and Graser, L.F., 2011, Regional groundwater-flow model of the Redwall-Muav, Coconino, and alluvial basin aquifer systems of northern and central Arizona: U.S. Geological Survey Scientific Investigations Report 2010-5180, 101 p.



USGS Hydrolgic Atlas
HA 664

Verde River Watershed
(basin fill areas in yellow
with ground water levels)





USGS has defined base flow from Basin Fill Aquifers

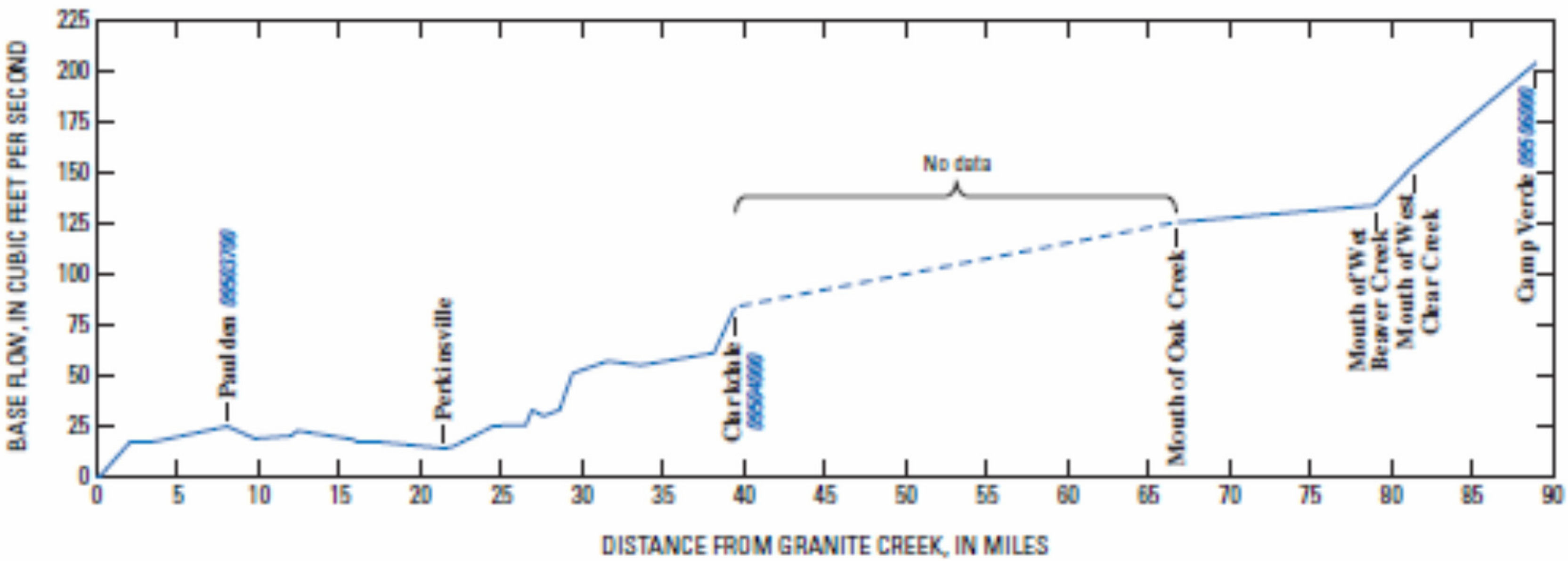


Figure 13. Base flow in the Verde River from the mouth of Granite Creek to the gaging station near Camp Verde (09506000).

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.

Before we take a photo trip up the Verde River lets consider a few of the many important items to keep in mind.

1. **We know a lot about the basin fill aquifers** (the USGS has studied/modeled these aquifers)
2. **We know little about the Quaternary alluvium and mountain front springs.** (see next slide)
3. **The USBR defined the Virgin (natural) runoff for the mouth of the Verde River**

Natural means just that—no humans.

No diversions for irrigation, no mining, no cattle, etc

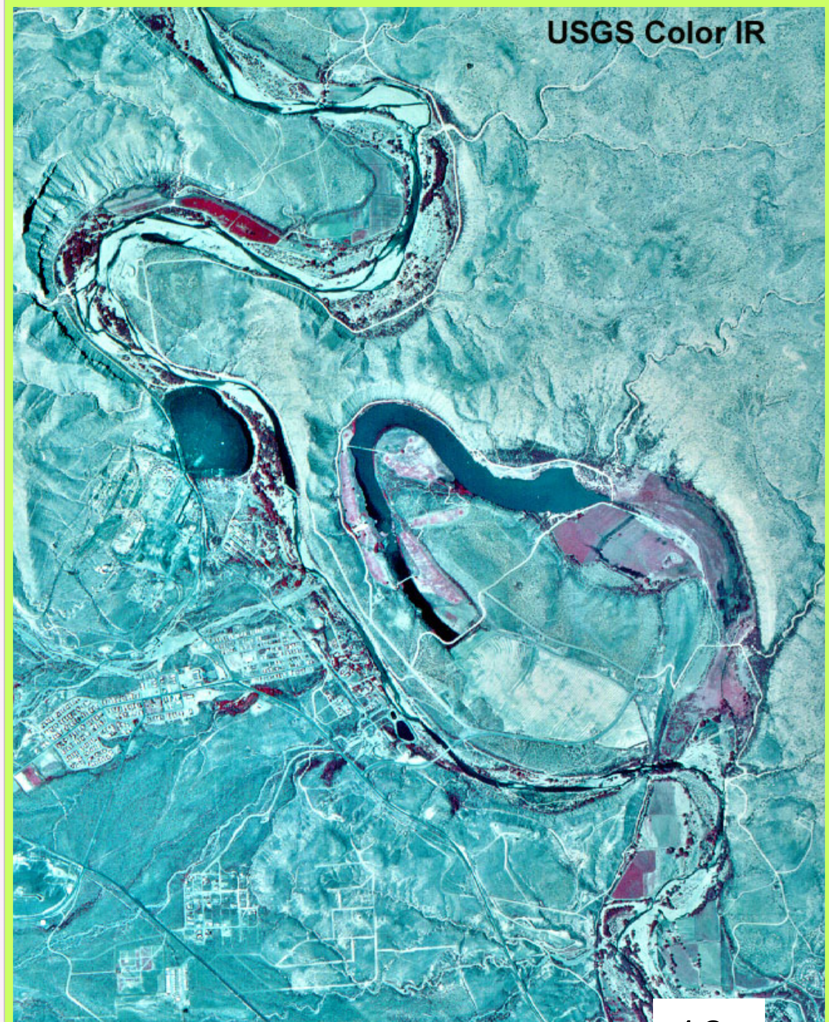
Upper Verde

Clarkdale area

Landsat Thematic Mapper (TM) Image of Big and Little Chino Basins, Arizona

Scale = 1:100,000

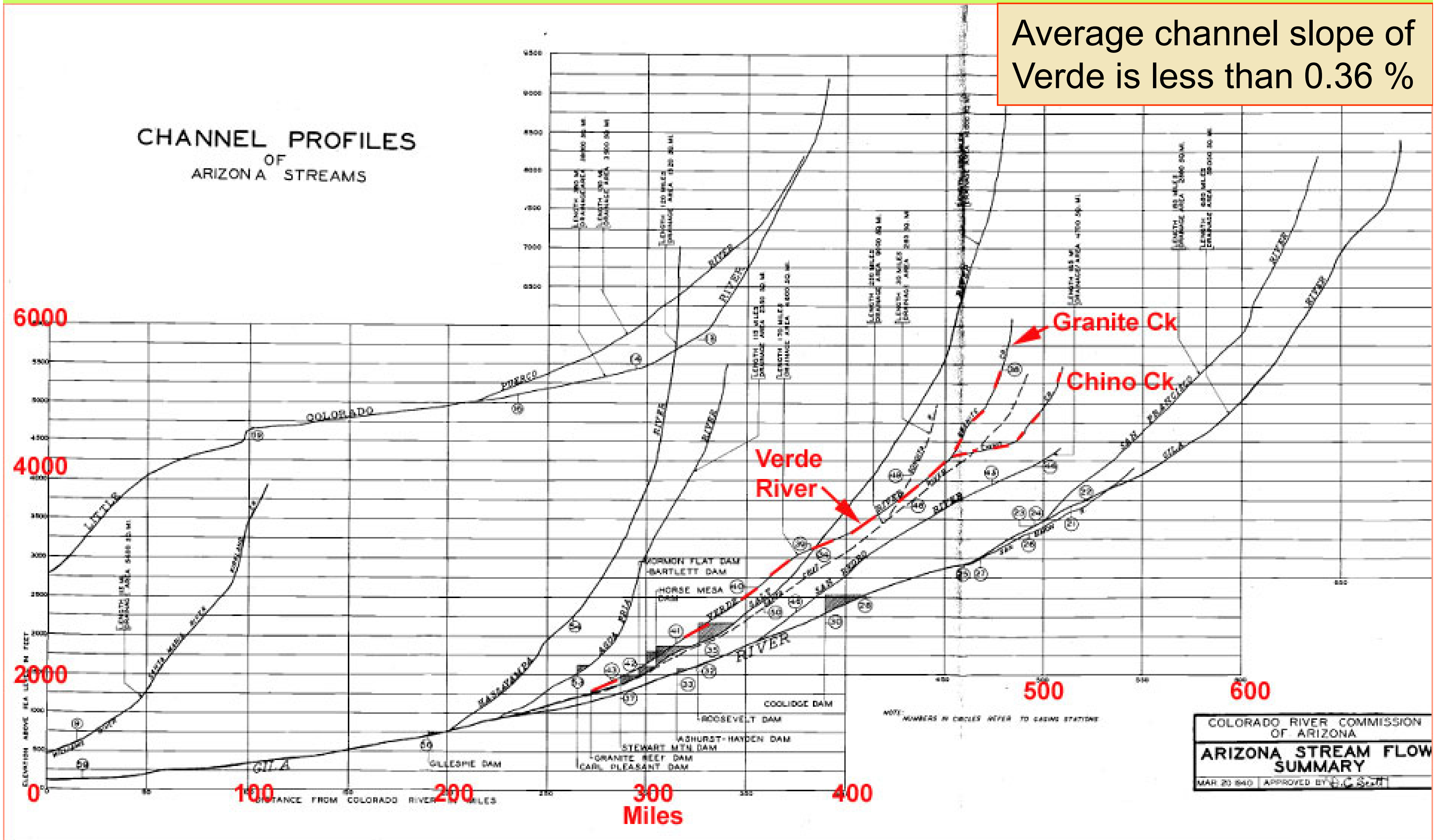
Bands 4, 3, and 2 Intensity, Hue, and Saturation (IHS stretch) Enhanced



NSAC

Colorado River Commission, 1940, Arizona Stream Flow Summary; 132p.

Average channel slope of Verde is less than 0.36 %



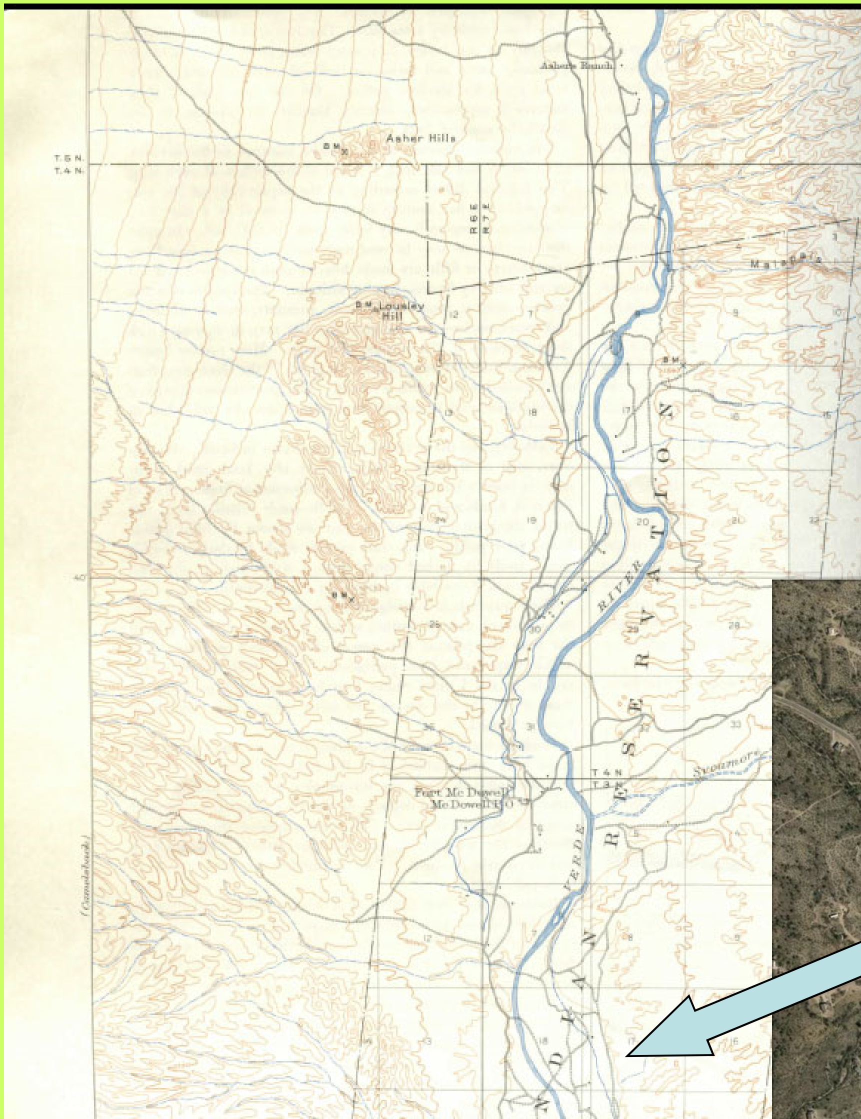
Mouth of Verde River

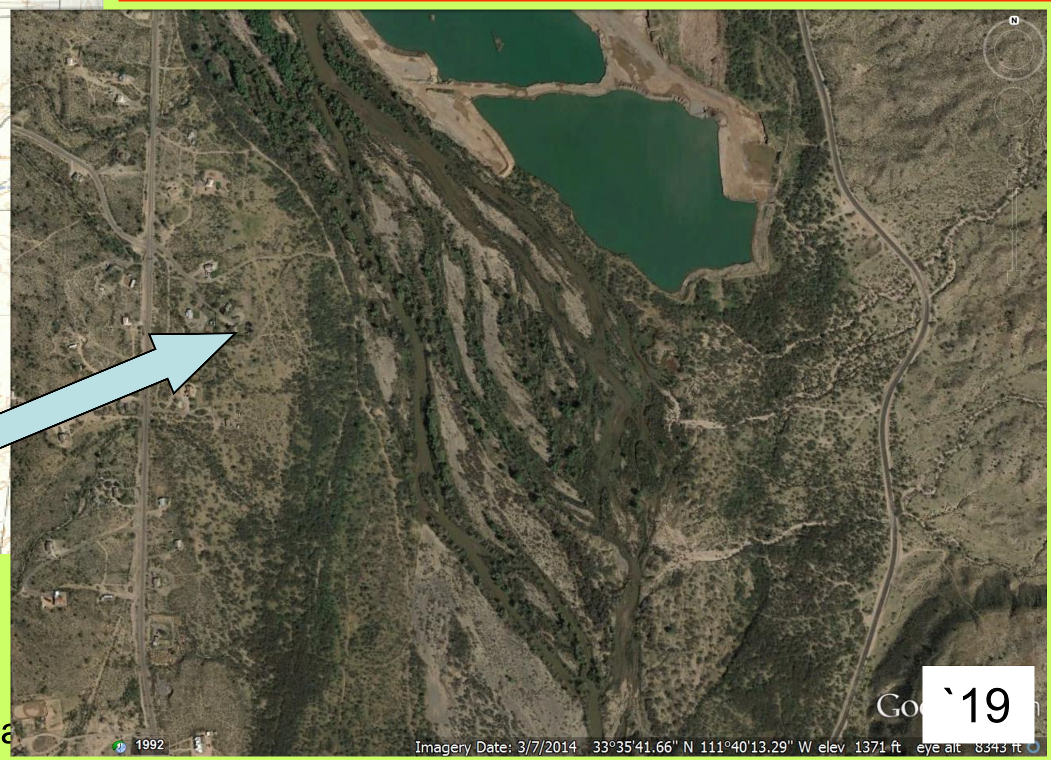
1906

About 4 miles above mouth

Single channel on Fort McDowell 15 min Quad 1906 edition

At least 5 braided channels on 2014 Google map





Hja

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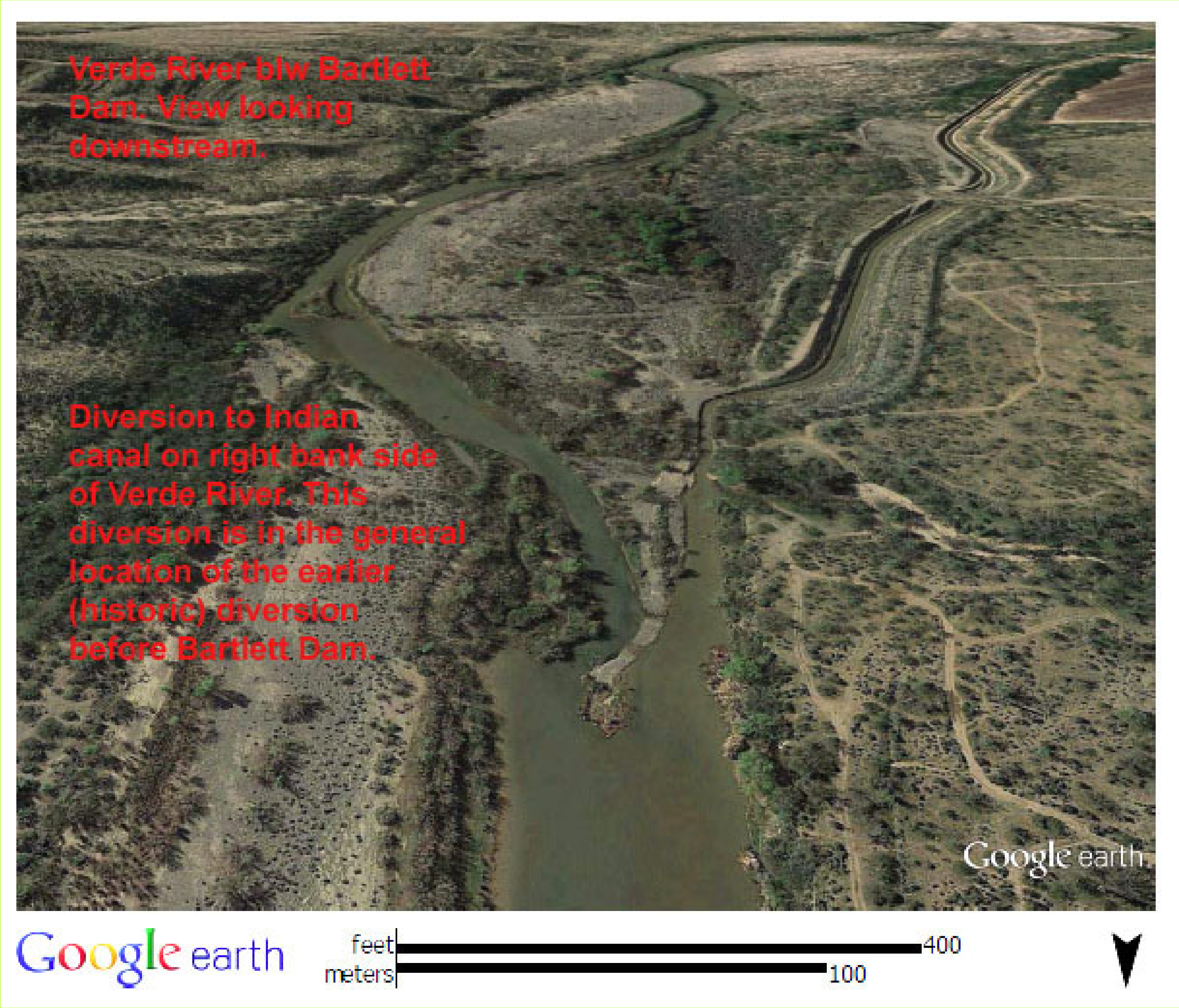
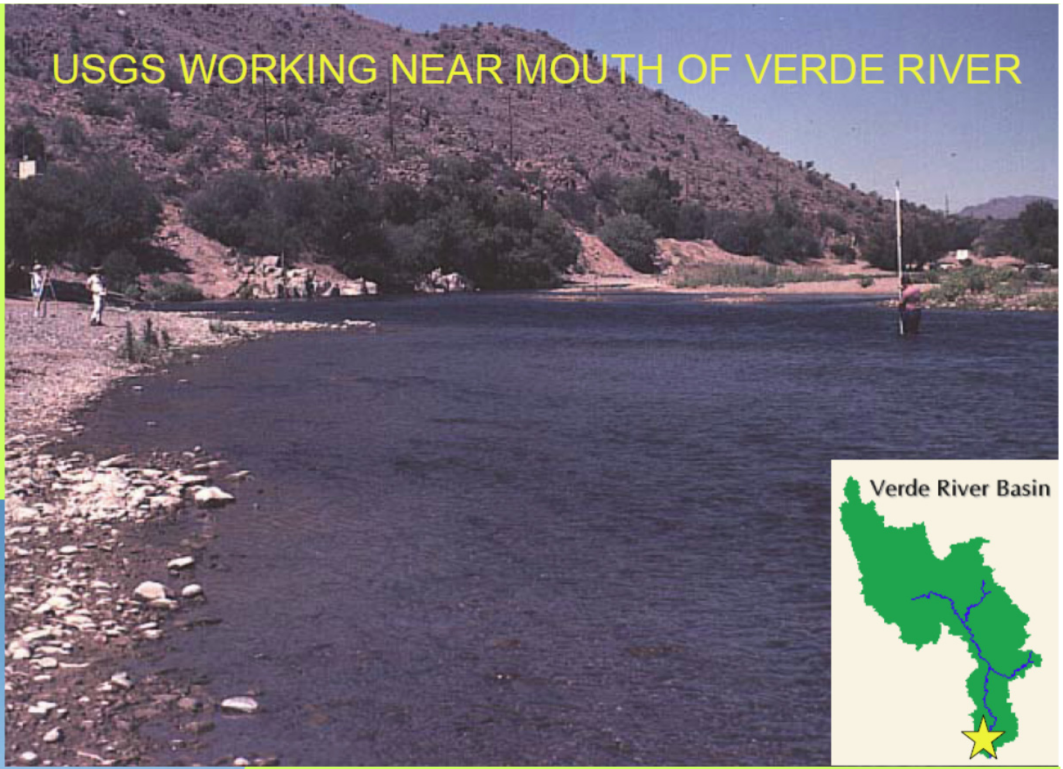
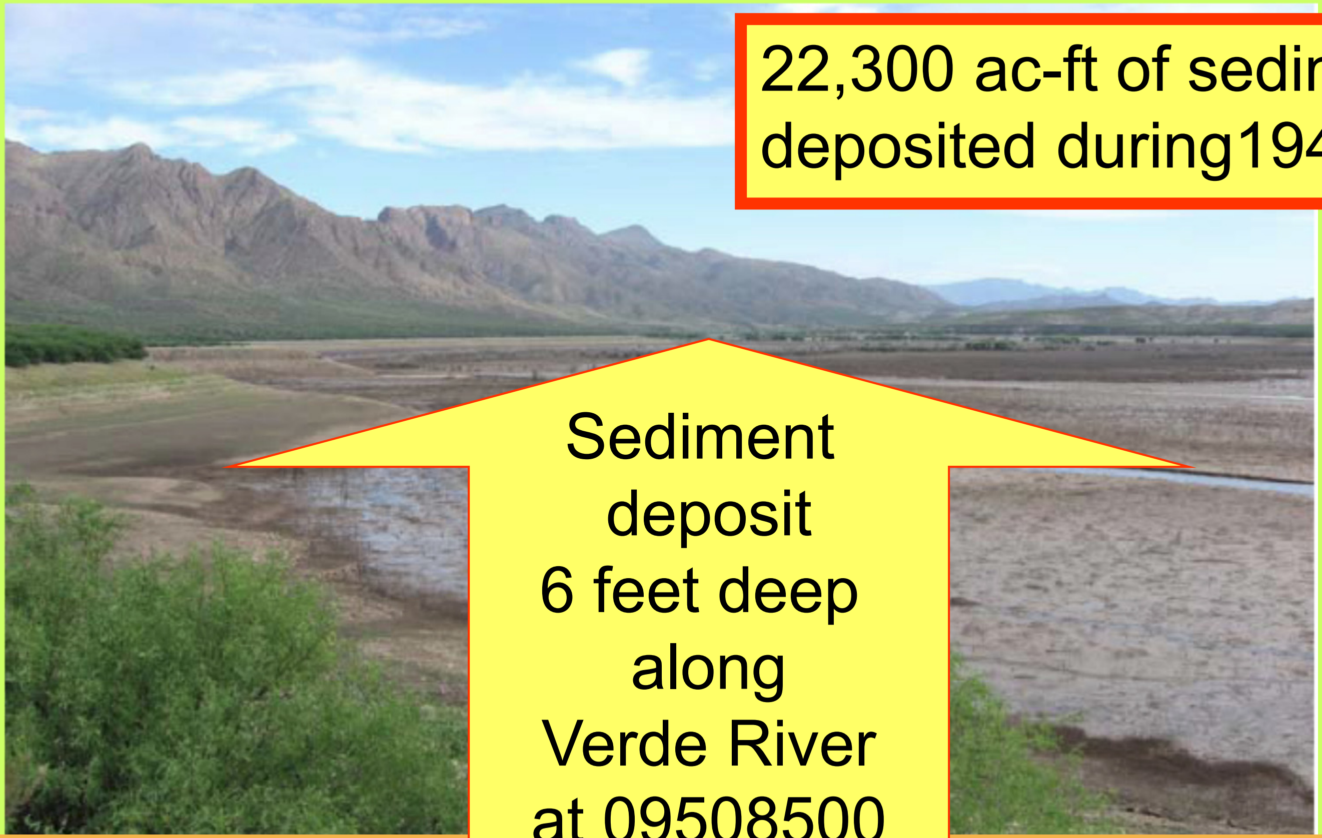

Verde River blw Bartlett Dam. View looking downstream.
Diversion to Indian canal on right bank side of Verde River. This diversion is in the general location of the earlier (historic) diversion before Bartlett Dam.
Google earth
Google earth
feet
400
meters
100

Many riffles are at the mouths of tributary streams

Boating the lower Verde River

Note the bedrock





Verde River in center is incised in large deposit of sediment behind the Horseshoe dam. Photo taken 6/09/09 by AZ GS, Horseshoe Reservoir 0% full.

Boating the middle Verde River

Note the bedrock

Sheep crossing

Verde Hot Springs

Title : Childs Electrical Plant, c. 1910
Date of Photograph : C. 1910; 1910
Collection : J. Hawley Collection

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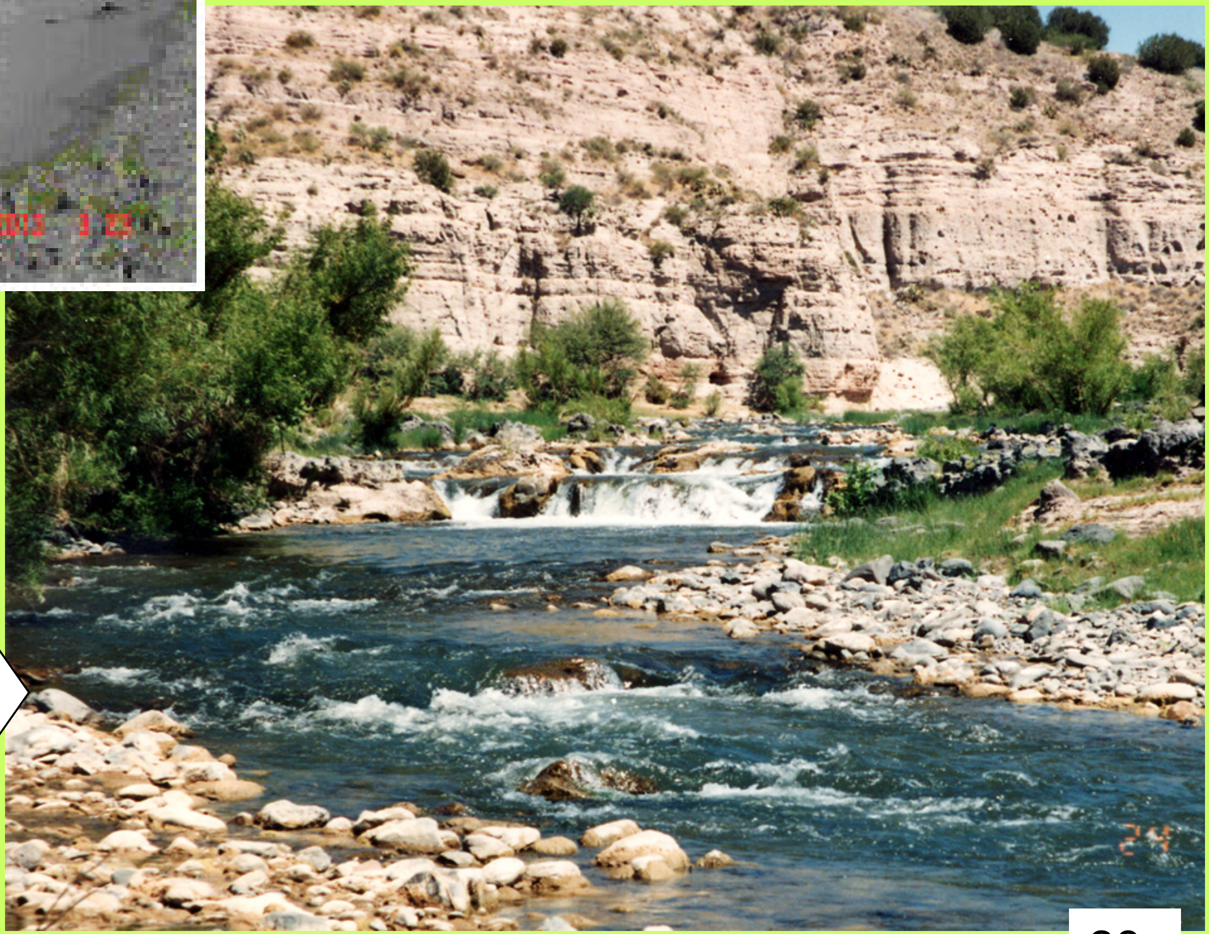
Below Camp Verde

Verde Falls area

2008
By Hjalmarson



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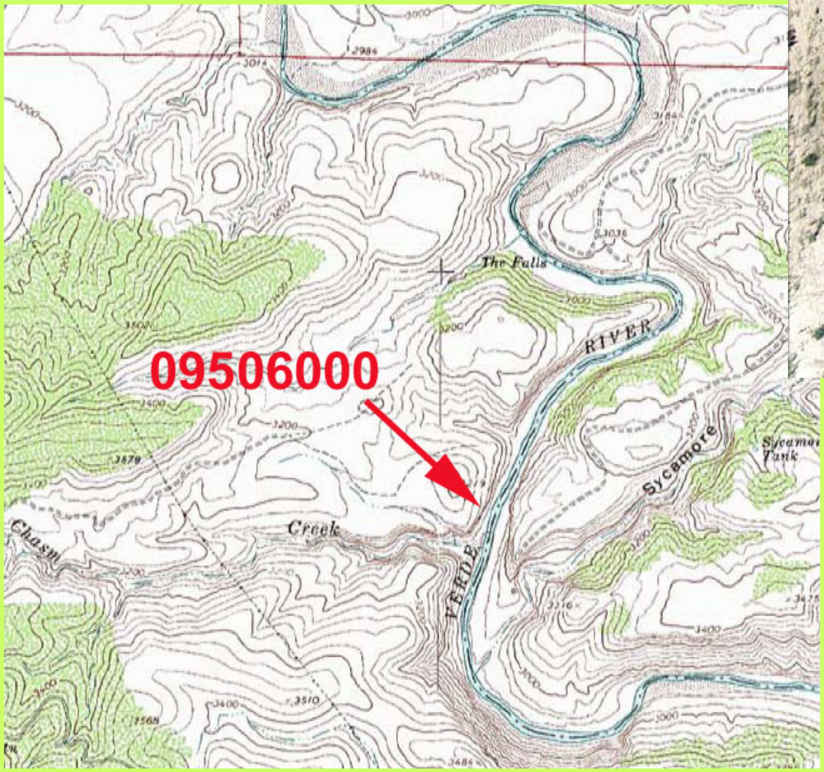
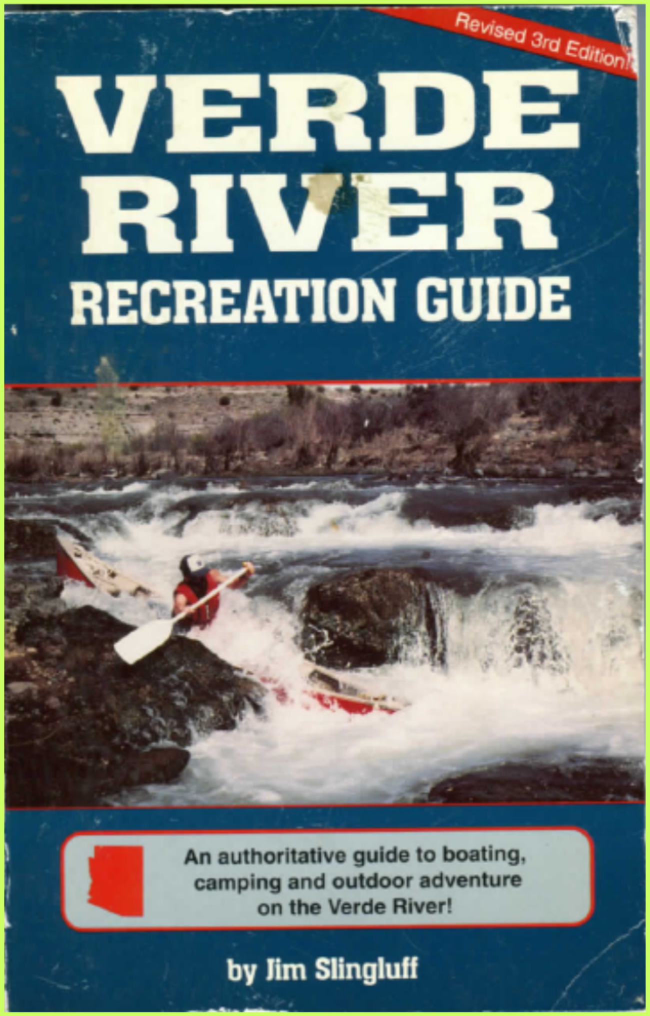


USGS gages 09508500 and 09506000

View looking upstream at Verde River Channel from below Black bridge in Camp Verde. The river channel has scoured through the alluvial sediments (Holocene material) into the Verde Formation (light colored material).

Hjalmarson



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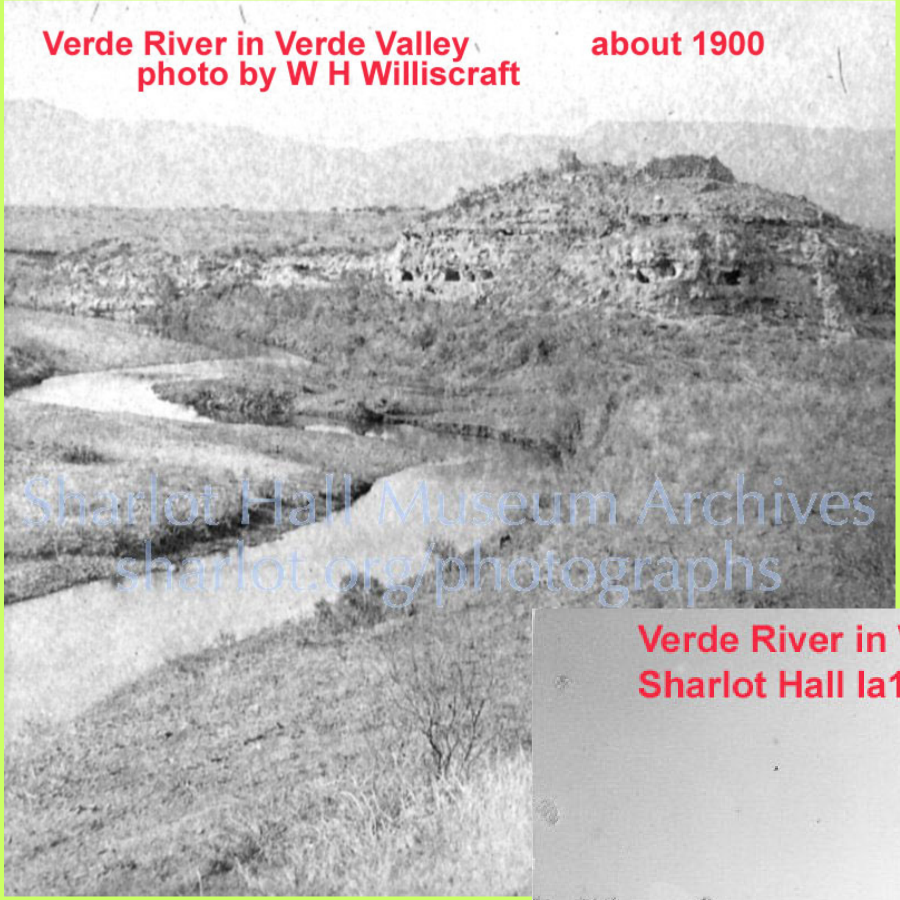
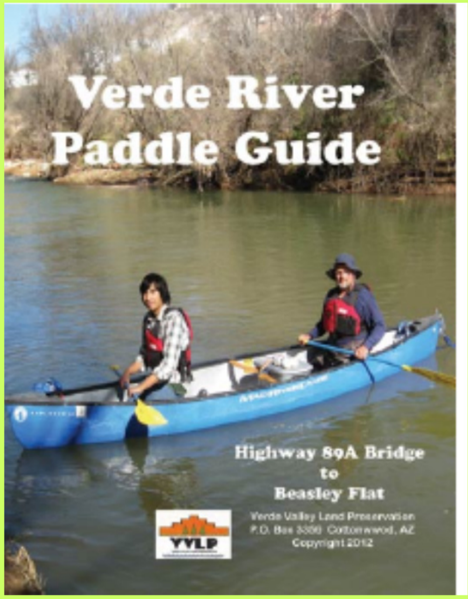

Verde River in Verde Valley
photo by W H Williscraft
about 1900
Sharlot Hall Museum Archives
sharlot.org/photographs


Verde River in Verde Valley
Late 1800s
Sharlot Hall la104po
Sharlot Hall Museum Archives
sharlot.org/photographs



Hjalmarson for ANSAC


CLARKDALE QUADRANGLE
ARIZONA—YAVAPAI CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
09504000
Reitz site
Reitz site
Reitz site
View looking upstream at Verde R.
1992

USGS Clarkdale gage 09504000

Clarkdale gage

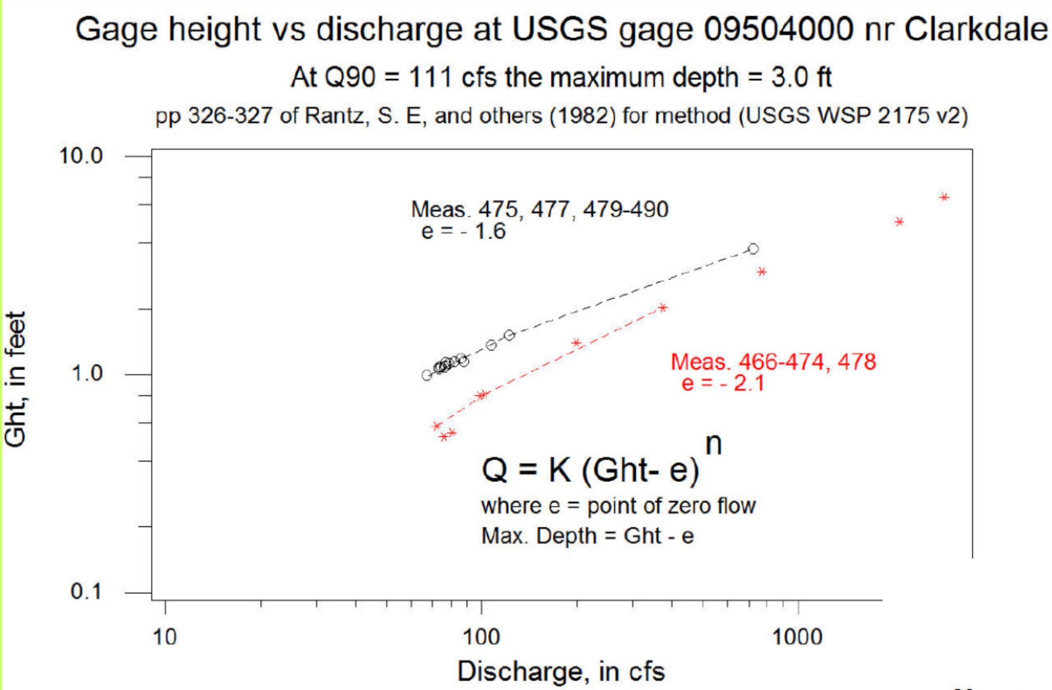
USGS
science for a changing world

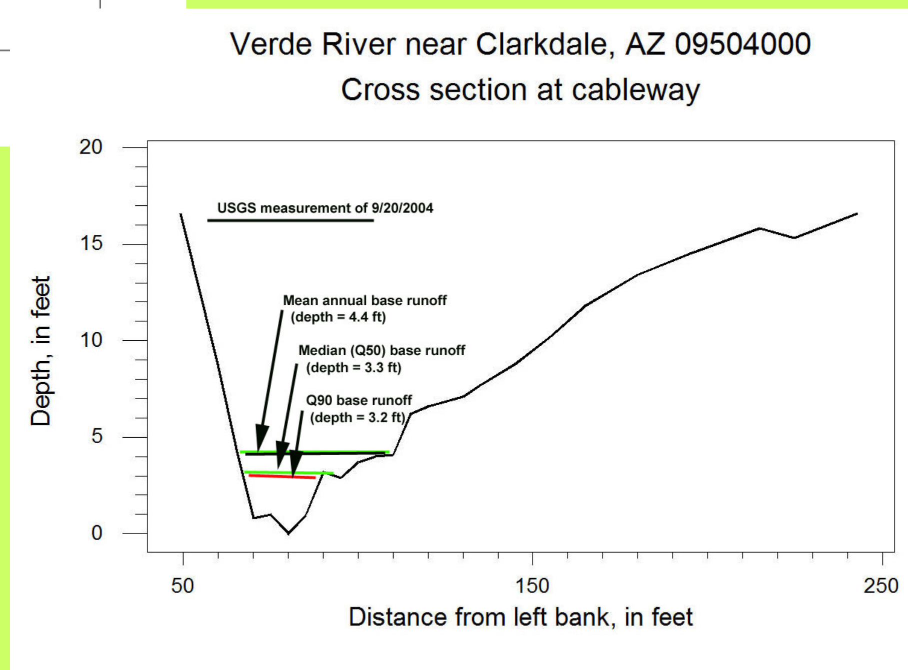
Views downstream from gage

About 2000 cfs

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.

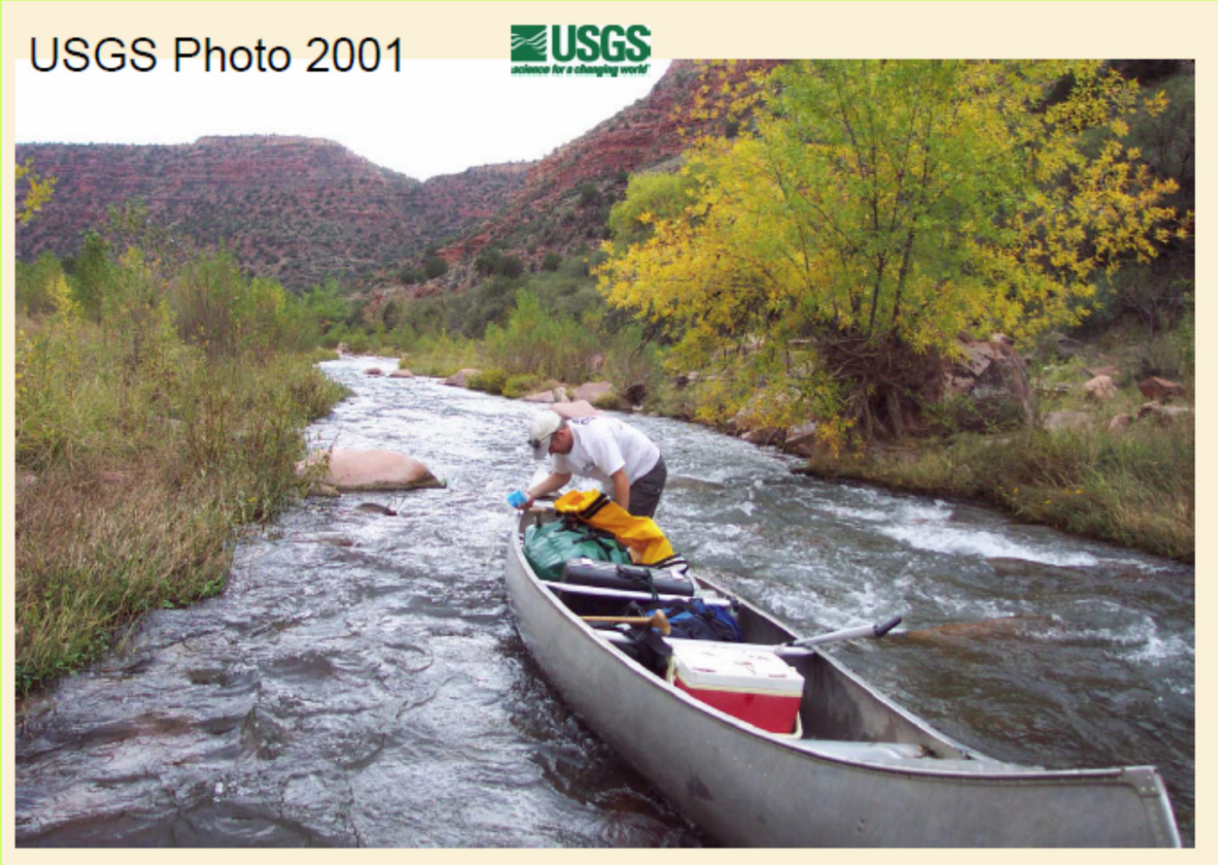
Verde River at USGS gage 09504000. View looking down and upstream. Q = 67 cfs.





USGS gage 09504000

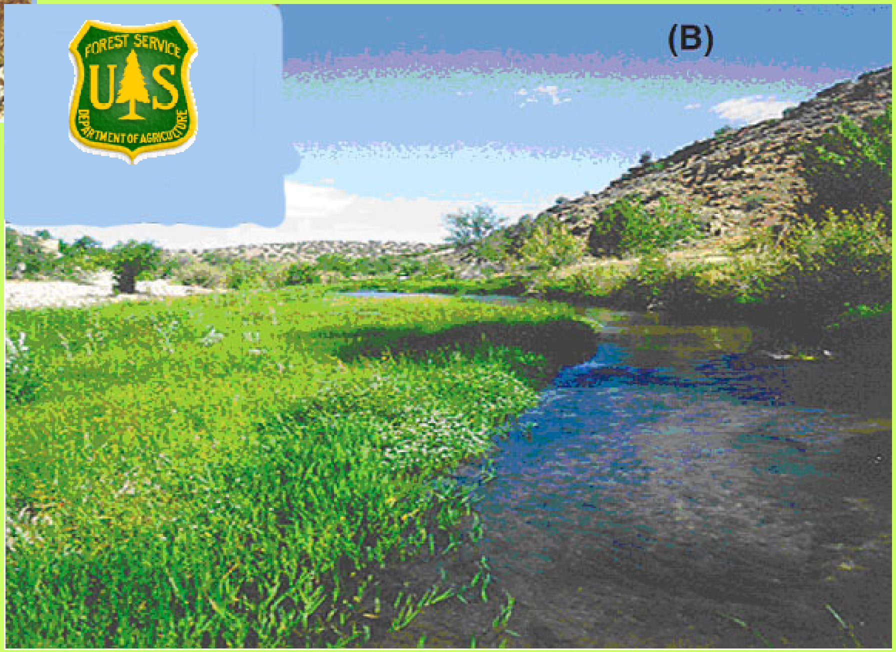
Computed maximum depths of natural flow (Q90 = 111 cfs) are 3.0 ft at the section control for the gage and 3.2 ft at the cableway.



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. Also—no dents!

Pools along the river act as small sediment traps that partially fill during small discharges and are flushed during large discharges.

Effect of 1993 floods along the Upper Verde River.



Comparison of vegetation next to the channel a decade before (A: 1979) and after (B: 2003) the 1993 floods, Verde River Ranch. (Photo A by James Cowlin and photo B by Alvin L. Medina, USFS.)

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

Duff Spring area

Mile 13.9

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.

There obviously is a considerable amount of silt, sand and gravel at this location.

Photo from Evans, K and McClain, C., 2005, Wild and Scenic River Proposal for The Upper Verde River, In conjunction with the Arizona Wilderness Coalition, 179p.

Bedrock bank

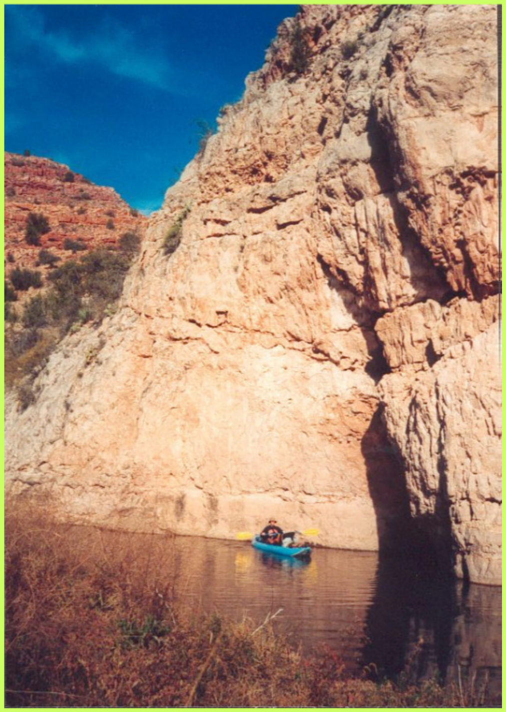
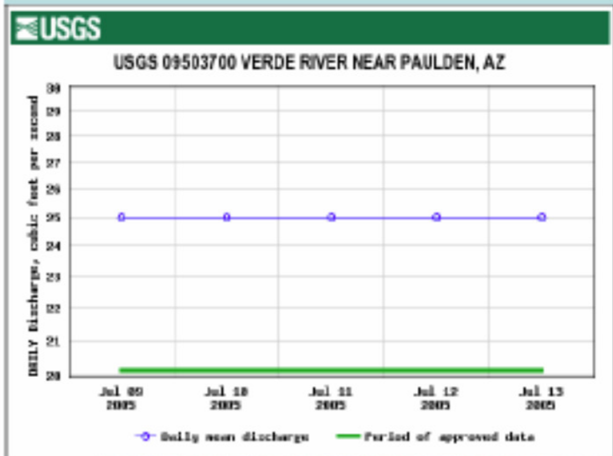


Photo from: Bowman, S. N., 2001, VERDE RIVER TMDL FOR TURBIDITY, Arizona Department of Environmental Quality, 33p.

A1

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



Mile 9.8

Hjalmarson for ANSAC

Settlers farmed floodplains

Natural grass with deep soil bonding roots

Crops with shallow non-bonding roots = EASILY ERODED SOIL

How settlers destroyed rivers

This photo shows a large root mass for native grass like that of the Great Plains.
As I discussed in section H7 of my Appendix H, there have been human impacts on several rivers because of farming on river floodplains.

Handout

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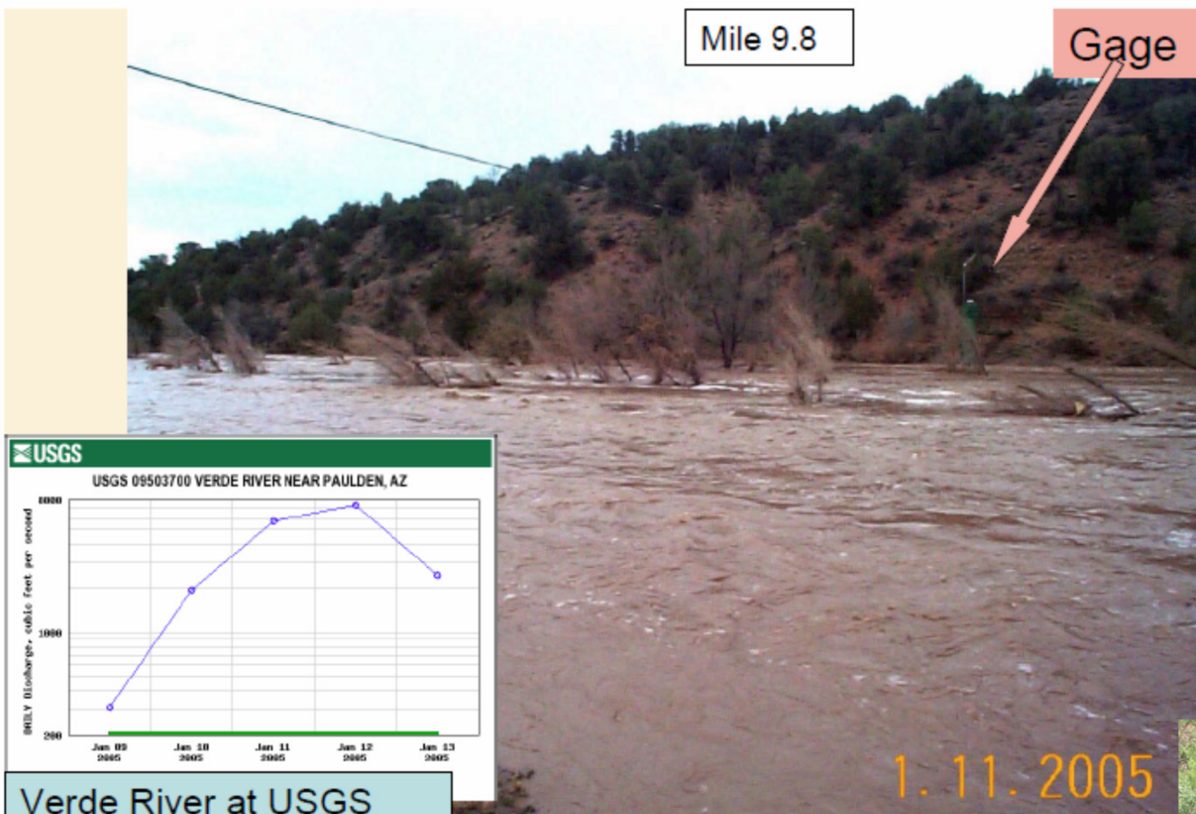
Paulden gage



Verde River at USGS gage 09503700. View looking downstream. Q = 6000 cfs.

Vegetation along the banks tends to stabilize channel banks and cause scour of the main channel. This scene is along the upper Verde following the 1993 flood. Flood debris (of 1993 flood) is on the trees with a beaver fallen tree in the left bank foreground of the scene. All along the Verde River the main channel bed generally stabilized and recovered to a navigable channel within days after the 1993 flood.

(Photo from Neary and others, 2012)

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

Hydrology

- At the time of statehood the base runoff was impacted by many upstream diversions for irrigation, storage, livestock and mining.
- Human activities that greatly altered the flow long before statehood challenged this evaluation of the navigability.

Hydrology

•There were diversions for livestock and irrigation 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.

The natural hydrology of the Upper Reach (headwater area including tributary streams) was defined using three independent hydrologic techniques.

These techniques use published information of the USBR, USGS, USFS, ADWR, Salt River Project and Federal Land Surveys.

Method 1

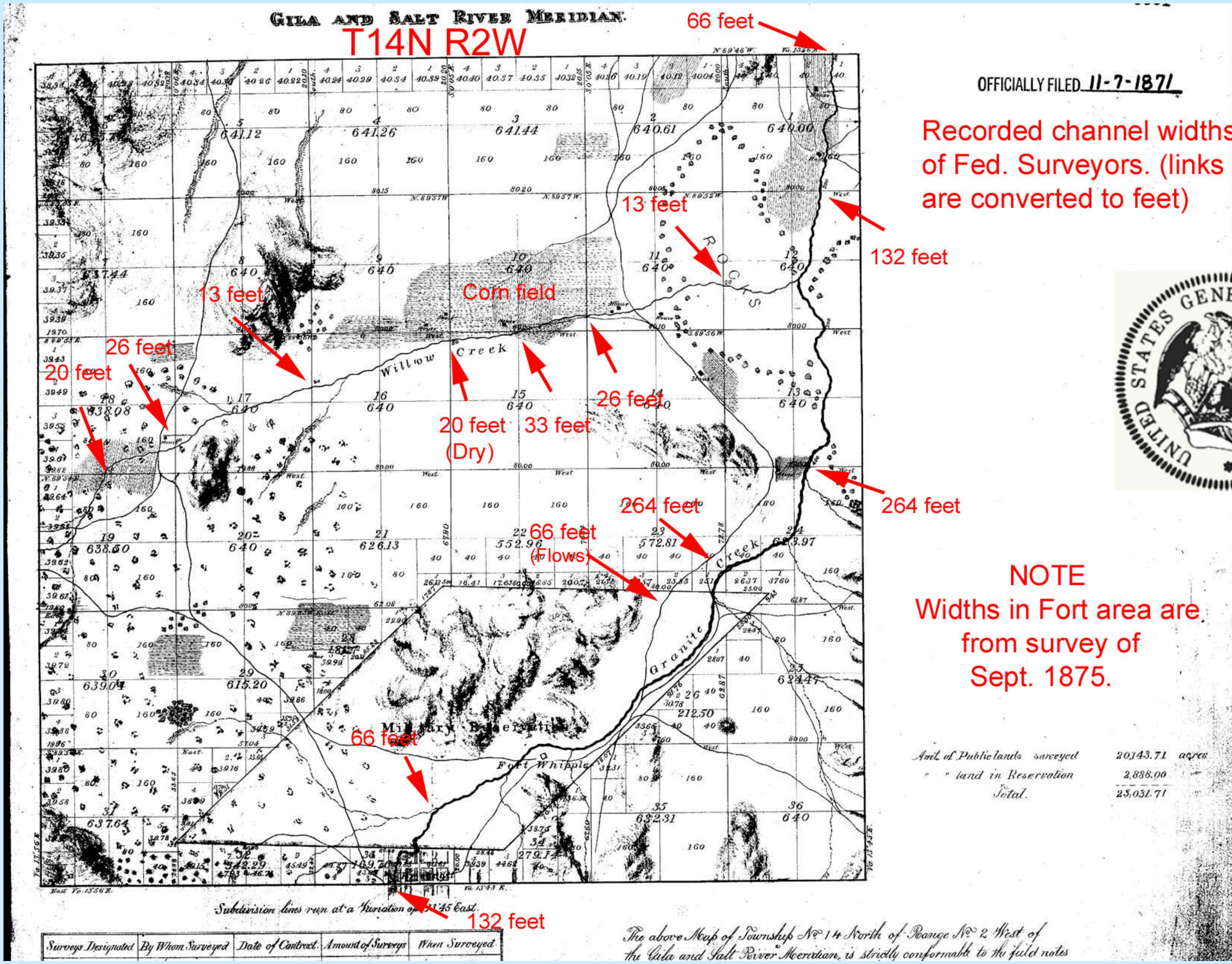
Estimate the human-caused reduction of base flow.

Irrigated acres X Consumptive use 3.15 ac-ft/yr = Reduction in base flow

Method 1

Cultivated acres were determined along intermittent and 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).

Sample plat-- one of many used for ANSAC analysis



Hjalmarson for ANSAC

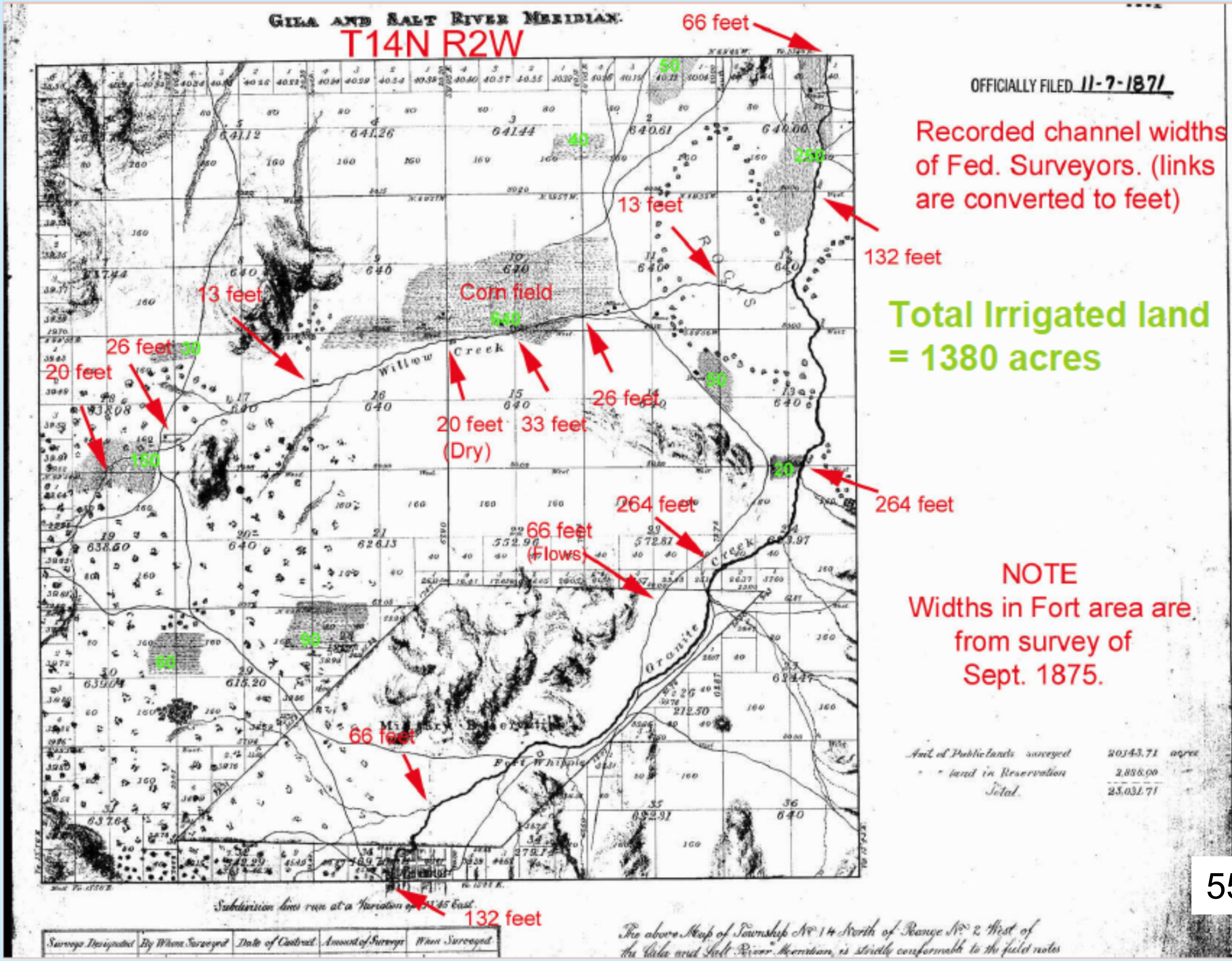
Base Qqa

of conceptual model

Recent USGS study shows base flow and plenty of groundwater storage along upper Granite Ck at the Yavapai-Prescott Indian Reservation.

Findings are consistent with accounts and use of the streamflow by early settlers.

Sample plat, on of many, used for ANSAC analysis



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.

With small adjustments for ET the flow for Method 1 is simply added to the base flow shown below.

26 Hydrogeology of the Upper and Middle Verde River Watersheds, Central Arizona

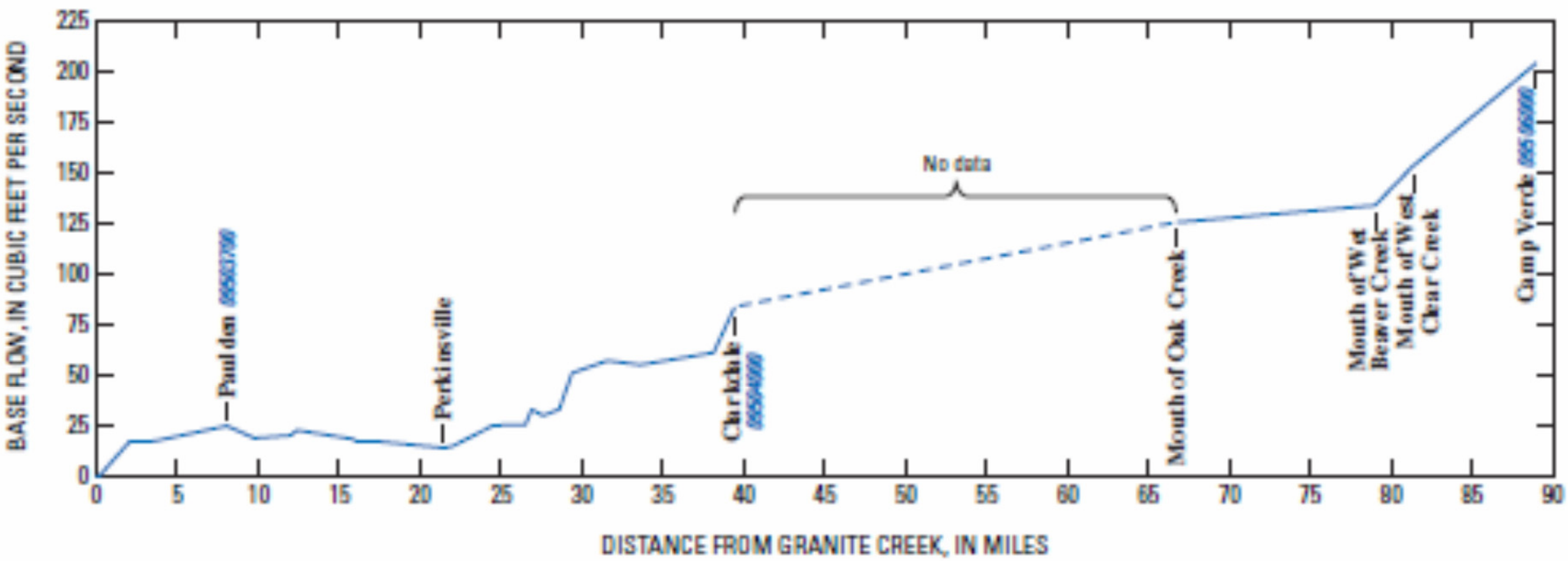


Figure 13. Base flow in the Verde River from the mouth of Granite Creek to the gaging station near Camp Verde (09506000).

METHOD 2

Method 2

Nearly all of the difference of 100 cfs (751 cfs – 651 cfs) between the Virgin average annual runoff (USGS, 1952) and the gaged mean annual flow USGS 09510000) 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).

METHOD 2

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 the ratio of irrigated acres for the two areas. About 28 cfs was lost to ET from irrigated land above gage 09503700 and 72 cfs was lost in the Verde Valley.

SRP
Delivering more than power.™

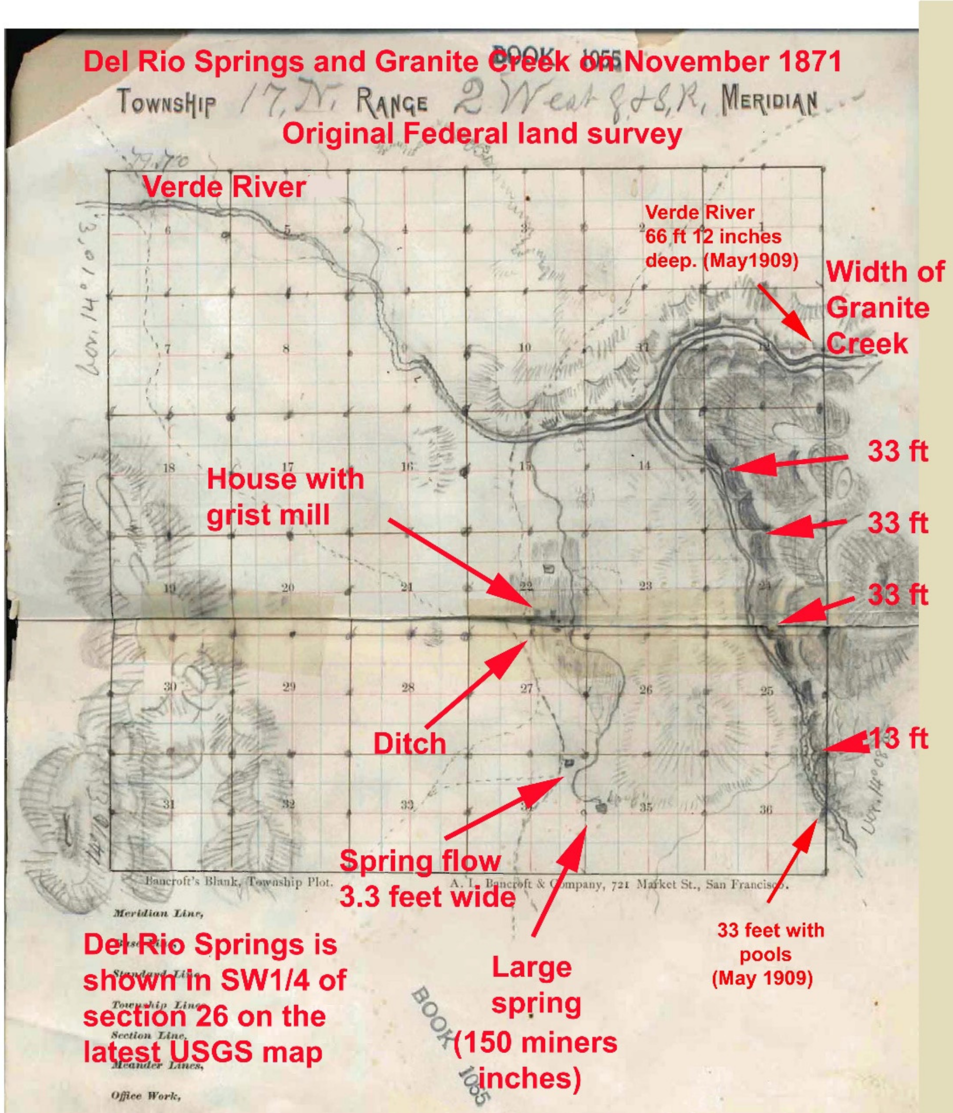
METHOD 3

Method 3

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.

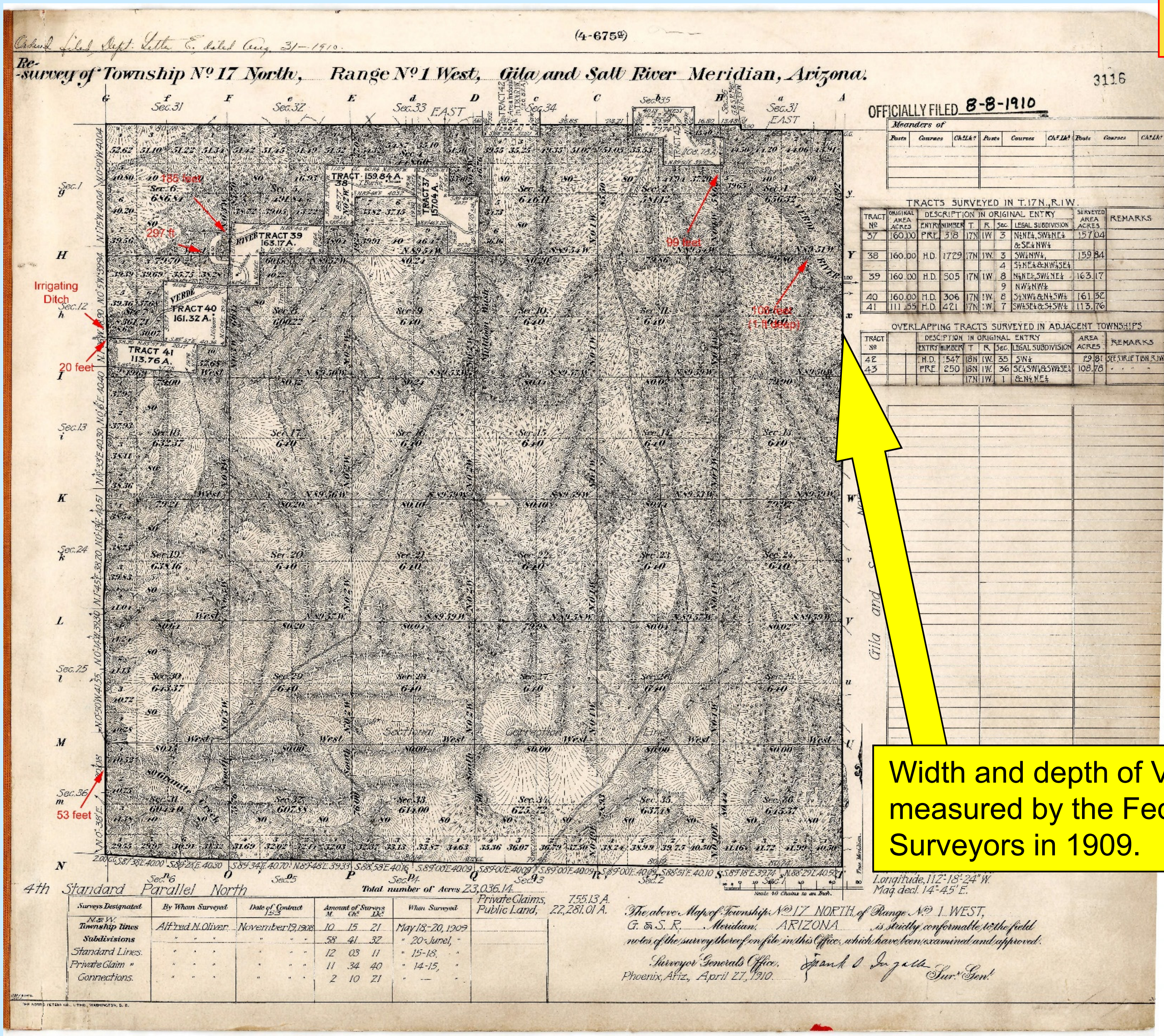
METHOD 3



NOTE: In 1940 eighteen wells were noted in operation in the Del Rio Springs area, of thich fourteen were free flowing. Also, the springflow of 150 miners inches that is shown here does not include all the springflow because additional springflow occurs for a few hundred feet to the north. In 1940 the flow was a minimum of about 175 miners' inches at the rim of the basin. Also, in 140 about 175 miners Inches (4-1/2 cfs) was used for irrigation of about 140 acres. These springs are the natural overflow or spill from the basin and roughly represent the excess over the exact amount of water which must be fed into the basin to maintain the present water level and pressure. Hjalmar W. Hjalmarson, PE

24,80	Cross wash 30 lks. wide course N. W.
30.00	Ridge bears E. and W. and descend.
37.00	Cross wash 1o 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
52.00	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 09¼S12BT. 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.

METHOD 3



Width and depth of Verde River measured by the Federal Surveyors in 1909.

Hjalmarson for ANSAC

METHOD 3

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. Several possible hydraulic conditions were assumed at the average discharge of several estimated is:

Q = 60 cfs

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 for the Upper Verde River.

Natural median (Q50) base runoff along study reach of Verde River

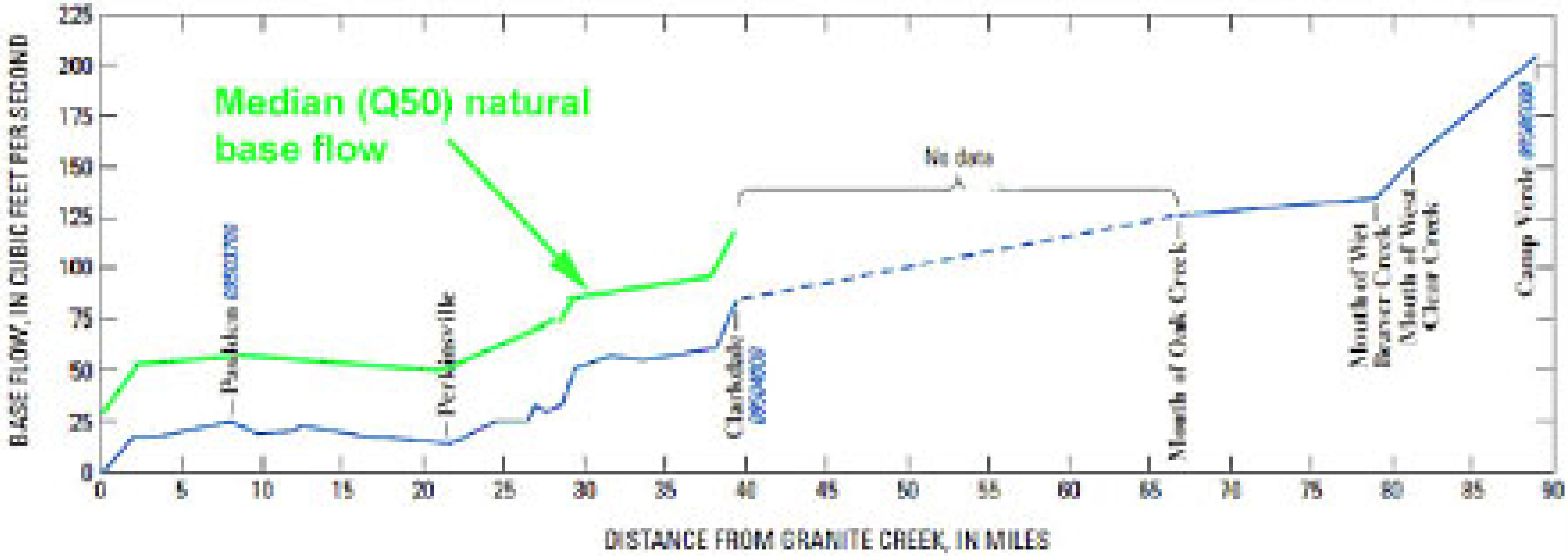


Figure 13. Base flow in the Verde River from the mouth of Granite Creek to the gaging station near Camp Verde (09506000).

Modified from: 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.

UPPER REACH

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

MIDDLE-LOWER REACH

Important parts of this analysis of the hydrology below USGS gage 09504000 include:

1. USGS records of stream flow at gages 09503700, 09504000, 0950600 and 09510000

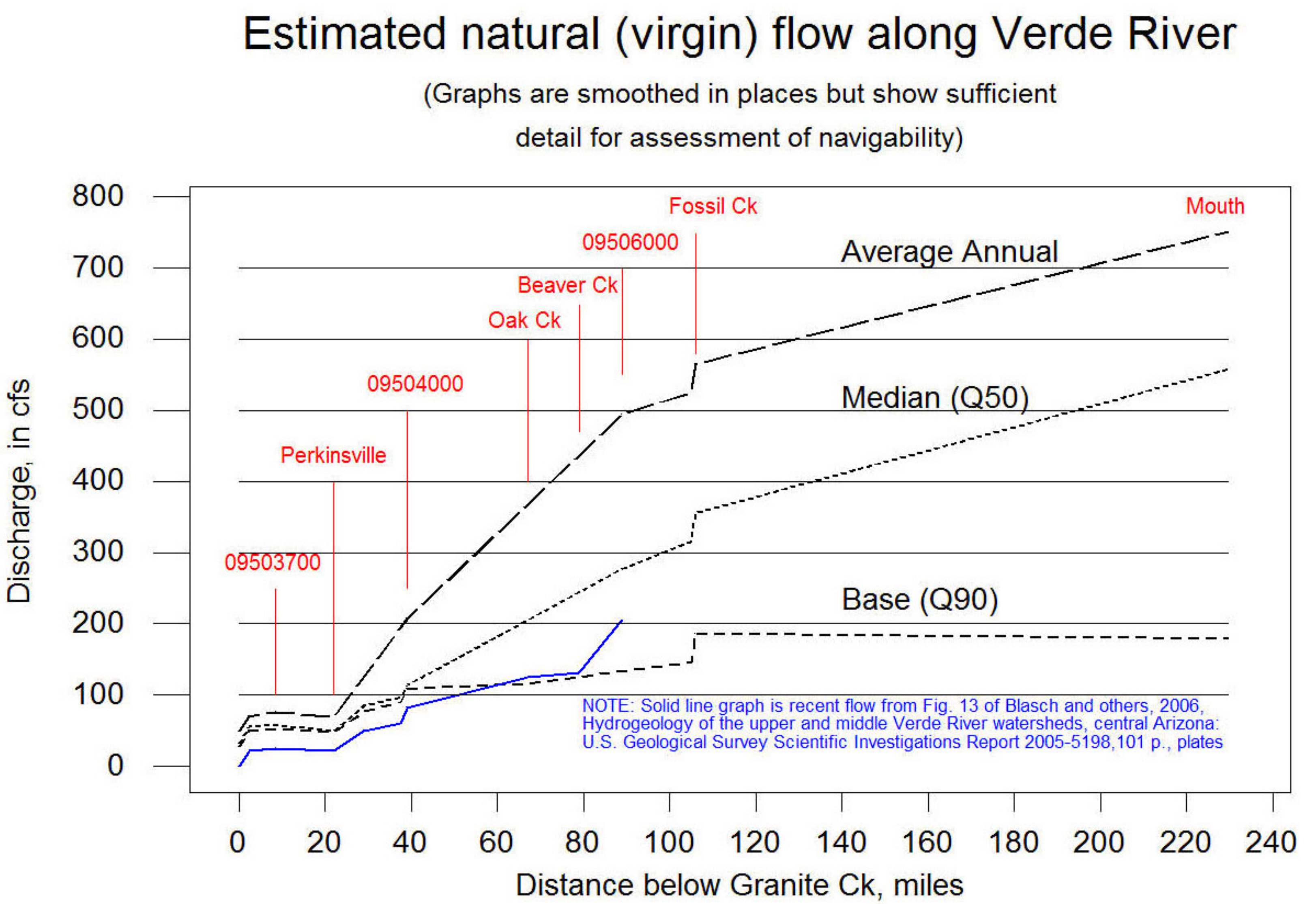
2. A report by the USBR (1952) that calculated the Virgin flow for the mouth of the Verde River

3. A report by the USGS (HA-664 by Freethey and Anderson (1986)) that estimated base runoff (Qbfa, the 90th percentile of daily discharge) for the basin fill and underlying aquifers.

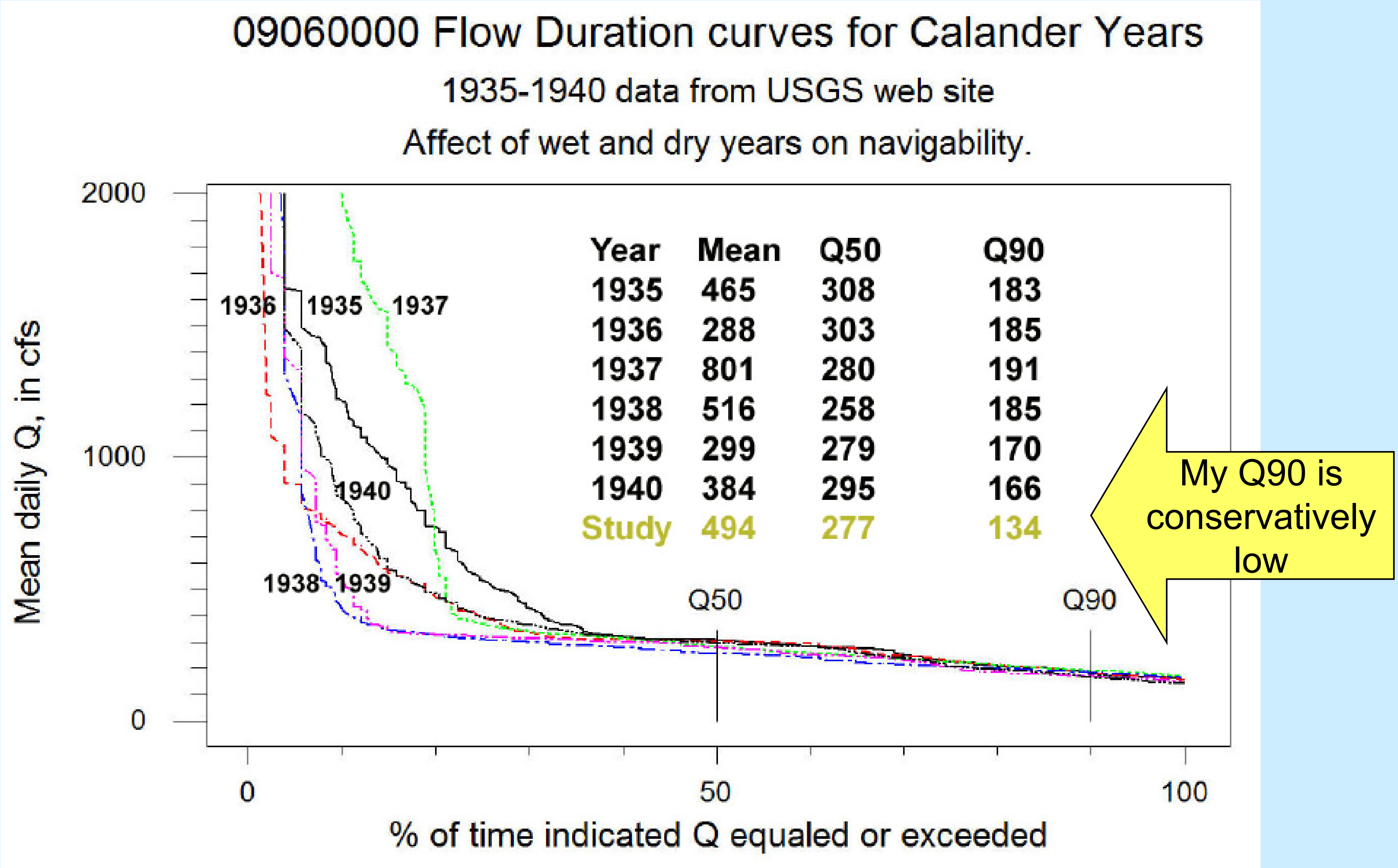
- Base runoff of the lower reach of the Verde River is simply computed by adding (1) the 100 cfs difference between the Virgin average annual runoff and the gaged average annual runoff at gage 09510000 (recall method 2 for upper reach) that was associated with early settler use of base flow and (2) the base flow (from USGS HA664) at and below the USGS gage 09506000.

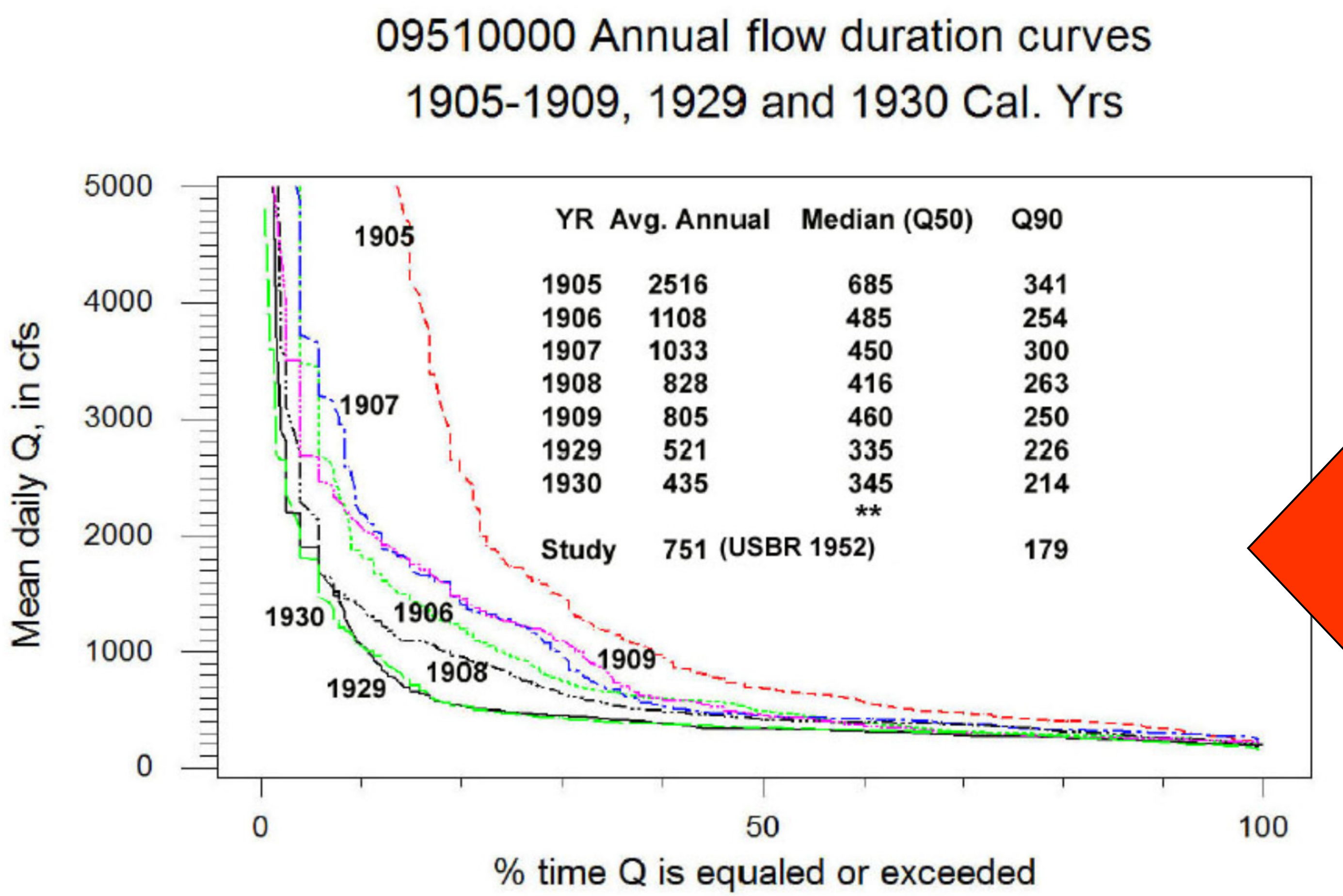
MIDDLE-LOWER REACH

- Base runoff of the lower reach of the Verde River is simply computed by adding (1) the 100 cfs difference between the Virgin average annual runoff and the gaged average annual runoff at gage 09510000 (recall method 2 for upper reach) that was associated with early settler use of base flow and (2) the base flow (from USGS HA664) at and below the USGS gage 09506000.
- The base runoff associated with Qqa and Qmf was simply distributed across the middle Verde River between USGS gages 09504000 and 09506000.
- The resulting natural base flow is shown in on the following slide.



Natural and recent flow in the Verde River from mouth of Granite Creek to the mouth.


09060000 Flow Duration curves for Calander Years
1935-1940 data from USGS web site
Affect of wet and dry years on navigability.
Year Mean Q50 Q90
1935 465 308 183
1936 288 303 185
1937 801 280 191
1938 516 258 185
1939 299 279 170
1940 384 295 166
Study 494 277 134
1936
1935
1937
1940
1938
1939
Q50
Q90
2000
1000
0
50
100
Mean daily Q, in cfs
% of time indicated Q equaled or exceeded
My Q90 is conservatively low



My Q90 is conservatively low

** Burtell (item 84, page 19) ignores USBR (1952) and shows Q50 = 437 cfs. However, Burtell is off the mark because the lower base flow (and associated depths) limits navigability. Q90 is not affected very much by large amounts of average annual Q.

Handout

HYDRAULICS and CHANNEL GEOMETRY (ANSAC)

USFS Report/Data
Federal Land Surveys
USGS Reports/Data
Sierra Club Data
Arizona Geolgical Survey
Energy considerations

Hydraulics and geomorphology

A simple way to think of much of the 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“ of in older in older material such as the Verde Formation and basin fill material.

A summary of a detailed assessment of the 36.6 mile reach of the upper Verde River from the dam at Sullivan Lake to the USGS stream gage near Clarkdale, AZ. is presented first and is followed by a summary of a more general assessment below the Clarkdale gage to the mouth at the Salt River.

Description of Upper Verde River Watershed

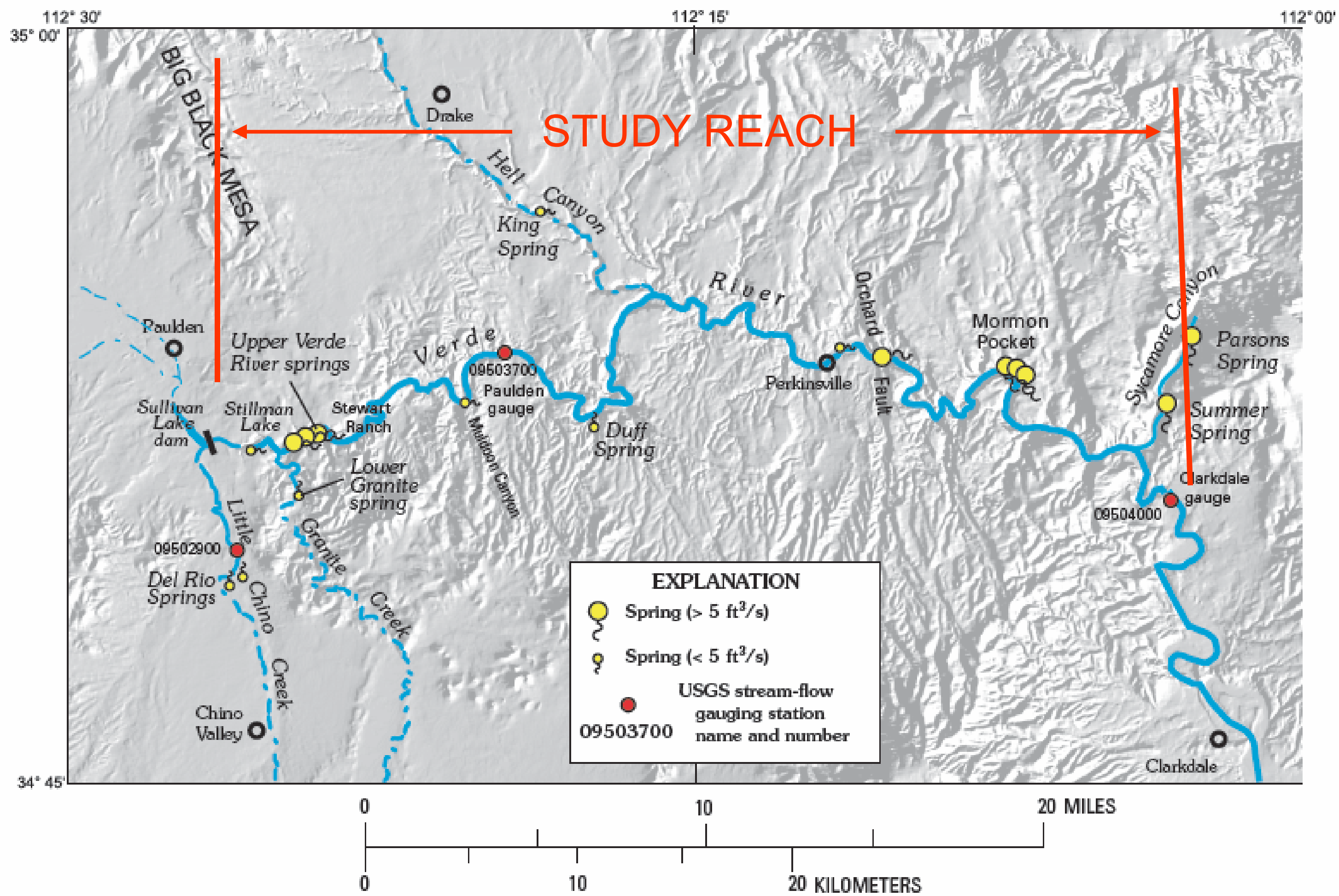
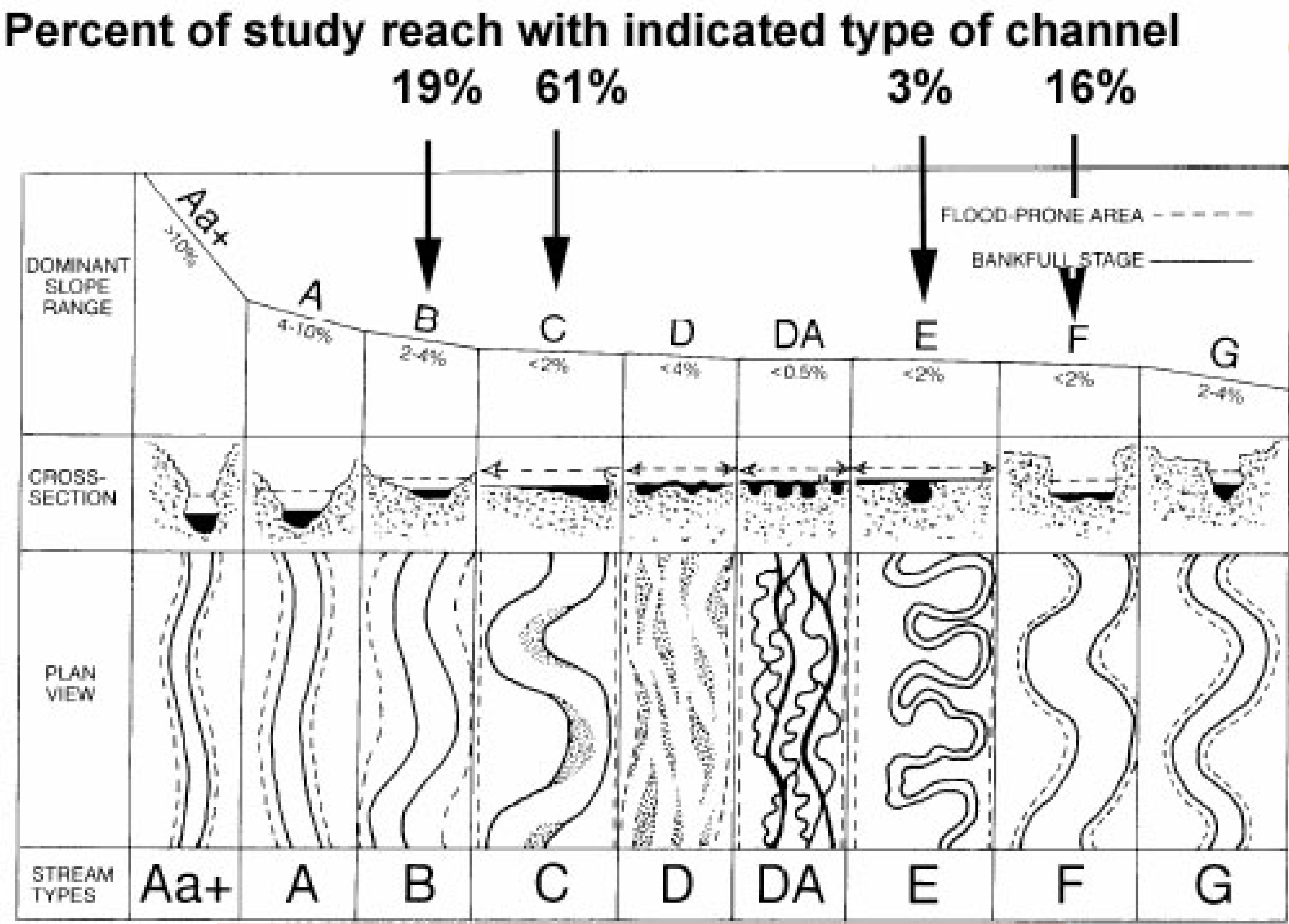


Figure A2. Locations of known springs along the upper Verde River from Sullivan Lake to Sycamore Creek. Base is from U.S. Geological Survey digital data 1:100,000; sun angle elevation is 45 degrees from southeast; azimuth is 120 degrees.

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.

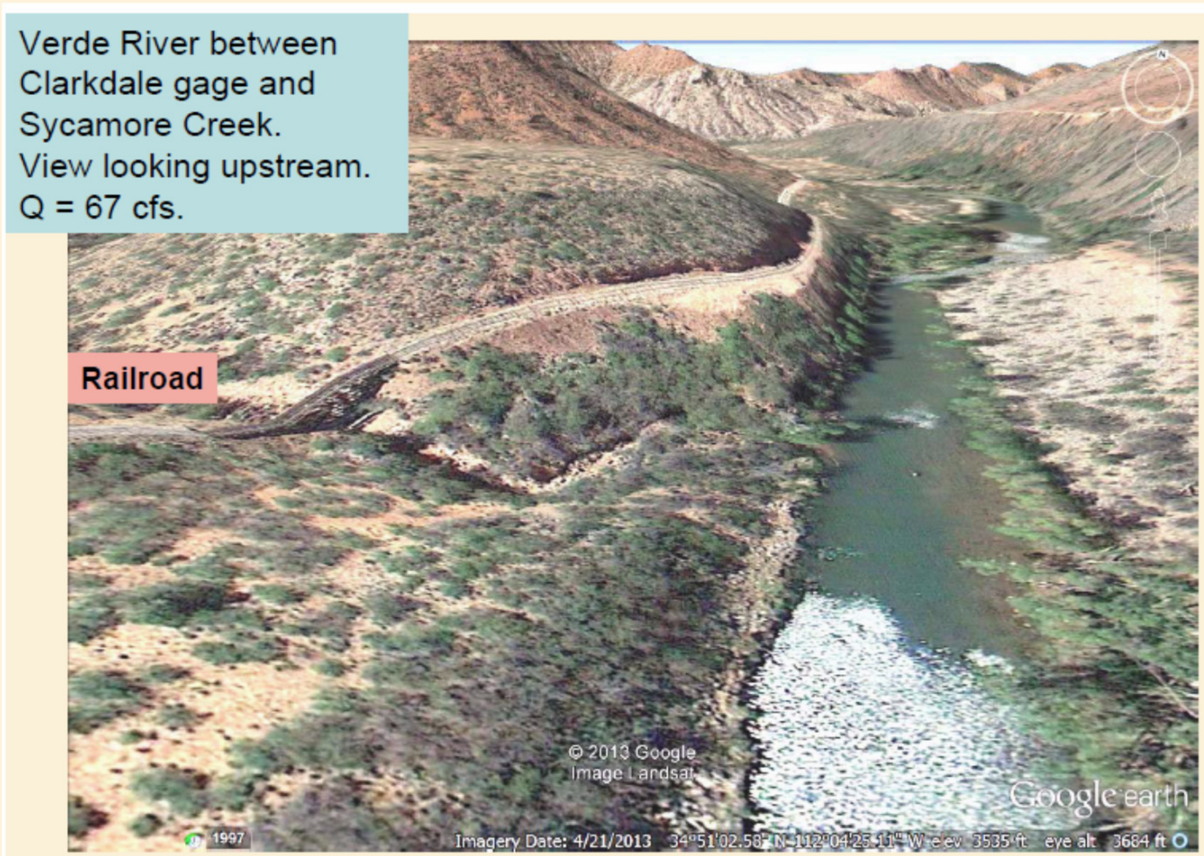
USFS Report



Rosgen stream classification used by USFS

Hjalmarson for ANSAC

The Verde River is a pool and riffle gravel-cobble bed stream. A typical riffle is shown below at the mouth of the tributary stream where tributary sediment has been deposited.



Large debris (boulders) from side slopes. Obviously only very large 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.

photo by USFS

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

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 floodflow but the duration of base flow is considerably longer.

•Many cross sections with channel widths have been measured by the Federal Surveyors, U S Forest Service, Sierra Club and the USGS upstream of the USGS Clarkdale gage.

•Many current meter measurements have been made by the Sierra Club, USFS and USGS along the river upstream of the USGS gage near Clarkdale.

•Downstream of the Clarkdale gage many cross sections were measured by the Federal Surveyors, Finally, the USGS operates stream gages 09503700, 09504000, 09506000, 09508500, 09510000 and 09511300 where many current meter measurements and a few rating curves are available.

SAMPLE

Mile 17.9

June 2000

P001370
(Verde R. above Hell Canyon Confluence)

P001371
(Verde R. above Hell Canyon Confluence)

P001372

P001373

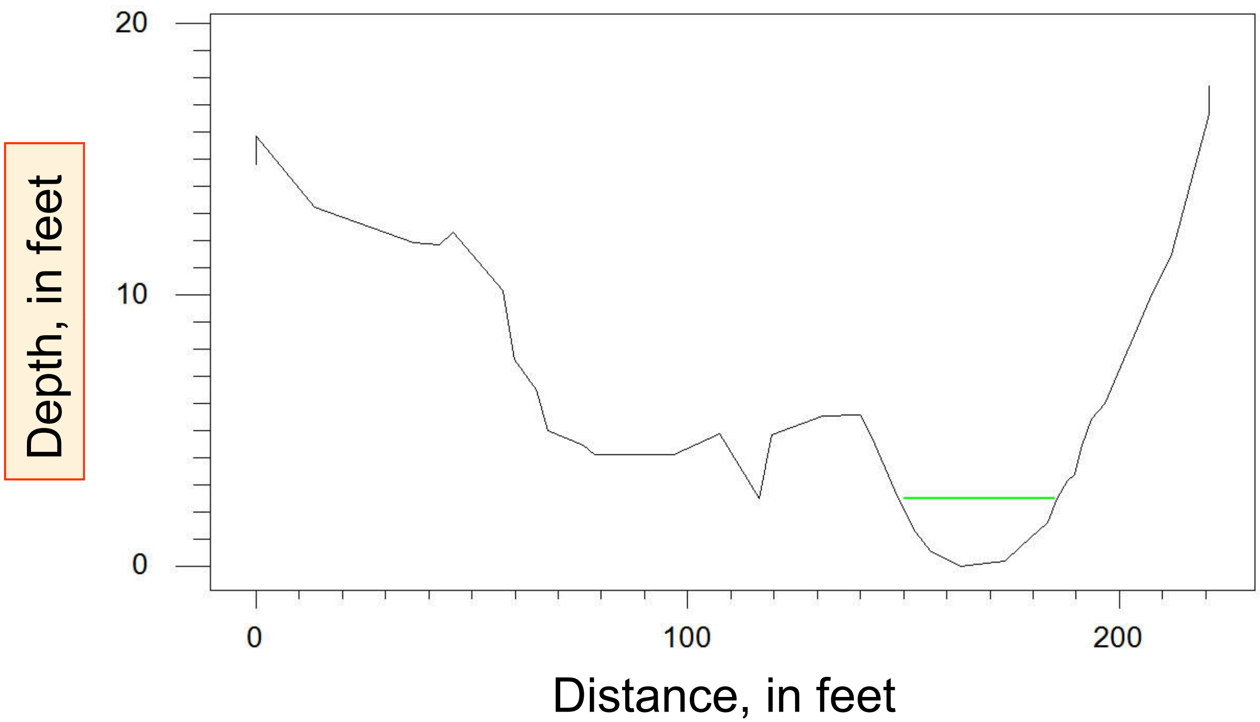
USGS data for June 13 and 14, 2000

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

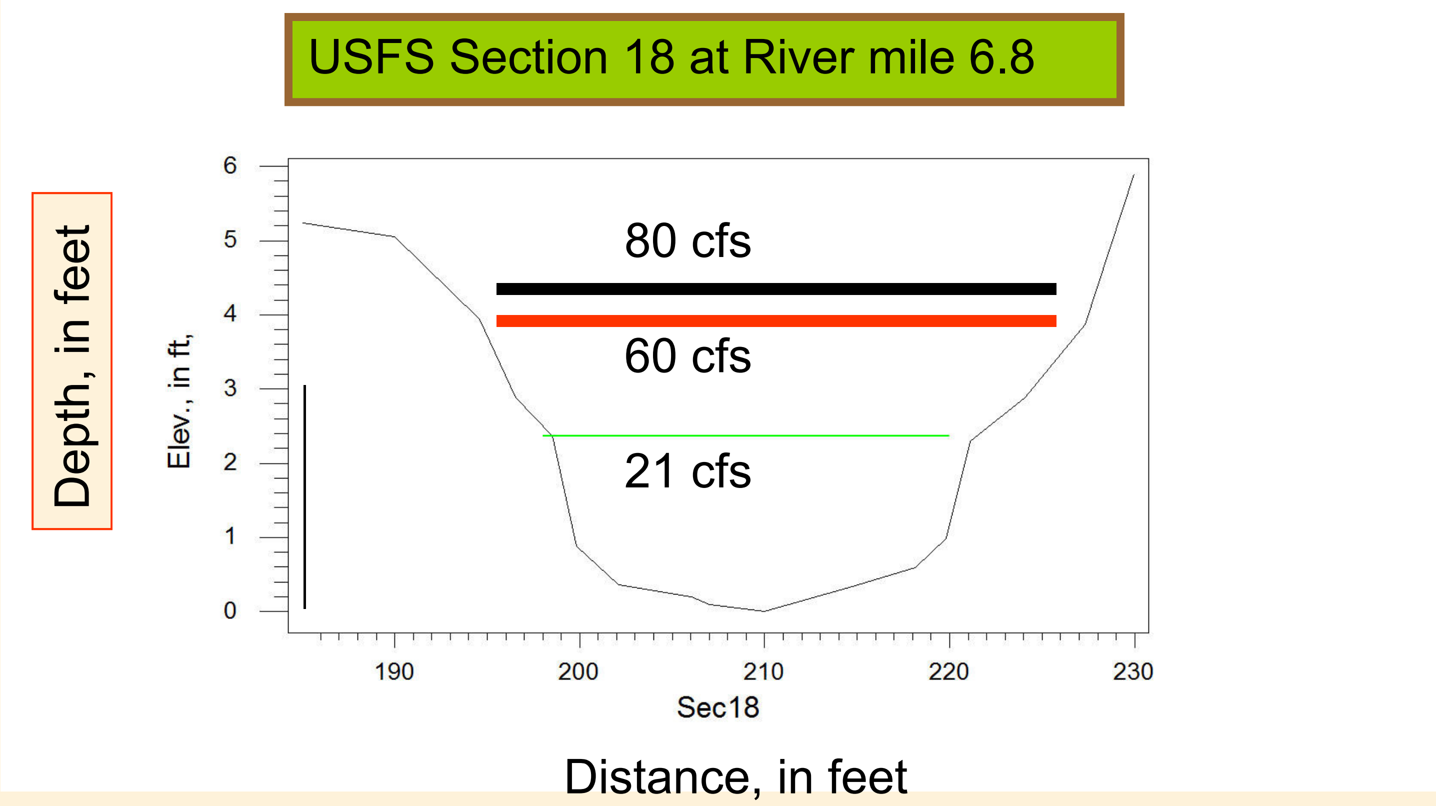
SAMPLE

USFS Section 18 at River mile 32.2



The USFS has surveyed 108 cross sections along the Upper Verde River . Dan Neary, PhD graciously furnished 6 representative cross section for this study.

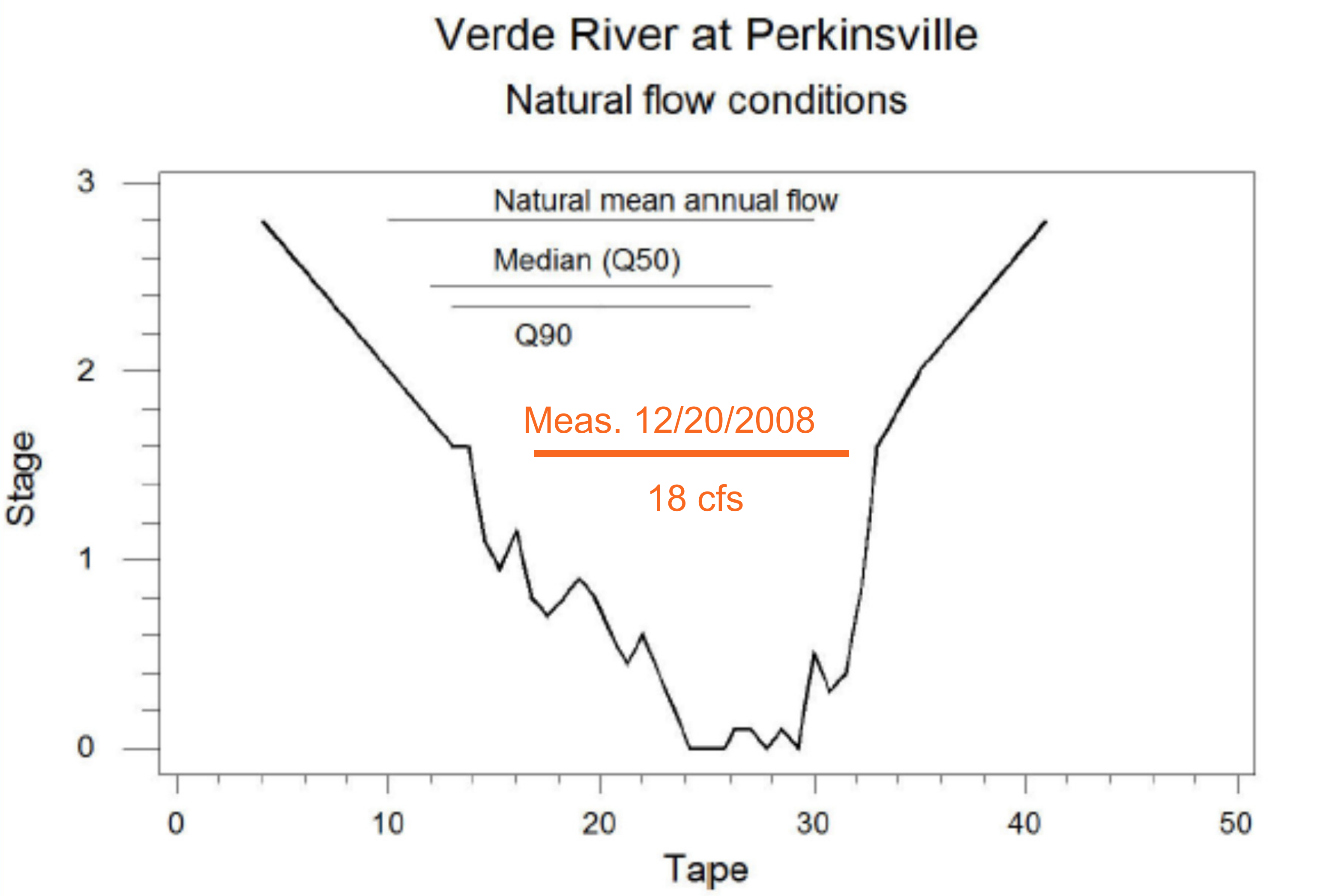
SAMPLE



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

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



SAMPLE

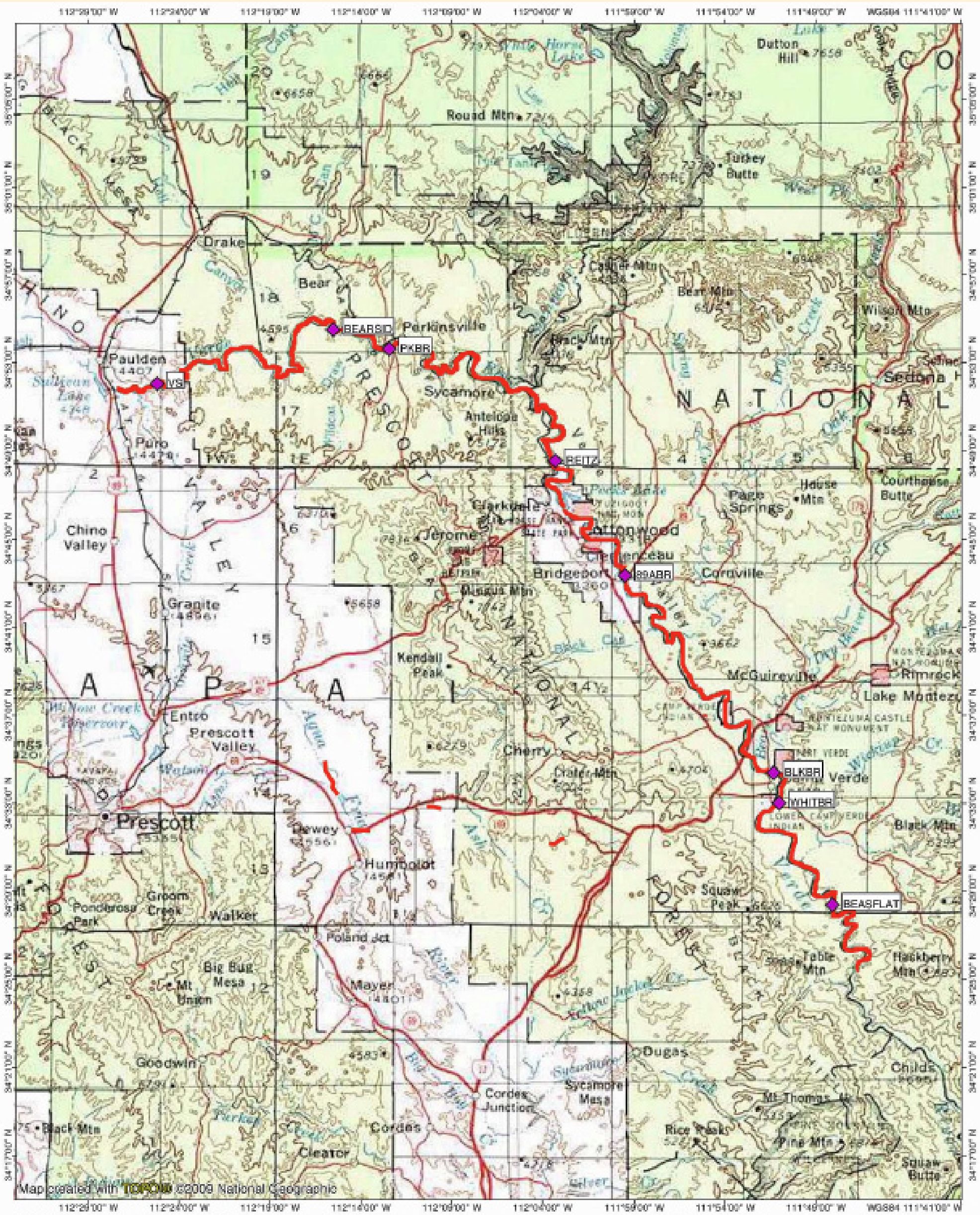
Mile 3.2

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

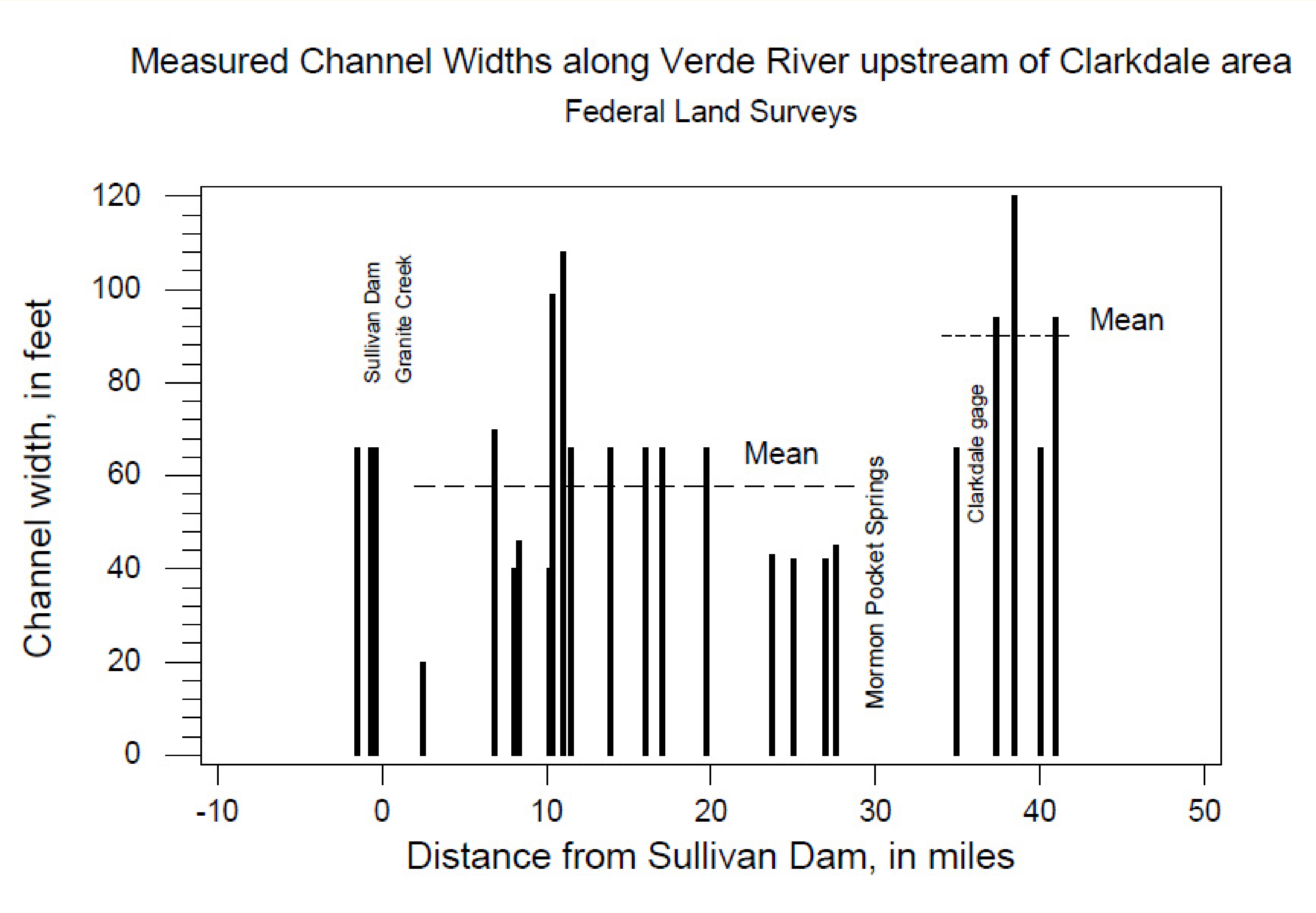
2013



Water Sentinels Sampling Sites

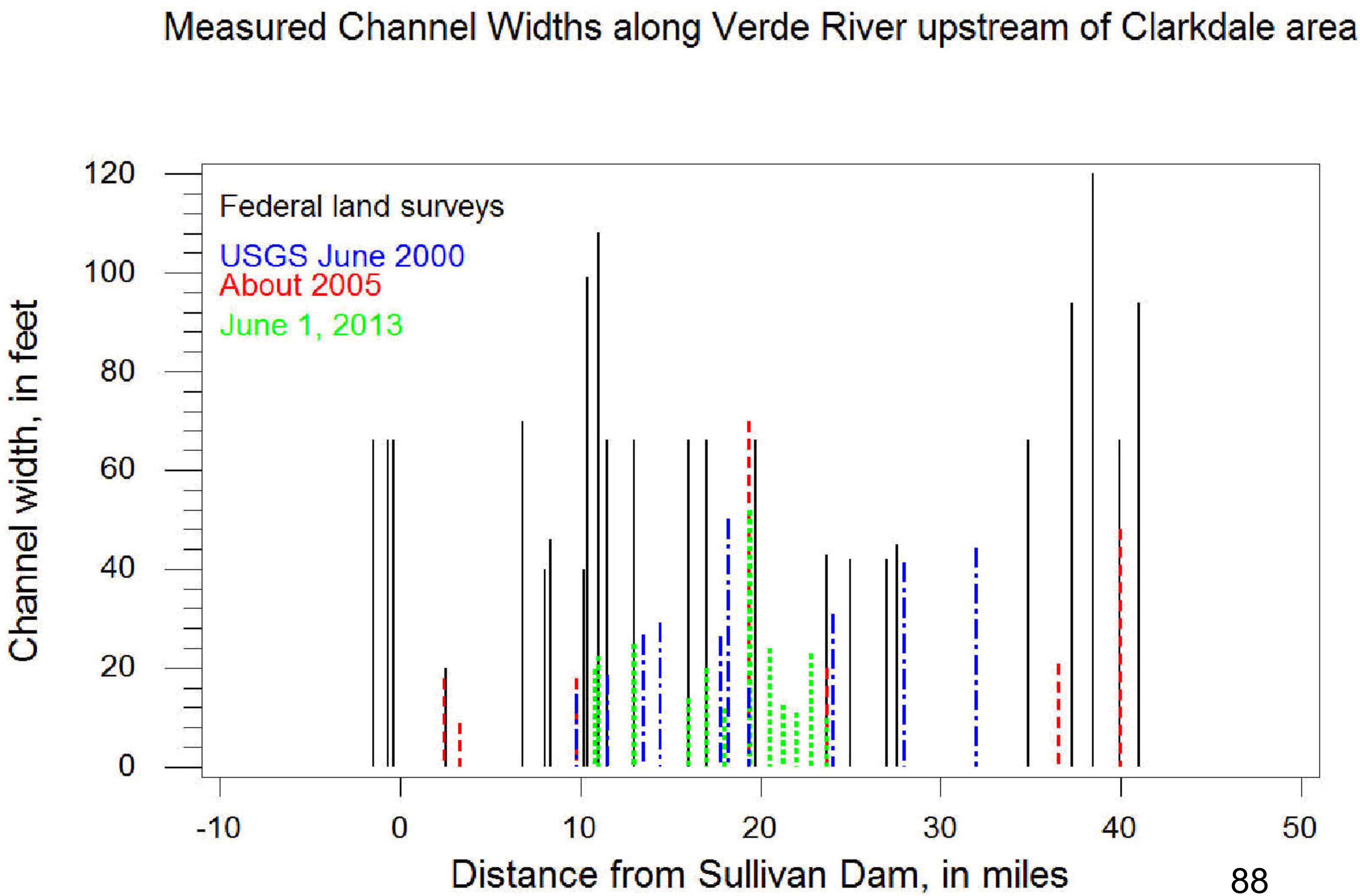
Miles	Site	Q cfs	W ft
9.8	Paulden gage		*
10.2			*
10.4			*
10.8	SR01	17.46	19.7
11.0	SR02	16.35	22.4
11.5	SR03	*	*
13.0	SR04	18.27	25.0
16.0	SR05	16.00	14.0
17.0	SR06	14.42	20.0
18.0	SR07	16.49	12.0
19.4			52.0
19.7	SR08	11.85	*
20.5	SR09	11.59	24.0
21.3	SR09A	11.86	12.5
22.0	SR10	11.42	11.0
22.8	SR11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

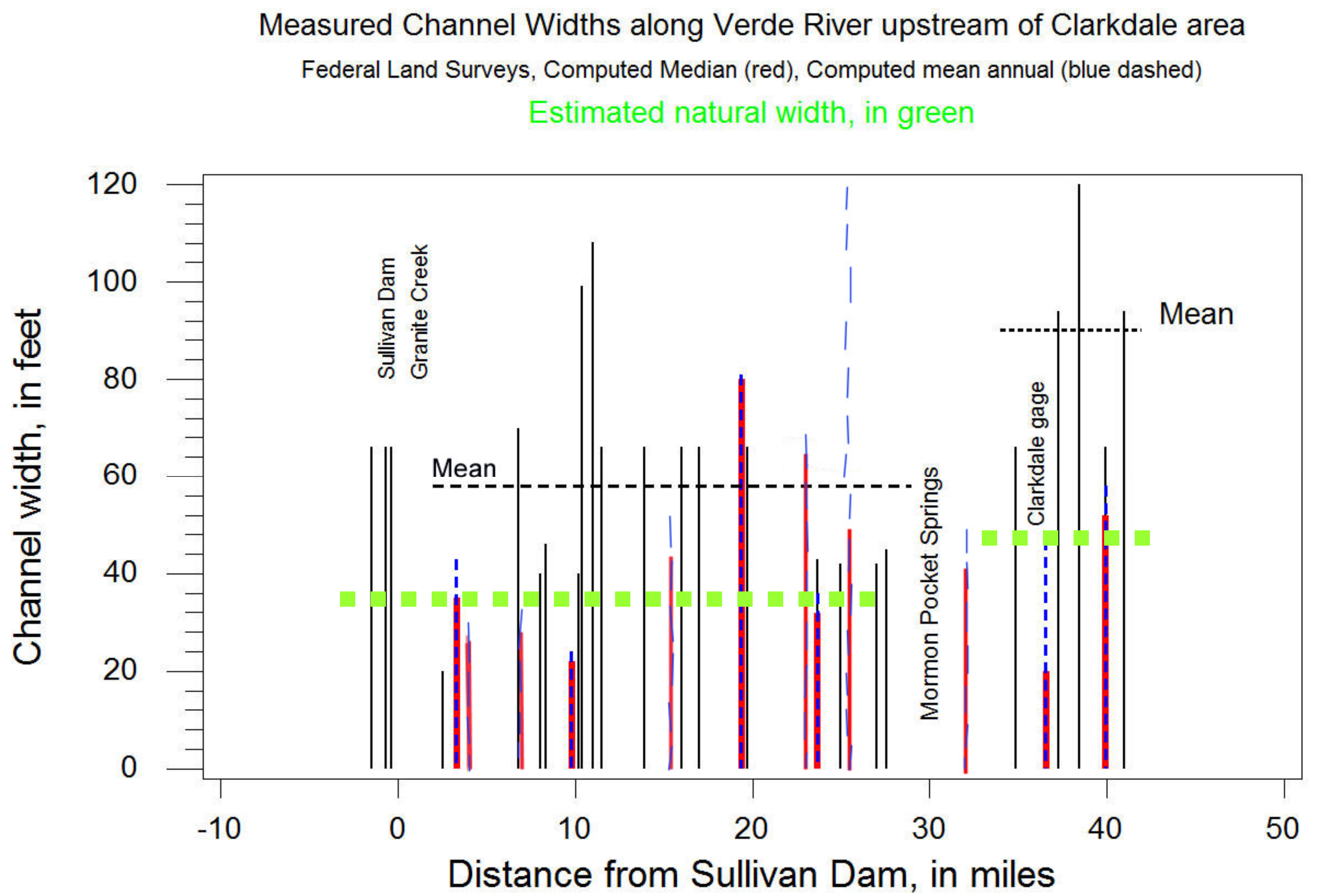
LAND SURVERYS - SUMMARY



Hjalmarson for ANSAC

Surveyed channel widths of the original land surveys are considerably greater than measured widths.





Estimated natural channel width is for typical channel with gradual riffles and most pools where hydraulic backwater conditions exist.

Because the cross sections are for measurements of river discharge where deep pools are avoided, the following depths typically are less than depths of the numerous pools along the upper Verde River.

Location	Mean annual		Median		Q90	
	Q	Max. Depth	Q	Max. Depth	Q	Max. Depth
	cfs	ft	cfs	ft	cfs	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

•Most of the Verde River is pools where 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), more than 3.0 ft (median, Q50) and about 3 ft. (Q90).

•Also, the depths closely represent depths along a potential navigation lane (or corridor) used for small water craft.

- 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.

- Most of the conditions along the Verde River are typical of many perennial gravel bed streams and streams where the bed material is larger than coarse sand.

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)

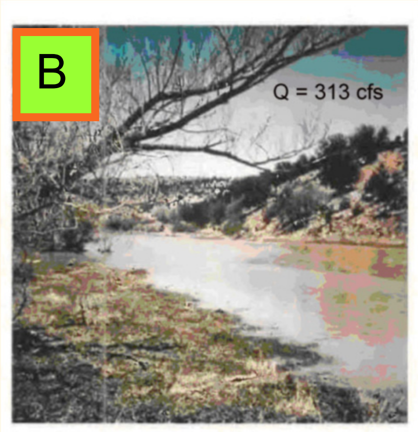
Flow velocities typically are subcritical except along the main thread of flow at a few rapids. (C)

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

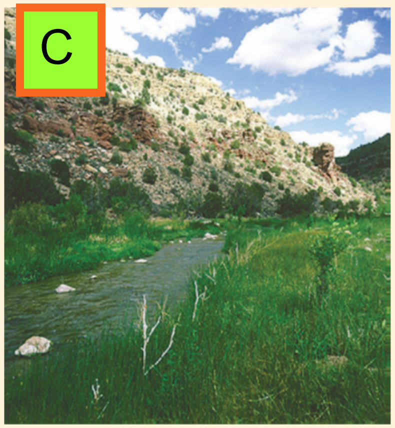
Note: Flow shown in photos A, C and D is considerably less than the natural base runoff.

A

B



C



D

Hjalmarson for ANSAC

Clarkdale gage to mouth

The evidence also suggests the natural and recent geometry of the channel upstream of Horseshoe Dam are approximately the same probably, to some degree, because of outcrops of bedrock and coarse channel material limited channel adjustment for the lesser base flow.

•The evidence in my report shows the Verde River upstream of Horseshoe reservoir behaves like a typical channel where “A natural channel migrates laterally by erosion of one bank, maintaining on the average a constant channel cross section by deposition on the opposite bank.

•In other words, there is general equilibrium between erosion and deposition.

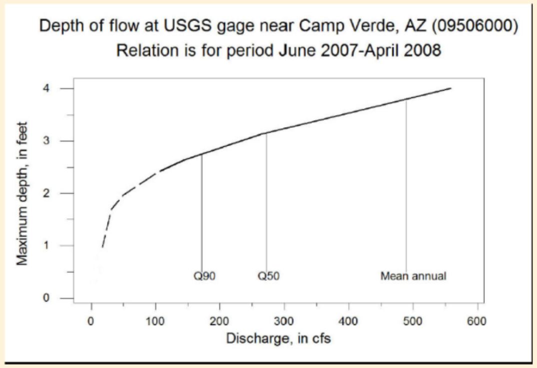
•The form of the cross section is stable, meaning more or less constant, but the position of the channel is not.” (As described by Leopold, 1994, p.5 for rivers in general.).

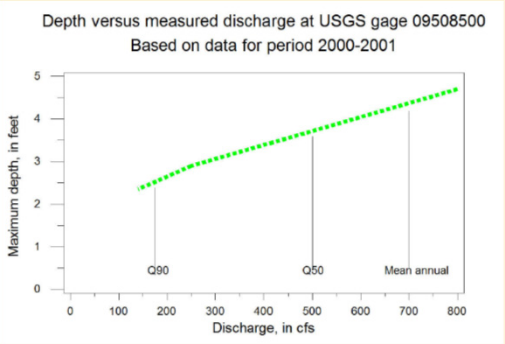
•The evidence also suggests there was a single well defined main channel along the entire river following the large floods of 1891 and even 1993.

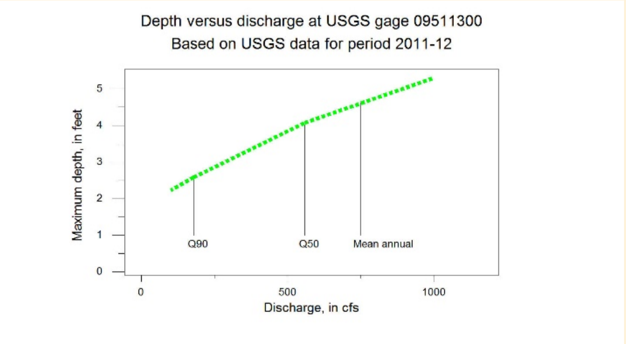
•Downstream of Horseshoe Dam where nearly all flow is from controlled releases from the two major reservoirs, the main channel typically is well defined but there are a few braided reaches where the recent channel (s) of the lower Verde River is (are) not considered representative of the natural condition.

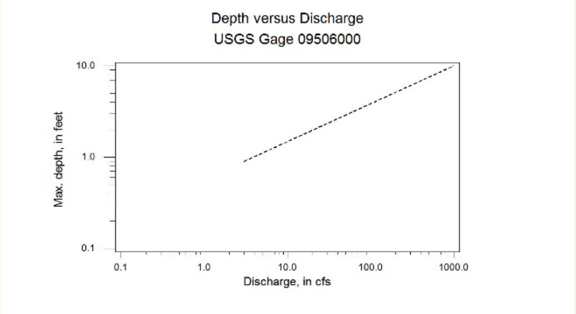
Thus, while much of the size and shape of the natural main channel are considered approximately the same as the recent channel for this study, it is likely that flow in the recent channel with the highly regulated flow below Horseshoe Dam is shallower and appears wider than was the natural channel.

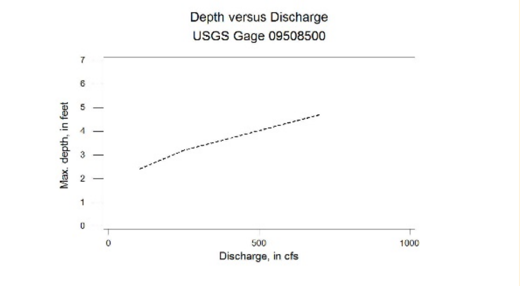
Depth-discharge relations for recent channel in the vicinity of USGS gages 09506000, 09508500 and 09511300.

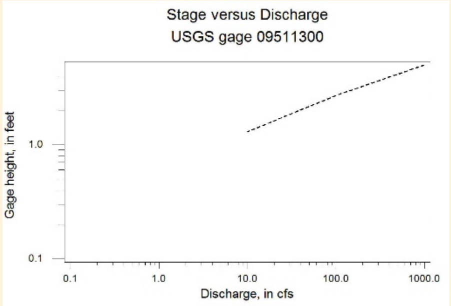












Hjalmarson for ANSAC

•Evidence shows active stream channel deposits composed of very poorly-sorted sand, pebbles, and cobbles with some boulders to moderately-sorted sand and pebbles.

•Channels are generally incised 3 to 7 ft below adjacent recent terraces. Channel morphologies generally consist of a single thread high flow channel or, in places, multi-threaded low flow channels with gravel bars.

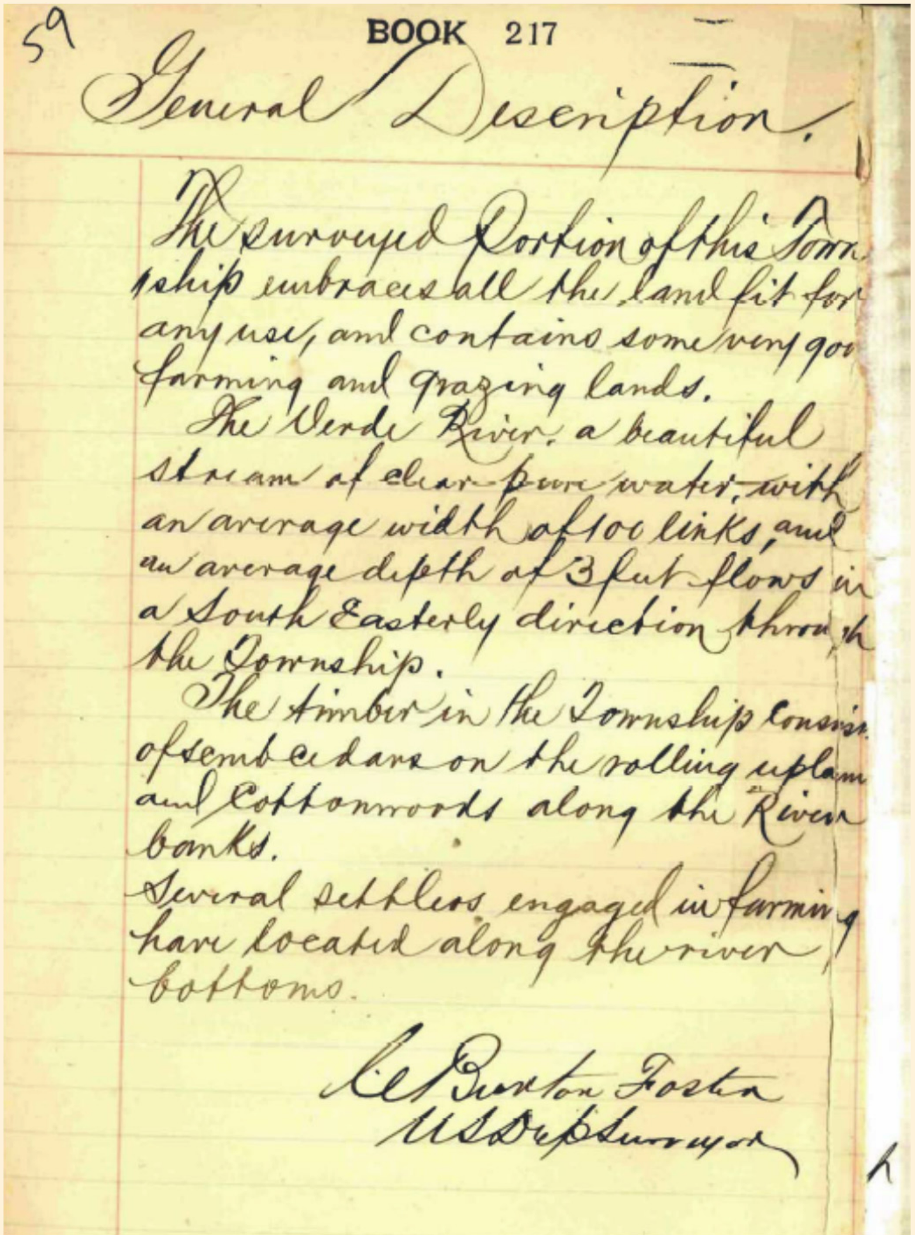
•These active channels of recent silt to boulder material convey base flow, direct runoff and flood flow.

• Downstream of Bartlett Dam where river sediments have been intercepted and stored the channel banks have eroded with some channel braiding.

Federal Surveys

Channel shape: The Federal Surveys indicate a fairly deep base flow and a rather wide channel with a few sand islands in the lower Verde River.

Depth of base flow: Depths typically are at least 3 ft. Federal surveyors recorded and average depth of 3 ft. at one crossing in the middle Verde. Depths of base flow of 3 and 4 ft. were recorded at a few crossings in the lower Verde River. Even the depths of flow at the time of the Federal Surveys were depleted to some degree by diversions for irrigation and mining.


59 BOOK 217

General Description.

The surveyed Portion of this Town-
ship embraces all the land fit for
any use, and contains some very goo
farming and grazing lands.
The Verde River, a beautiful
stream of clear-pure water, with
an average width of 100 links, and
an average depth of 3 feet flows in
a South Easterly direction through
the Township.
The timber in the Township consis
of scrub cedars on the rolling uplan
and Cottonwoods along the River
banks.
Several settlers engaged in farming
have located along the river
bottoms.

C. Burton Foster
U.S. Dep. Surveyor

General description of T16N R3E is to the left. Survey was by C. B. Foster during April 23-24 and May 3-8, 1877.

For this Township the 10 miles of Verde River was described as <u>a beautiful stream with an average width of 66 ft (100 links) and an average depth of 3 ft.</u>

MxC

Retracement N. bdy. of old Camp McDowell Reservation.

T4N

R7E

Chains	
	M C in E.
	2 M P C [illegible] I R W C 1911 in S.
	Land, smooth and sloping to the E. Soil, 2nd rate, gravelly. Timber, palo verde and ironwood. Mesquite brush, greasewood and ontolaw.
	- Feb. 20, 1911.

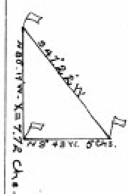
February 21, 1911, at 8h., a.m., l.m.t., I set off 33° 42½' on the lat. arc, 10° 46' S. on the decl. arc, and determine a meridian with the solar at 2nd mile cor. on the N. bdy. of old Camp McDowell Reservation.

Thence I run

N. 80° 17' E. on a random line

Along the 3rd mile, W ½.

2.50 Triangulation point on right bank of Verde River.



To determine the distance across the river I set a flag on line on a sand bar across the channel for triangulation point. Then from the triangulation point on the East side of the Verde River channel, I measure a base N. 9° 43' W., 5.00 chs., from which the flag on West bank of channel bears S. 47° 22' W. Therefore, the distance is the tan. 57° 5' x base or 1.5447 x 5.00 equal 7.72. 2.50 + 7.72 makes

10.22 Triangulation point on East side of channel.

40.08 Fall 3 lks. N. of 2½ mile cor., which is a malpais stone 8x10x20 ins. firmly set, mkd. P L on N. face, Ft McD M R 2½ M on S. face, and witnessed by a mound of stone to the S.

Returning to the 2nd mile cor., which is also the M. C.,

Thence I run

N. 80° 20' E. on a true line

Along the 3rd mile, W ½.

Descending left bank of the Verde River, 15 ft. high.

0.20 Point for old M. C. which has been obliterated by erosion.

Now part of bank.

Thence through dense arrow weed over sand bar.

2.50 Enter dangerous quicksand of Verde River, course S.

3.00 Channel, about 5 ft. deep, course S.

9.50 Leave channel, course S.

5 feet deep

T3N R7E : Widths and average depths correspond to a portion of the total width that was considered the main channel that was at least 250 ft wide. My estimate of the mean of the **maximum depths is 4 ft.** for the 250 + ft wide main channel.

Book 2396 3N 7E Feb. 18 to Mar. 9, 1911 Surveyor Farmer

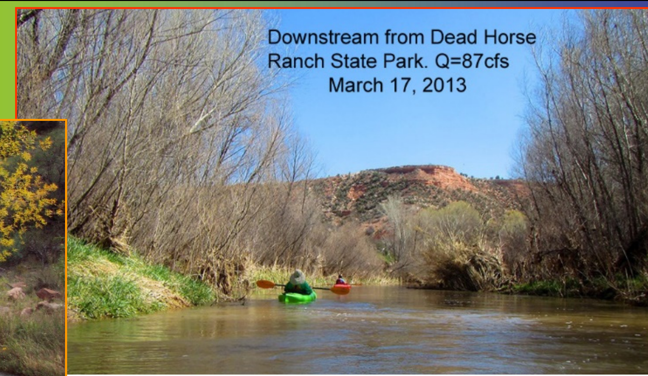
Row	Width in chains	Width, in feet	Average Depth, in feet
1	4	264	3.0
2	6	396	3.0
3	4	264	2.5
4	4	264	2.5
5	4	264	3.0
6	4	264	2.5
7	5	330	3.0
8	4	264	4.0
9	4	264	3.0
10	5	330	3.0
11	7	462	2.5
12	6	396	2.5
13	5	330	3.0
14	3	198	2.5

Mean of Average Depth, in feet

Mean of Average Depth, in feet = 2.9

NAVIGABILITY

Verde River



The following factors formed the basis of the conclusions for this assessment of navigability for 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.

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.

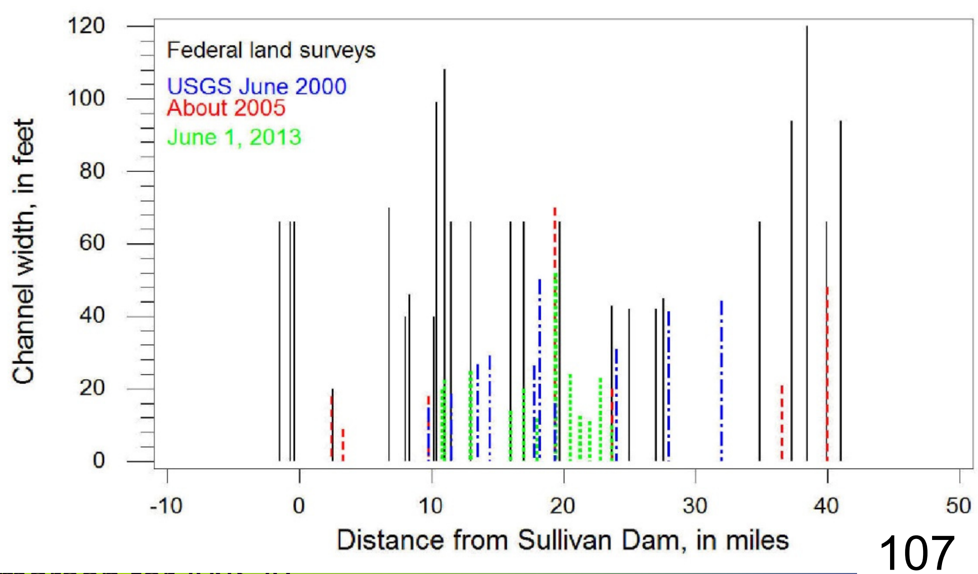
Station	Q90 cfs	Median (Q50) cfs	Mean annual cfs
95037000	54	60	80
09504000	111	116	211

This completes the Hydrology

Study based on:

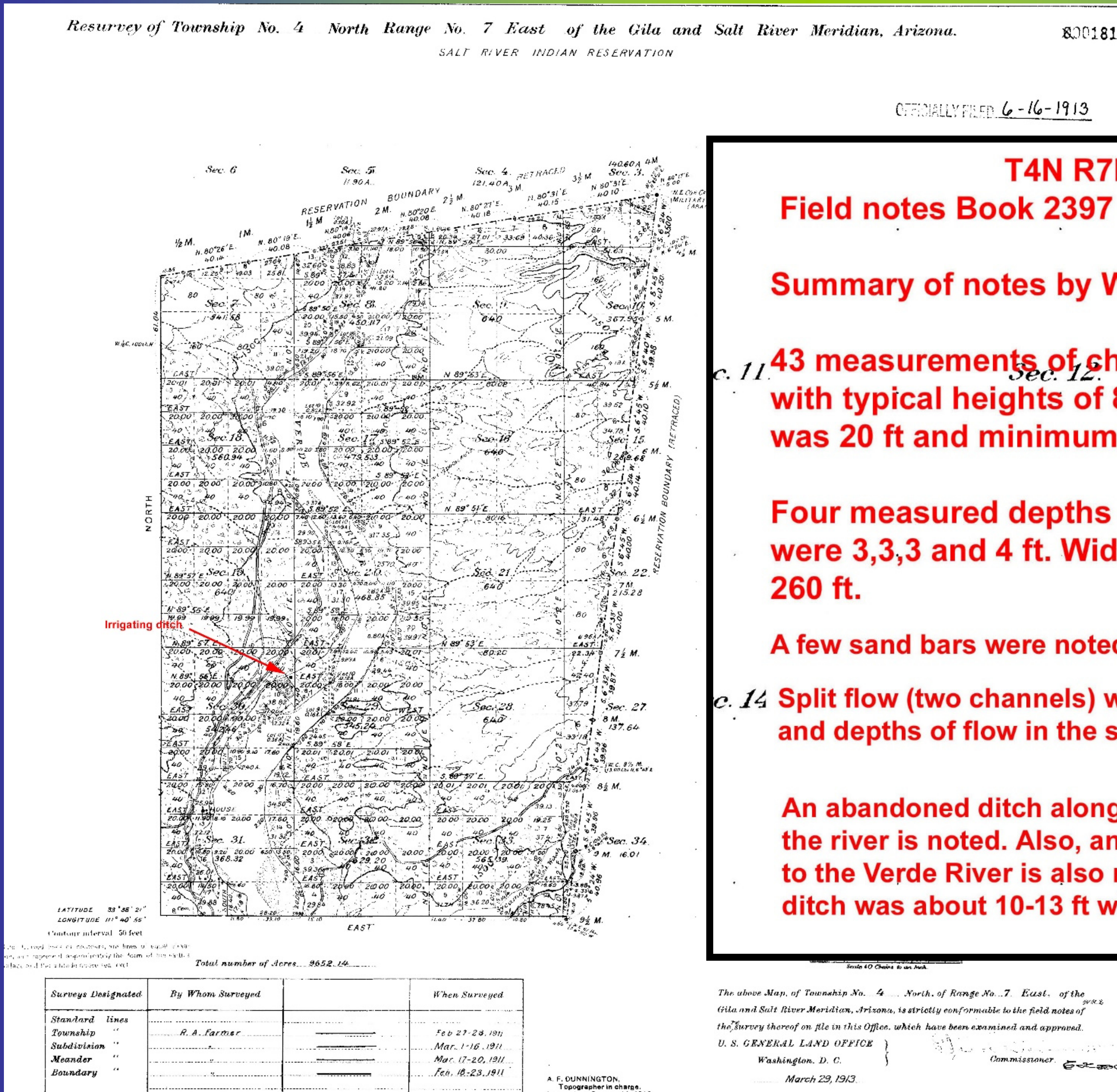
- Published information
- Standard engineering methods
- fundamental hydrologic/morphologic principles
- Systematic three-step method (hydrology, hydraulics-morphology, navigability)

asured Channel Widths along Verde River upstream of Clarkdale area



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.



T4N R7E

Field notes Book 2397 -- Survey of March 1-20, 1911

Summary of notes by Win Hjalmarson follows:

43 measurements of channel bank height were recorded with typical heights of 8 to 10 ft. Maximum bank height was 20 ft and minimum was 4 ft.

Four measured depths of flow in the main channel were 3,3,3 and 4 ft. Width of main channel was about 260 ft.

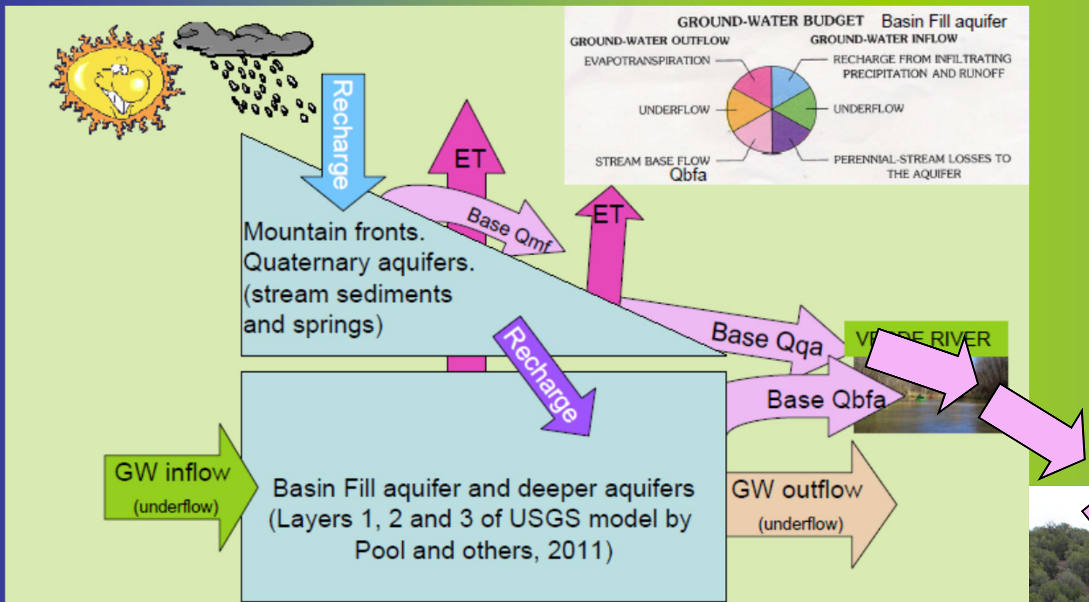
A few sand bars were noted in the survey notes.

Split flow (two channels) was noted for at least four locations and depths of flow in the smaller channel was noted as 1-2 ft.

An abandoned ditch along much of the reach to the west of the river is noted. Also, an active irrigation ditch located closer to the Verde River is also noted along most of the reach. This ditch was about 10-13 ft wide.

C

- Human impacts are just that and 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.

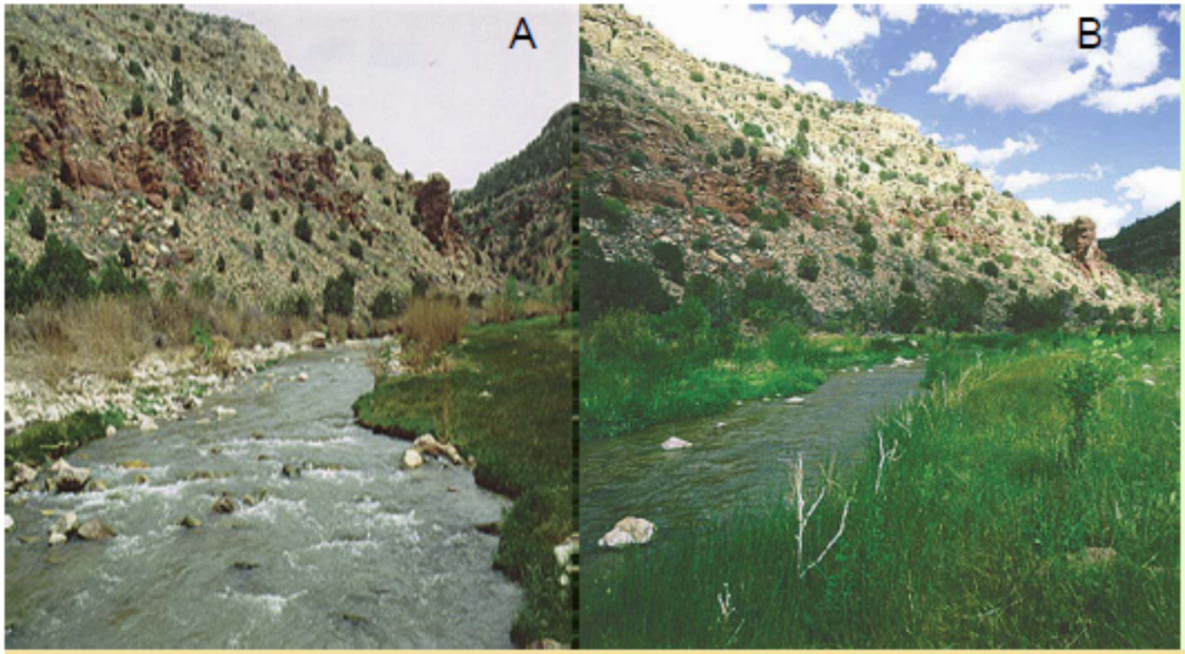


Modified from: Freethey, G. W. and Anderson, T. W., 1986, Predevelopment hydrologic conditions in the alluvial basins of Arizona and adjacent parts of California and New Mexico, U. S. Geological Survey Hydrologic Investigations Atlas HA-664, 3 sheets.

The Bainbridge Steel Dam 1897

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.



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.)

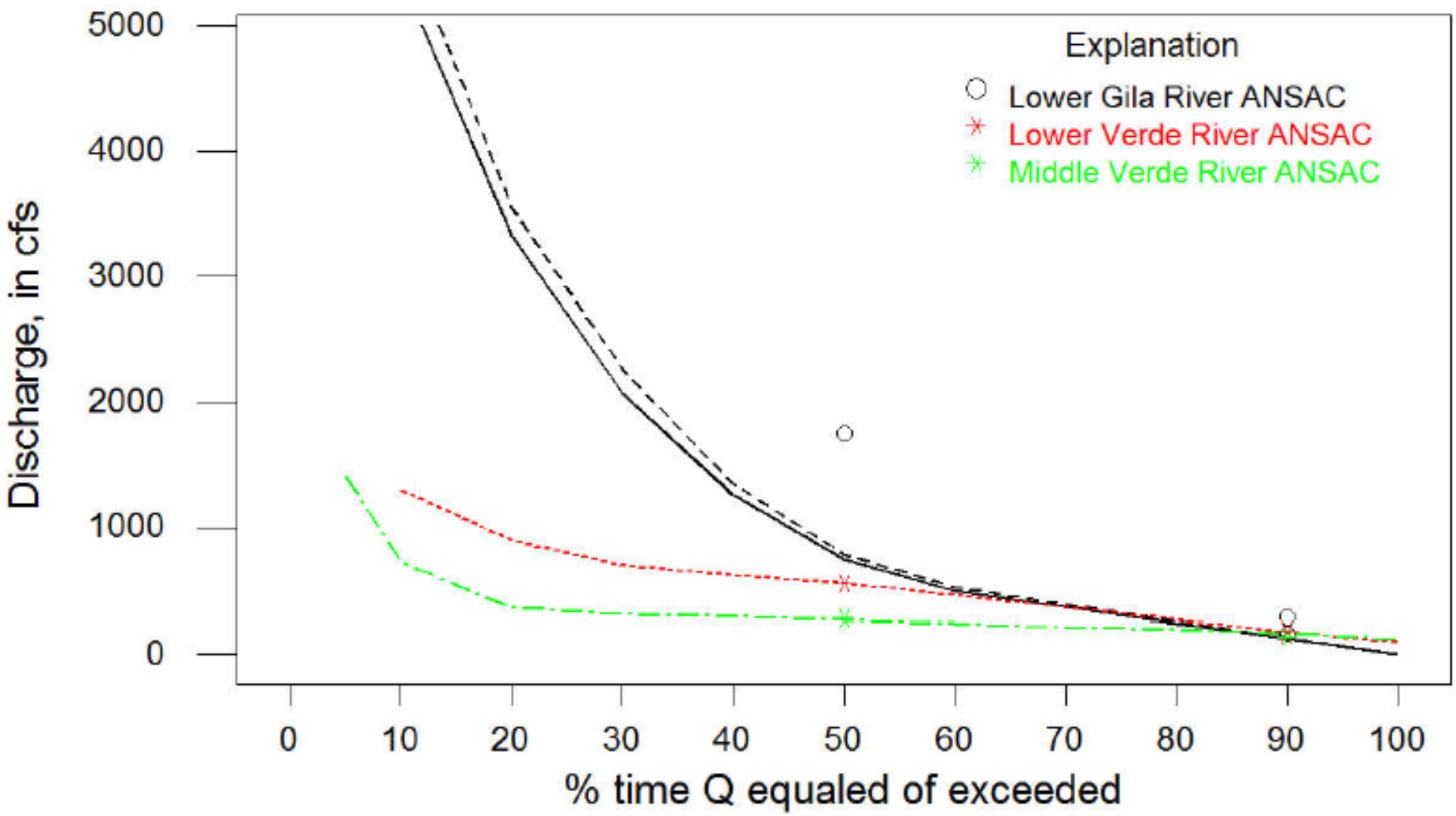
An example of slope processes where debris is shed toward and into the river channel. Large debris (boulders) will remain as obstructions to navigation until moving downstream by continuous and high energy river flow.

E

- The base runoff and channels of both the Verde and John Day (an Oregon river) Rivers are similar and the John Day River is considered navigable by the state of Oregon.
- Also, the depths of base flow along the entire Verde River are several times larger than the drafts for canoes and kayaks used by Oregon for the assessment of the John Day River.

John Day River in Oregon-- Flow duration curves

(comparison with natural flow of Verde and Gila Rivers)



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.

Upper

BOATING CANOEING-KAYAKING

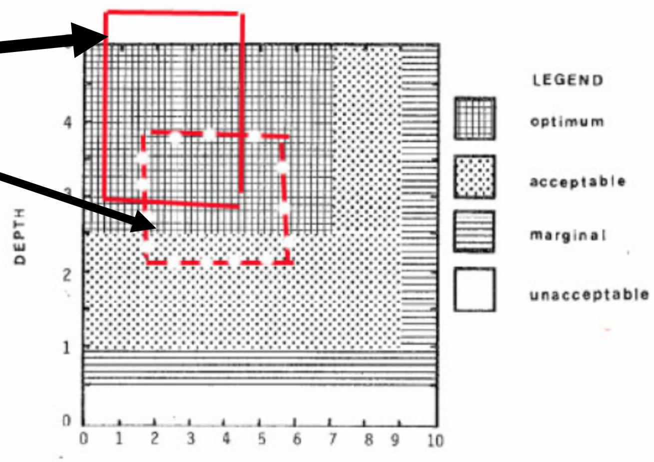
CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			2.5 ft +
minimum	0.5 ft	1.0 ft	
maximum	NA	NA	
VELOCITY			0.5-7.0 fps
minimum	0 fps	0 fps	
maximum	10.0 fps	9.0 fps	

COMMENTS: Higher velocities exclude open canoes. Higher velocities safe only under certain conditions.

Most of the river (pools)

Riffle areas



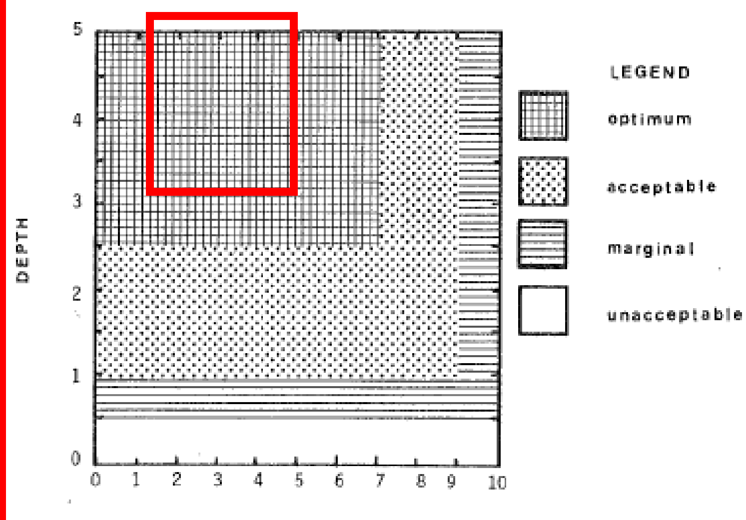
Lower

BOATING CANOEING-KAYAKING

CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			2.5 ft +
minimum	0.5 ft	1.0 ft	
maximum	NA	NA	
VELOCITY			0.5-7.0 fps
minimum	0 fps	0 fps	
maximum	10.0 fps	9.0 fps	

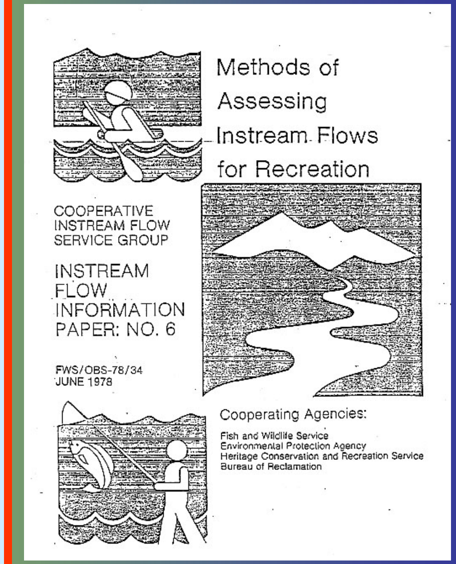
COMMENTS: Higher velocities exclude open canoes. Higher velocities safe only under certain conditions.



HOWEVER

- My opinion on the following is based on a high standard.
- 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.

Hyra(1978) presents minimum depth and width requirements for canoes, kayaks, drift boats and row boats and power boats (See table on next page). The minimum width and depth requirements are met for canoes, kayaks, drift and row boats along nearly all of the Verde River.



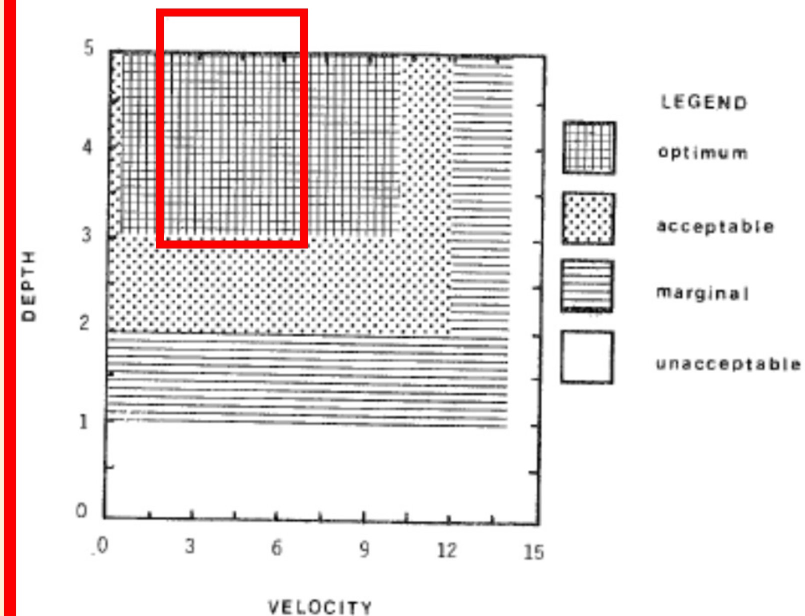
(Hyra, R., 1978, Methods of assessing instream flows for recreation: Instream Flow Information Paper No. 6, U. S. Fish and Wildlife Service and others, 14p.)

BOATING ROWING-RAFTING-DRIFTING

CRITERIA

.	PHYSICAL	SAFETY	OPTIMUM
DEPTH			3.0 ft +
minimum	1.0 ft	2.0 ft	
maximum	NA	NA	
VELOCITY			1.0-10.0 fps
minimum	0 fps	0 fps	
maximum	14.0 fps	12.0 fps	

COMMENTS: Higher velocities require boats/rafts of a type specifically designed for white water. Higher velocities safe only under certain conditions.



Slide should follow slide 119.

Sorry for any inconvenience

Win

119a.

OPINION

- 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.
- During ordinary years the river was susceptible to navigation more than 90% of the time.
- Evidence relied upon to form this opinion is in my report and in the references for my report.