Navigability of the San Pedro River
August 1-2, 2013

By T. Allen J. Gookin

On Behalf Of The

Gila River Indian Community

GILA RIVER INDIAN COMMUNITY · 1939 · ARIZONA

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Registered Professional Engineer (Civil) · CERTIFICATE NO. 12255 · THOMAS ALLEN JAUDON GOOKIN · Date Signed 7/23/13 · ARIZONA U.S.A.

Expires 12/31/14

Legal Standards

Navigable in Fact or Susceptible of Navigability

Ordinary and Natural as of the date of Statehood

Navigable in Fact

- Only 1 instance of using a boat is recorded
  - Pattie Beaver Trapping Party made a canoe
  - Probably on the San Pedro River
    - It was made because “one of our number had already been drowned, man and horse, in attempting to swim the river”
  - This means that the river was at or near flood stage

Navigation was Needed

- Mines began in 1877

  Needed equipment

  Needed way to get the product out

- “Large shipments of mining and smelting equipment transported in twenty-mule team freight wagons to the early developed mining regions of southern Arizona, crossed over this bridge"

Navigation was Needed (cont.)

- The Railroad arrived

- “The nearest settlement of any size was Tucson, from which all supplies for this region were freighted. The growth of the settlement was consequently slow until in 1880, in which year the Southern Pacific Railroad was built, giving more ready access to the region.”

Susceptible of Navigability

- Ordinary and Natural as of the date of Statehood

- Ordinary relates to flow
  - Not a flood
  - Not an exceptional drought

- Natural relates to the channel and watershed

  What would the channel and watershed have looked like in 1912, **IF** you were the first human to enter the area.

“Ordinary”

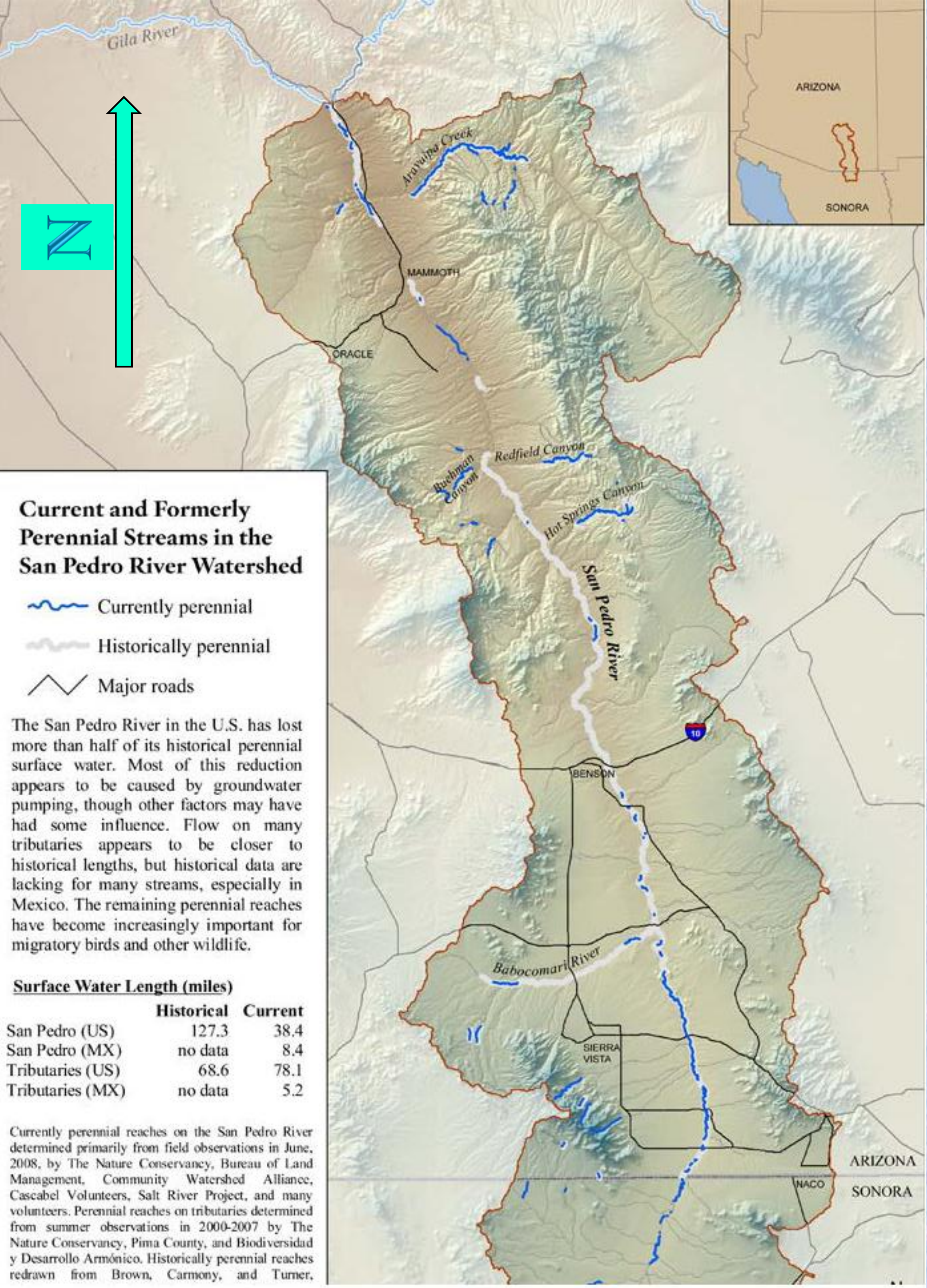
- “ ‘ordinary’ means ‘[o]ccurring in the regular course of events; normal; usual.’ ”

- The Court goes on to add that it does not include major droughts or floods

.

Freethey and Anderson Map

- "…the maps have limitations that require ADWR to undertake additional verification. Limitations include the quality of the sources of information and inconsistencies, inaccuracies, and omissions in the maps." (Special Master Schade)



Current and Formerly Perennial Streams in the San Pedro River Watershed

- Currently perennial
- Historically perennial
- Major roads

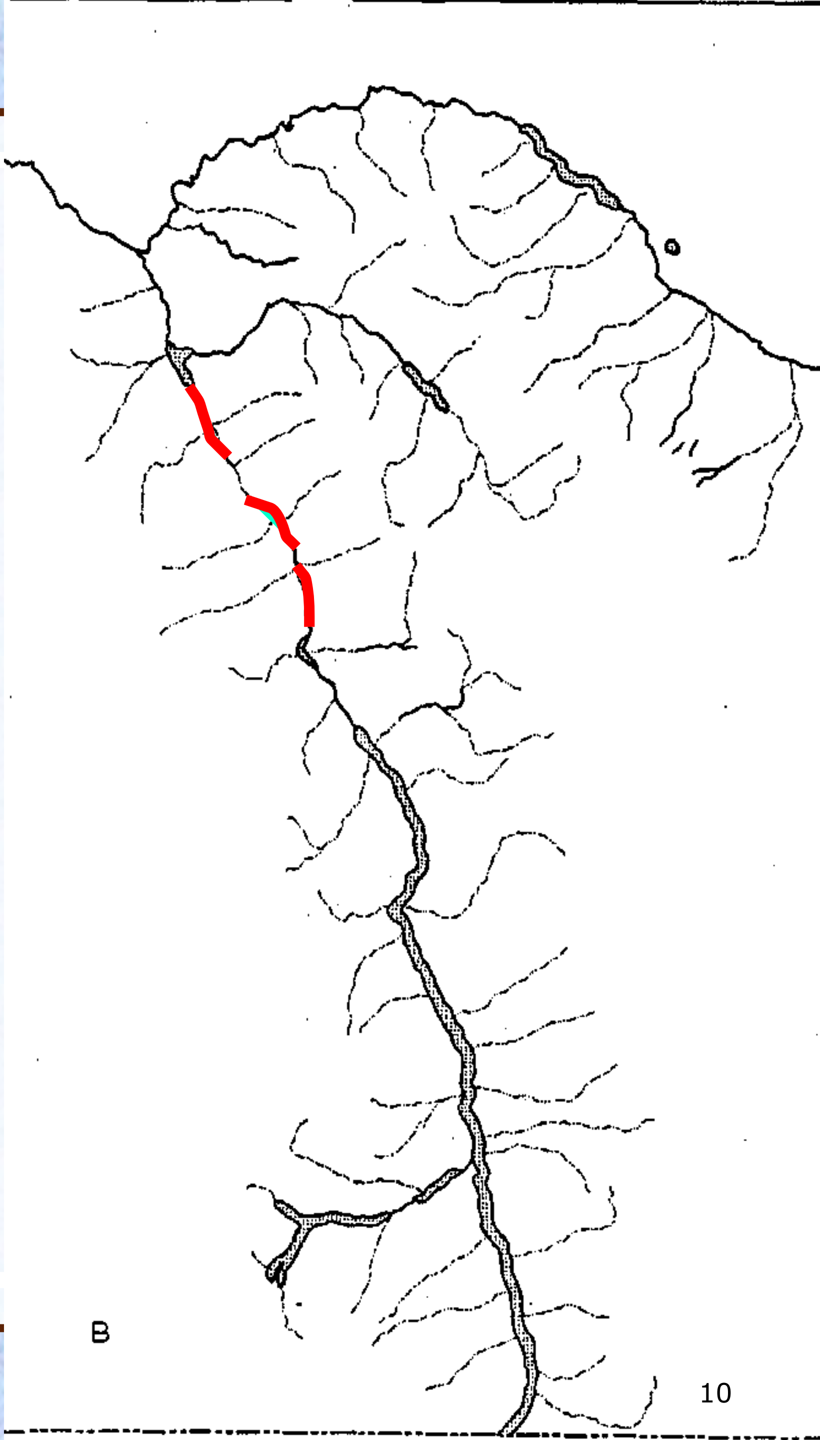
The San Pedro River in the U.S. has lost more than half of its historical perennial surface water. Most of this reduction appears to be caused by groundwater pumping, though other factors may have had some influence. Flow on many tributaries appears to be closer to historical lengths, but historical data are lacking for many streams, especially in Mexico. The remaining perennial reaches have become increasingly important for migratory birds and other wildlife.

Surface Water Length (miles)

	Historical	Current
San Pedro (US)	127.3	38.4
San Pedro (MX)	no data	8.4
Tributaries (US)	68.6	78.1
Tributaries (MX)	no data	5.2

Currently perennial reaches on the San Pedro River determined primarily from field observations in June, 2008, by The Nature Conservancy, Bureau of Land Management, Community Watershed Alliance, Cascabel Volunteers, Salt River Project, and many volunteers. Perennial reaches on tributaries determined from summer observations in 2000-2007 by The Nature Conservancy, Pima County, and Biodiversidad y Desarrollo Armónico. Historically perennial reaches redrawn from Brown, Carmony, and Turner,

Pre 1890 Conditions



Historic Accounts Support Non-Perennial Reaches

- "The flow of water, however, is not continuous. One or two localities were observed where it had entirely disappeared, but to rise again a few miles distant, clear and limpid." Hjalmarson
- Numerous observations in the 1840's and 1850's reported dry reaches

Important Terms

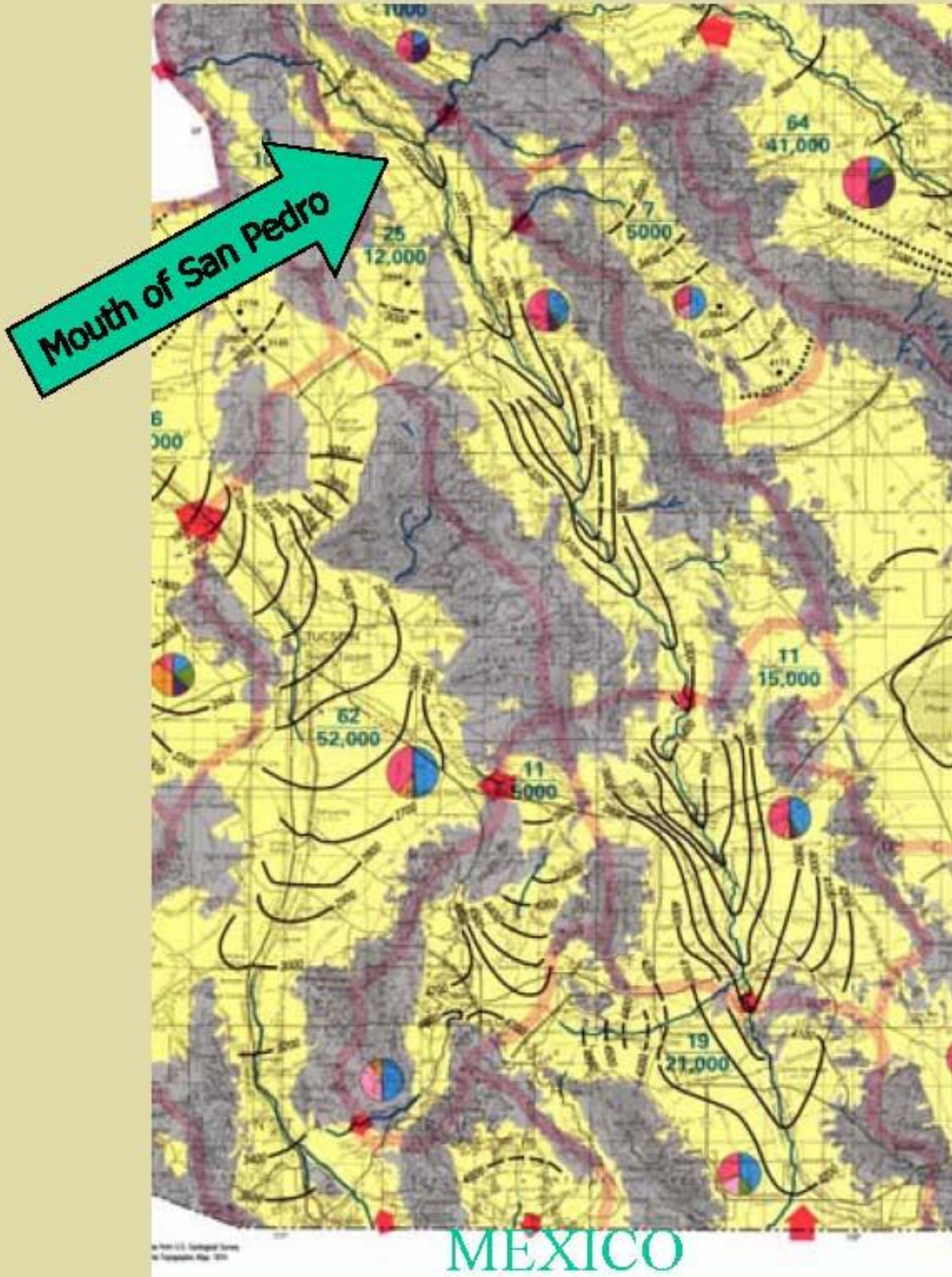
- Mean Average or Average
- Median Average
- Base Flow
- River Gage

Base Flow

- Why does a river flow when the snow is not melting and it has not recently rained?
- Numerous definitions
- The Tombstone Report spent a full page listing many of the definitions
- Q_{90} is not one of them

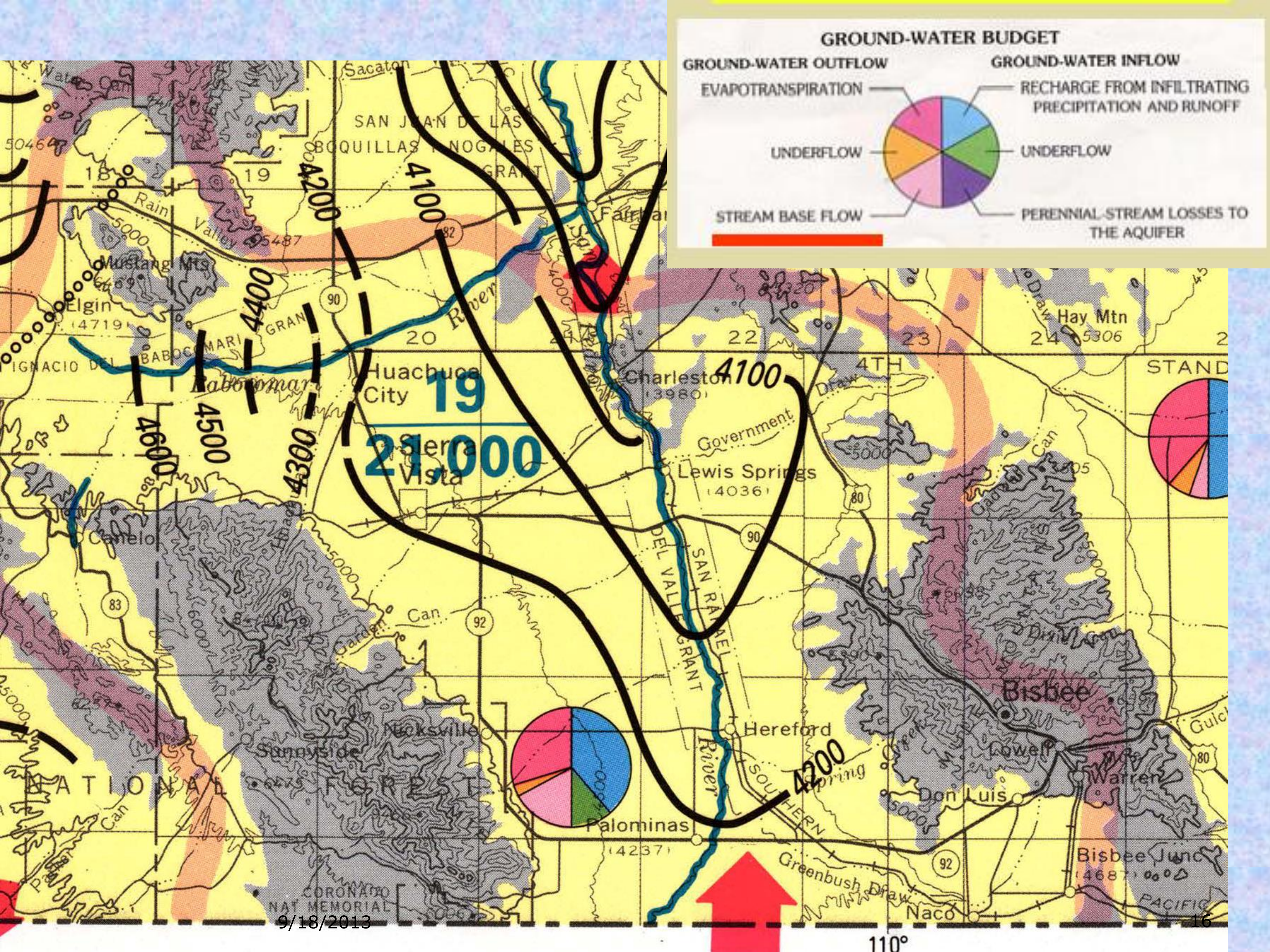
Freethey and Anderson Warn

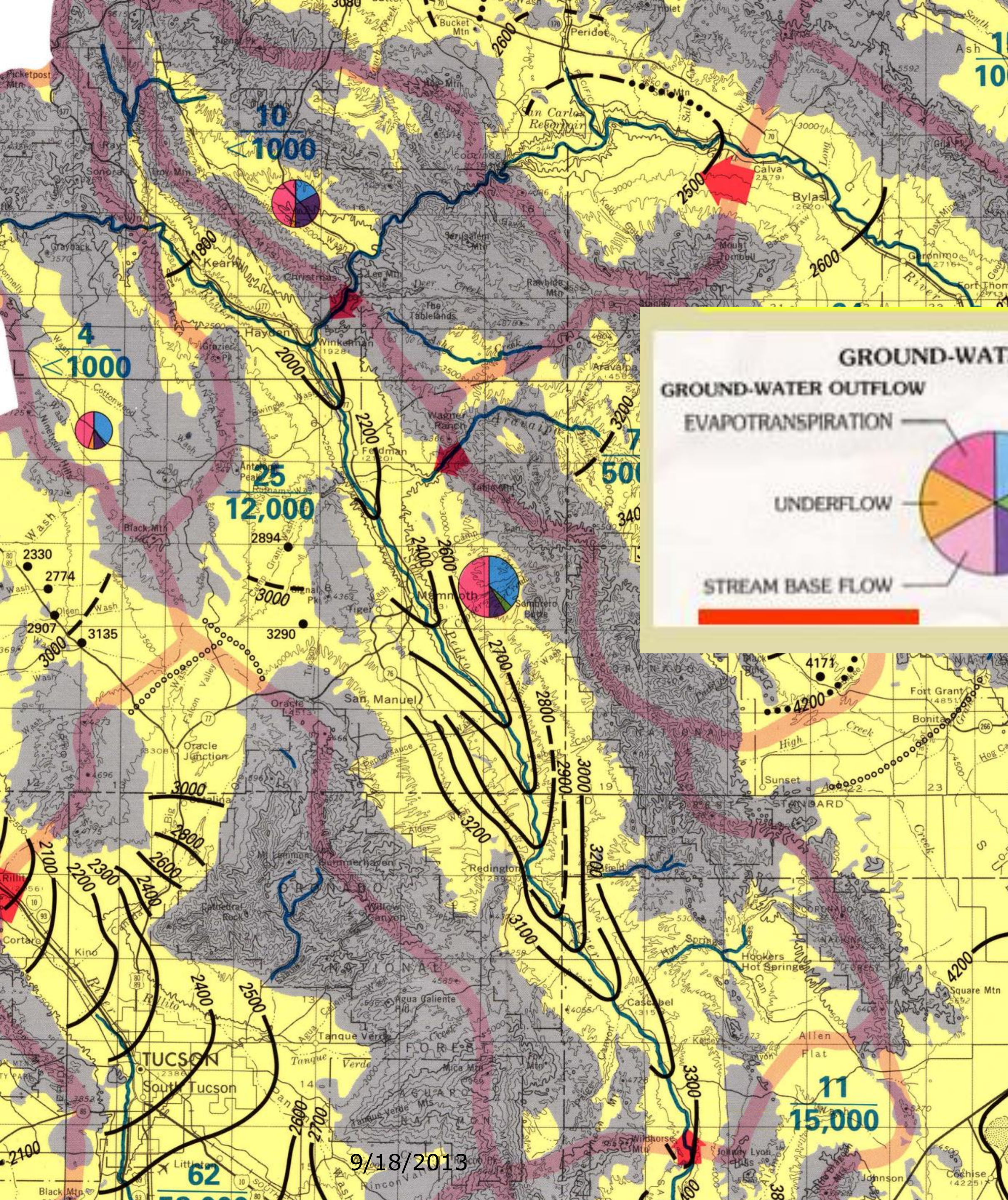
- "The data …represent a conceptual model…"
- "The individual … values represent an approximation of each component derived by balancing the entire regional water budget. The diagrams represent a means of comparing the magnitude of the total budget and the individual components…"

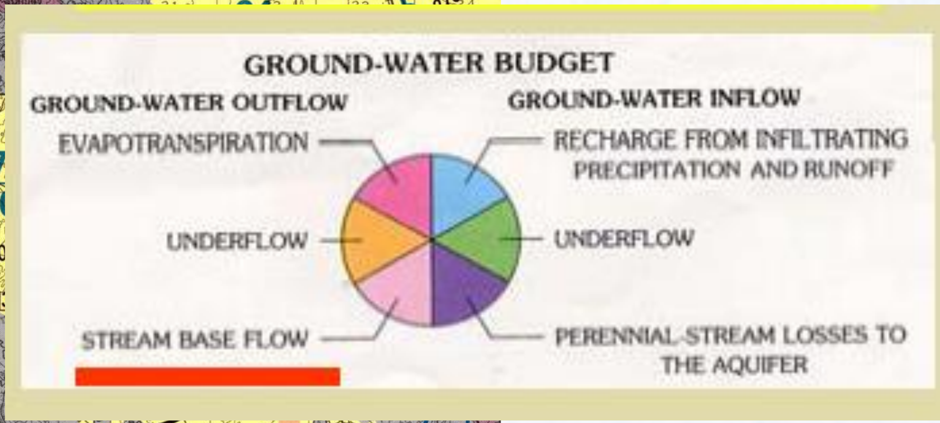


San Pedro River (predevelopment)

Sheet 3 of USGS Hydrologic Investigations Atlas HA-664


GROUND-WATER BUDGET
GROUND-WATER OUTFLOW
GROUND-WATER INFLOW
EVAPOTRANSPIRATION
RECHARGE FROM INFILTRATING PRECIPITATION AND RUNOFF
UNDERFLOW
UNDERFLOW
STREAM BASE FLOW
PERENNIAL-STREAM LOSSES TO THE AQUIFER
19
21,000
SAN JUAN DE LAS BOQUILLAS Y NOGALES GRANT
Rain Valley
Mustang Mts
Elgin (4719)
Babocomari River
Huachuca City
Sierra Vista
Charleston (3980)
Lewis Springs (4036)
Government Draw
SAN RAFAEL DEL VALLE GRANT
Hereford
Palominas (4237)
Bisbee
Lowell
Warren
Don Luis
Bisbee Junc (4687)
Naco
Greenbush Draw
Hay Mtn 5306
Canelo
Sunnyside
NATIONAL FOREST
CORONADO NAT MEMORIAL
4100
4200
4300
4400
4500
4600
110°


10
<1000
4
<1000
25
12,000
15
1000
11
15,000
62
Kearny
Hayden
Winkelman
Mammoth
San Manuel
Oracle
Oracle Junction
Redington
Cascabel
Bylas
Calva
Geronimo
Fort Thomas
Aravaipa
Fort Grant
Bonita
Sunset
Hookers Hot Springs
Square Mtn
Tanque Verde
TUCSON
South Tucson
Cortaro
Peridot
Black Mtn
Allen Flat
Cochise


GROUND-WATER BUDGET
GROUND-WATER OUTFLOW
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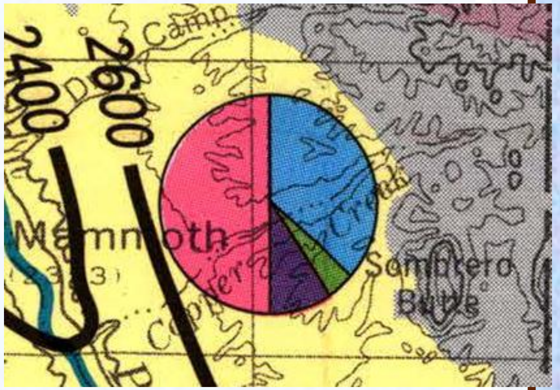
UNDERFLOW
UNDERFLOW
STREAM BASE FLOW
PERENNIAL-STREAM LOSSES TO THE AQUIFER


2400
2600
Camp
Mammoth
Sombrero Butte

Baseflow Answers According to Freethey and Anderson

Gage	Baseflow (cfs)	
	Gookin	Hjalmarson
• Palominas	0	4*
• Charleston	9	10*
• Narrows (join)	7.3	7.5
• Mouth	???	4

* From a different source

Table 3. Base-flow statistics for San Pedro River near Tombstone (USGS station number 09471550).

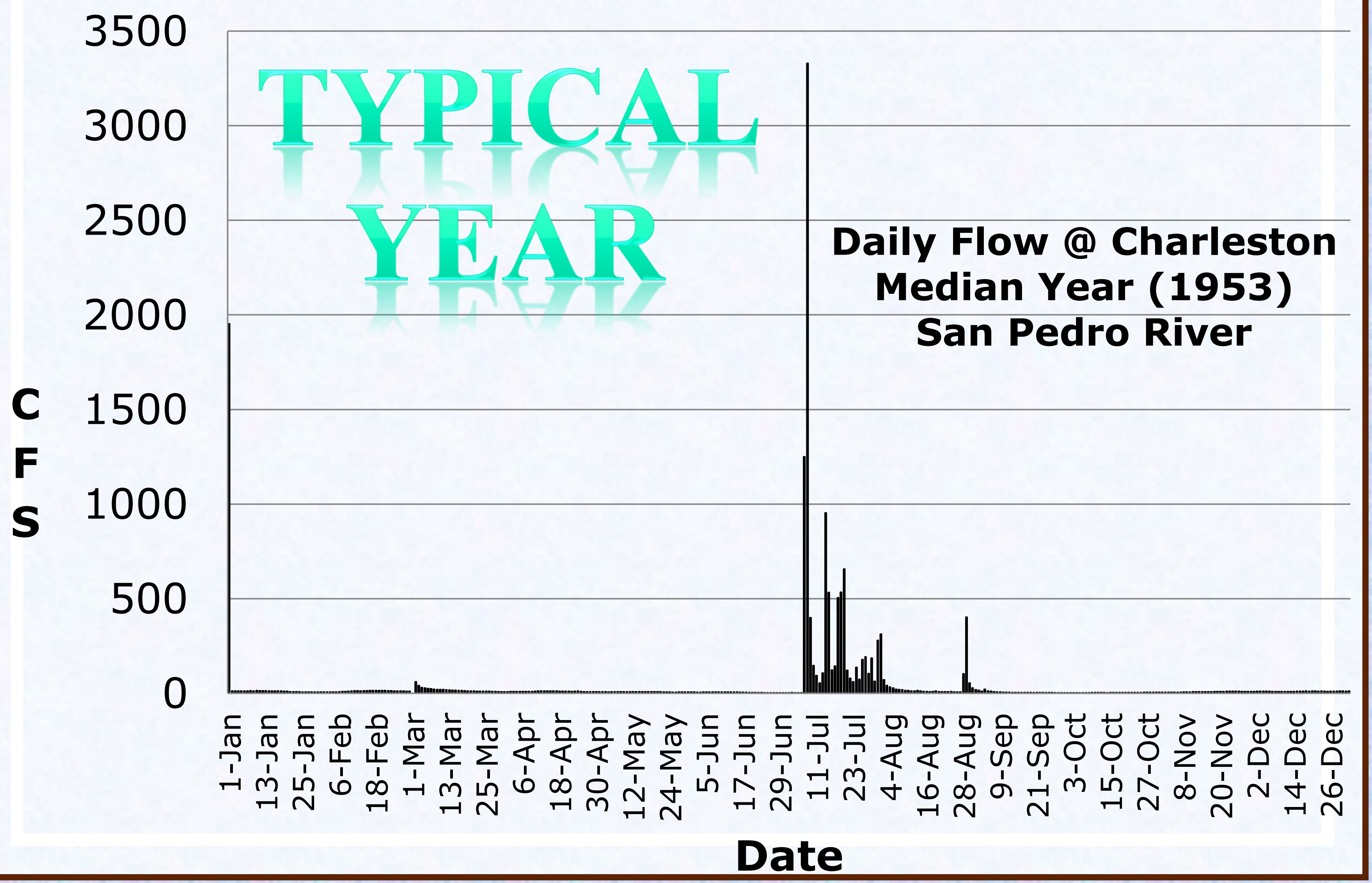
[cfs, cubic feet per second; C_{50}, median value. **Bold,** Continuous flow through fall months; date estimated as first date of continuously increasing streamflow. *Italic,* Base flow could not be estimated from hydrograph; a linear regression model between 25th percentile and mean daily flow was used (fig. 6). NA, Start date could not be estimated, because storm runoff events obscured start of base flow. 1979 and 1982, flow begins on 10/21 with a storm event in both years, not used. --, Flow was continuous through spring 1979; base flow as a percent of total flow between start and end dates is calculated assuming an end date of 7/1]

Water year	Base flow start date	Base flow end date	Days of base flow	25th percentile flow (cfs)	Percent dry	Base flow (acre-ft)	Base flow as a percent of total flow between start and end dates
				Median			
Median, 1967–1986	10/20	6/10	234	16.0	7.9	5830, $5000<C_{50}<9260$	95
Median, 1997–2009	11/18	5/16	180	9.8	29.8	2880, $1910<C_{50}<3990$	99
Median, 1967–2009	10/31	5/30	207	15.0	14.6	4890, $3860<C_{50}<5400$	96

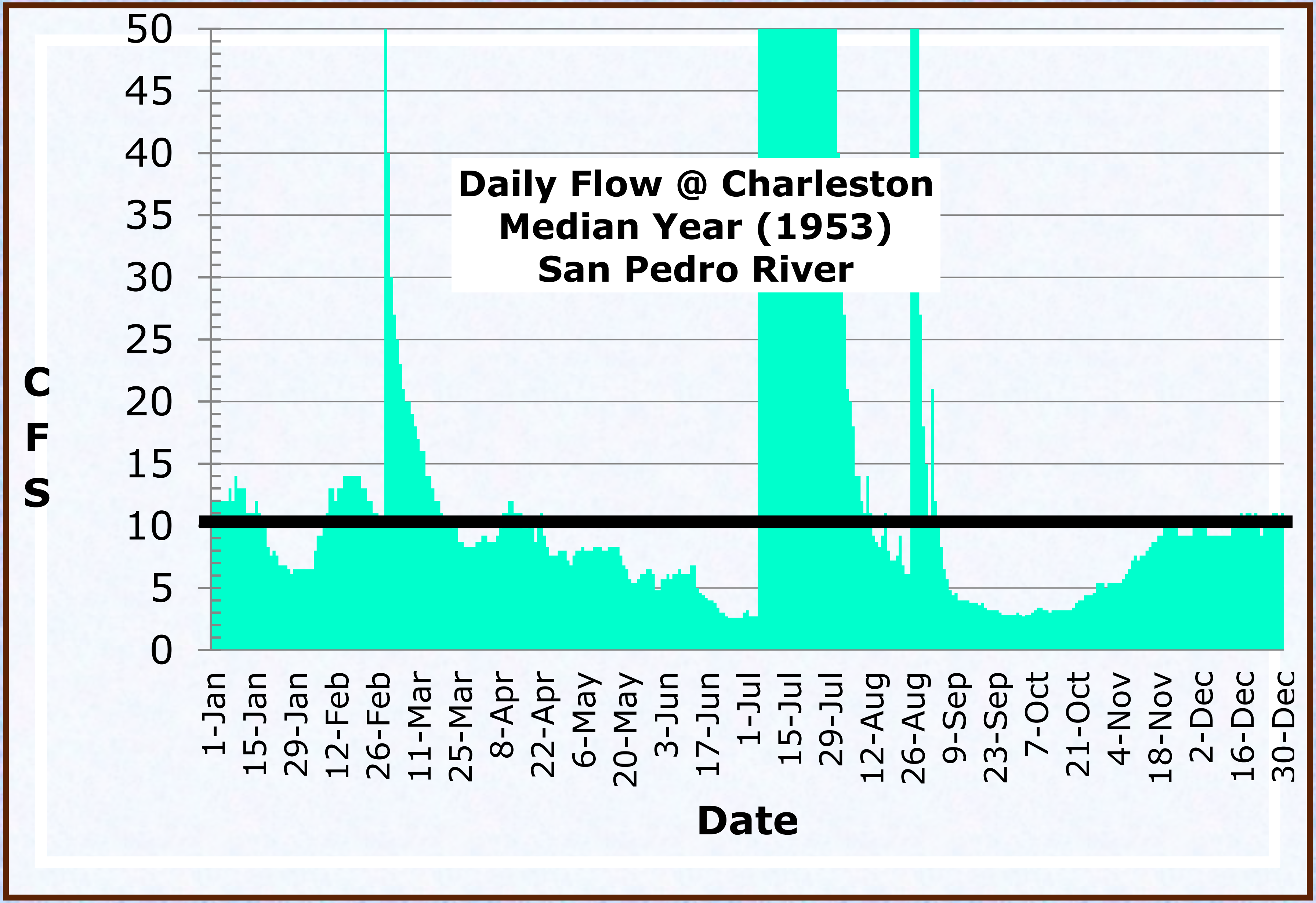
1998	**10/31**	5/30	211	15.0	15.3	4400	79.6
1999	12/7	5/7	151	6.7	33.6	1220	99.6
2000	**10/15**	5/9	207	9.6	2.5	2710	97.7
2001	NA	6/11		43.5	8.2	11800	55.6
2002	11/13	5/19	187	13.0	35.5	3860	100.0
2003	12/2	5/17	166	7.0	41.5	1790	99.7
2004	12/16	5/10	146	6.3	46.2	1530	84.3
2005	11/26	5/15	170	9.1	33.1	1910	79.2
2006	11/23	5/2	160	10.0	32.8	2270	100.0
2007	**11/5**	5/18	194	13.0	15.8	3990	99.9
2008	11/27	5/17	172	13.0	29.8	2880	97.9
2009	**10/30**	5/14	196	14	29.5	4620	100.0
				Median			
Median, 1967–1986	10/20	6/10	234	16.0	7.9	5830, $5000<C_{50}<9260$	95
Median, 1997–2009	11/18	5/16	180	9.8	29.8	2880, $1910<C_{50}<3990$	99
Median, 1967–2009	10/31	5/30	207	15.0	14.6	4890, $3860<C_{50}<5400$	96

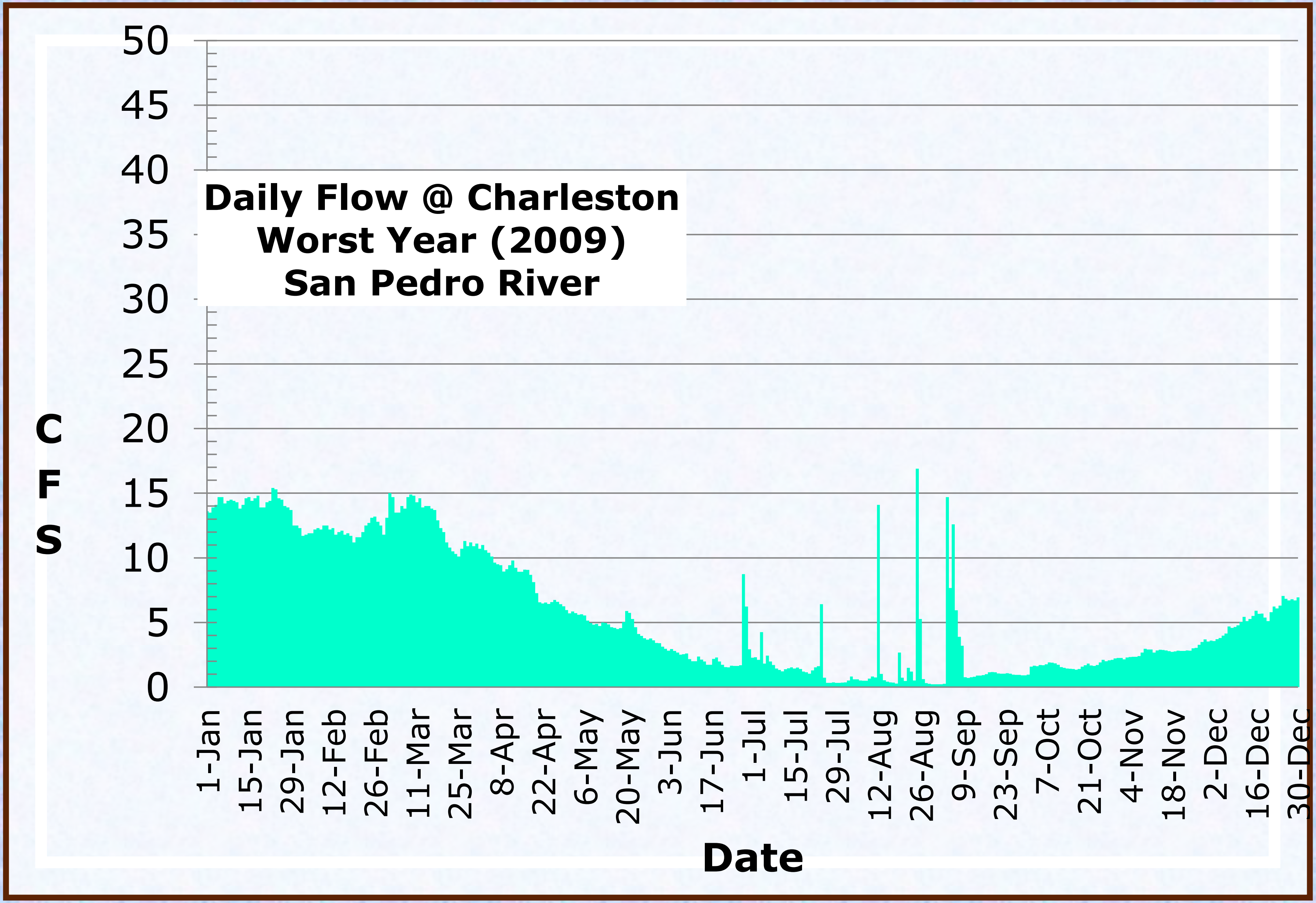
Median = Baseflow

- It seems counter intuitive until you look at the flows
- Virtually no snow melt
- Most significant flows are in direct response to precipitation



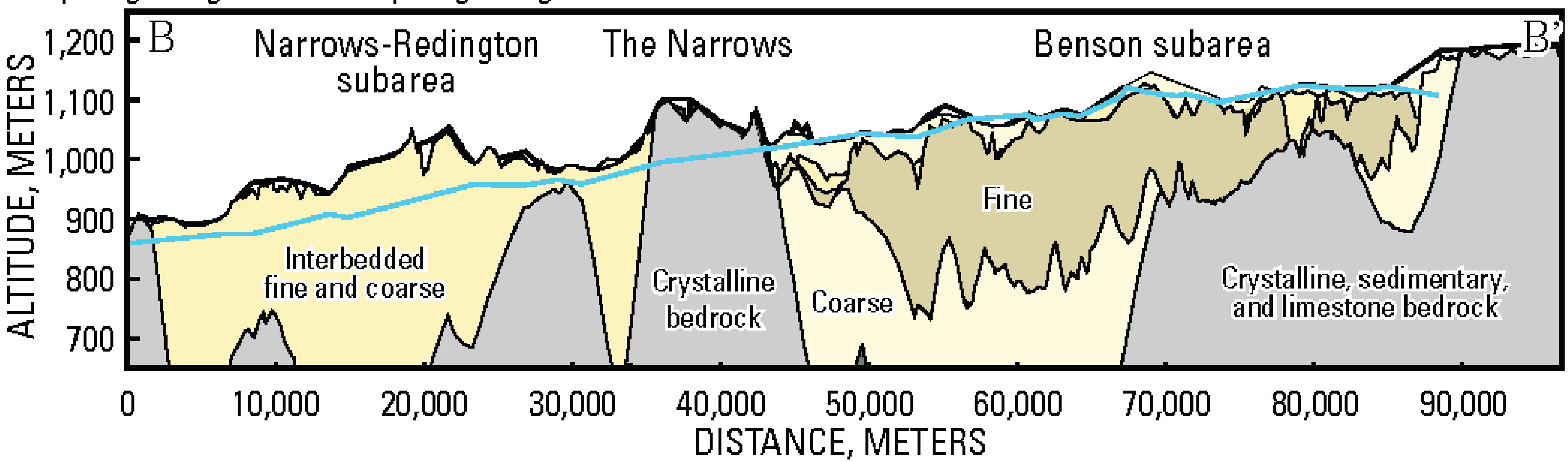
TYPICAL YEAR
Daily Flow @ Charleston
Median Year (1953)
San Pedro River
C F S
3500
3000
2500
2000
1500
1000
500
0
1-Jan
13-Jan
25-Jan
6-Feb
18-Feb
1-Mar
13-Mar
25-Mar
6-Apr
18-Apr
30-Apr
12-May
24-May
5-Jun
17-Jun
29-Jun
11-Jul
23-Jul
4-Aug
16-Aug
28-Aug
9-Sep
21-Sep
3-Oct
15-Oct
27-Oct
8-Nov
20-Nov
2-Dec
14-Dec
26-Dec
Date


Daily Flow @ Charleston
Median Year (1953)
San Pedro River
C F S
50
45
40
35
30
25
20
15
10
5
0
1-Jan
15-Jan
29-Jan
12-Feb
26-Feb
11-Mar
25-Mar
8-Apr
22-Apr
6-May
20-May
3-Jun
17-Jun
1-Jul
15-Jul
29-Jul
12-Aug
26-Aug
9-Sep
23-Sep
7-Oct
21-Oct
4-Nov
18-Nov
2-Dec
16-Dec
30-Dec
Date


Daily Flow @ Charleston
Worst Year (2009)
San Pedro River
CFS
50
45
40
35
30
25
20
15
10
5
0
1-Jan
15-Jan
29-Jan
12-Feb
26-Feb
11-Mar
25-Mar
8-Apr
22-Apr
6-May
20-May
3-Jun
17-Jun
1-Jul
15-Jul
29-Jul
12-Aug
26-Aug
9-Sep
23-Sep
7-Oct
21-Oct
4-Nov
18-Nov
2-Dec
16-Dec
30-Dec
Date

Baseflows at gages are the best case scenario

C. Hydrogeologic units in hydrogeologic framework model



N

Mean Average Flow

- Krug Report “Average Annual Runoff”
  - 1951-1980
  - Groundwater Pumping is large
  - Considerable Development
  - Computed flows at 5,951 stations
  - Extrapolated data for over 3,000 stations
  - 5 years
  - Almost six gaging stations per work day

Bureau of Reclamation- White Book

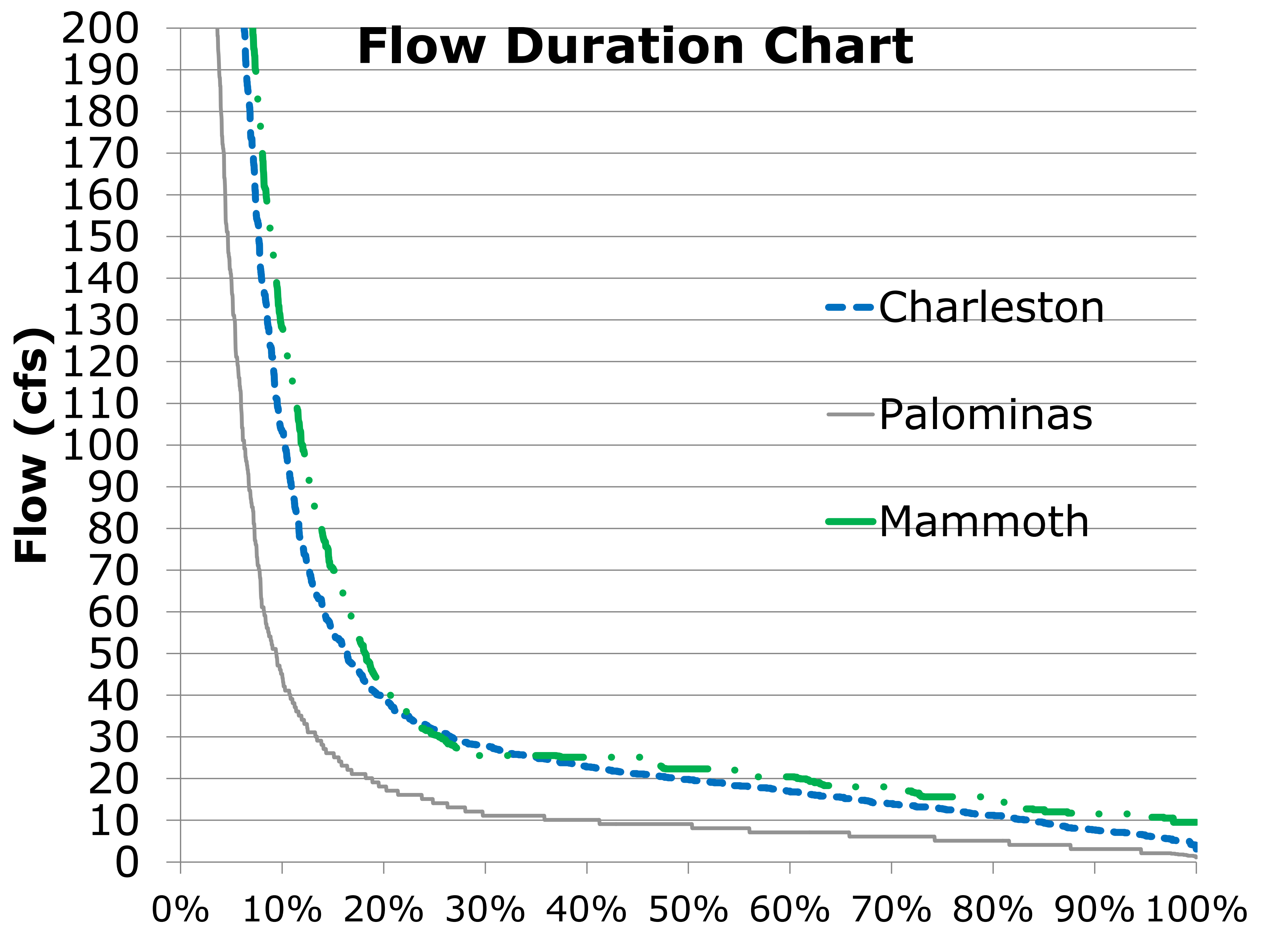
- 1914-1945 Close to Arizona Statehood
- Groundwater pumping is small
- Vegetative changes are not as extensive
- Fewer human uses
- More information was available on early uses at the time the report was written
- Over 1 million hours involved in producing it

Bureau of Reclamation- White Book

- BOR accounts for replacement of native vegetation
- BOR accounts for human induced riparian vegetation change
- BOR accounts for M&I use
- BOR accounts for irrigated acreage year by year

BOR "White Book" Depletions

White Book						
Net Depletions Generallly in Acre Feet per Year						
	Plus Human Use	Minus Replacement of Native Vegetation	Plus Growth Change	Algebraic Sum	Cumu-lative	Cumulative Depletion in CFS
Palominas	800	300	-	1,100	1,100	1.5
Charleston	800	600	(300)	(100)	1,000	1.4
Mammoth	10,300	4,600	5,900	11,600	12,600	17.4
Winkleman	3,600	2,100	1,700	3,200	15,800	21.8



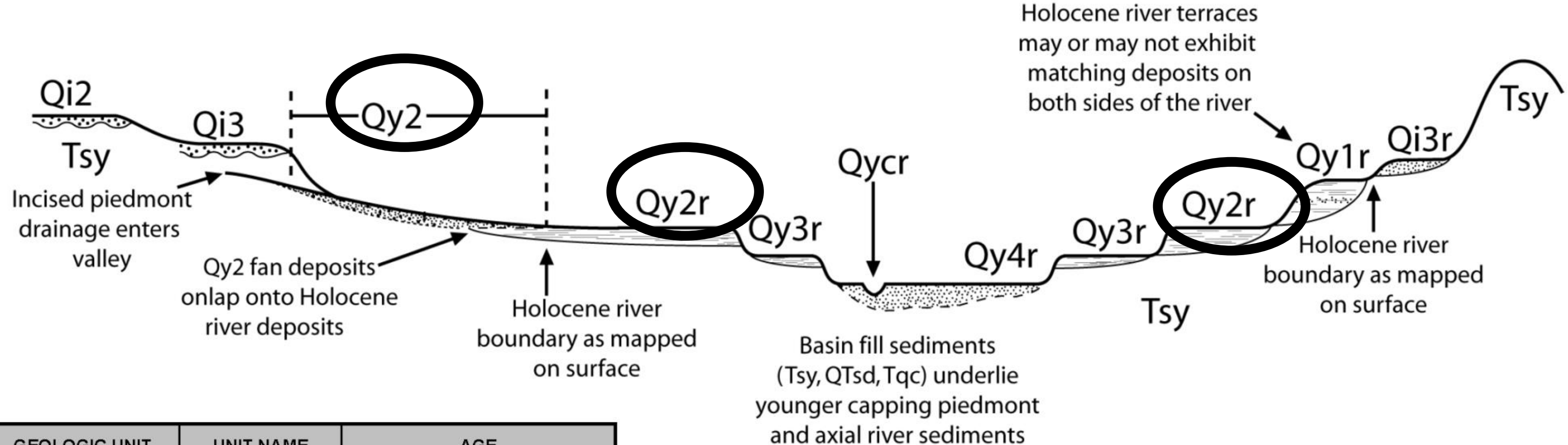
Flow Duration Chart
Flow (cfs)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Charleston
Palominas
Mammoth

Equation 2

$$Q = (1.49/n)\ (0.67d)^{5/3}\ W\ So^{1/2}$$

Where: d = depth of water above channel invert,
S_o = energy gradient, and
n = roughness coefficient.

- Need to determine 3 things
  - Soils and Vegetation in the Channel--→n
  - Slope-→S_0
  - Shape of the Channel →$(0.67d)^{5/3}W$
    - 0.67 is the shape factor for Parabolic
    - Changes to1.0 if the channel is Rectangular



Pre-Entrenchment Alluvium

GEOLOGIC UNIT	UNIT NAME	AGE
Active\Modern Channel Deposits	Qycr	Holocene (10,000 years ago to present)
Stream Terraces	Qy4r (youngest)	Holocene
	Qy3r	
	Qy2r	
	Qy1r	
	Qi3r (oldest)	Pleistocene (2 million to 10,000 years ago)
Piedmont Deposits (Tributary Alluvium and Younger Basin Fill)	Qy2 (youngest)	Holocene
	Qi3	Pleistocene
	Qi2 (oldest)	
Older Basin Fill	QTsd (youngest)	Tertiary (2 million years ago and before)
	Tqc	
	Tsy (oldest)	

Source: AZGS (2009)

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ARIZONA DEPARTMENT OF WATER RESOURCES

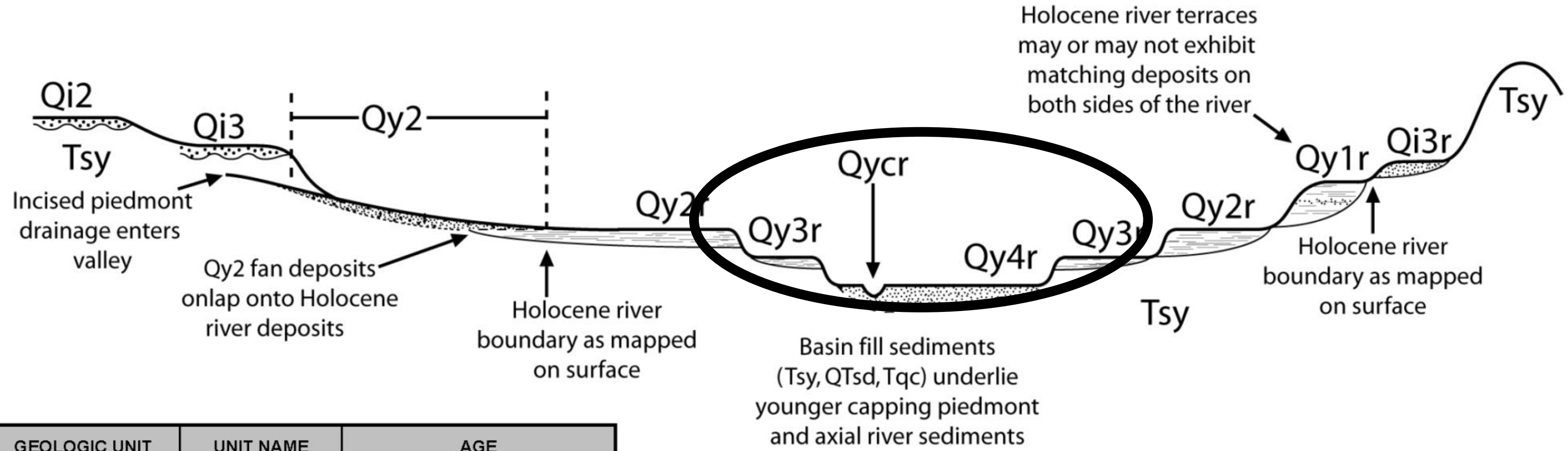
Figure 4-1

Generalized Cross Section of Stream Terraces and Piedmont Deposits Flanking the San Pedro River

Subflow Zone Delineation Report for the San Pedro River Watershed

Pre-Entrenchment Alluvium

- Is not medium silt clay
- The pre-entrenchment channel was in 1924:
  - Fine Sandy Loam
  - Silt Loam
  - Fine Sand
  - Silty
- "…interfingering coarse sandy to pebbly braided channel and fine sand to silty river floodplain deposits…" AzGS
- Saturated Floodplain Holocene or Subflow due to high well yields because it lacks clay



GEOLOGIC UNIT	UNIT NAME	AGE
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	Qy3r	
	Qy2r	
	Qy1r	
	Qi3r (oldest)	Pleistocene (2 million to 10,000 years ago)
Piedmont Deposits (Tributary Alluvium and Younger Basin Fill)	Qy2 (youngest)	Holocene
	Qi3	Pleistocene
	Qi2 (oldest)	
Older Basin Fill	QTsd (youngest)	Tertiary (2 million years ago and before)
	Tqc	
	Tsy (oldest)	

Source: AZGS (2009)

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Post Entrenchment Alluvium

Figure 4-1

Generalized Cross Section of Stream Terraces and Piedmont Deposits Flanking the San Pedro River

Subflow Zone Delineation Report for the San Pedro River Watershed

Post-Entrenchment Alluvium

- Is coarser than the Pre-Entrenchment Alluvium

- Sands
- Gravel
- Cobbles
- Boulder

Charleston
October 8 1964
10 CFS

Figure 14*D*. View from left bank looking downstream toward right bank of cross-section 1, October 8, 1964, San Pedro River near Charleston.

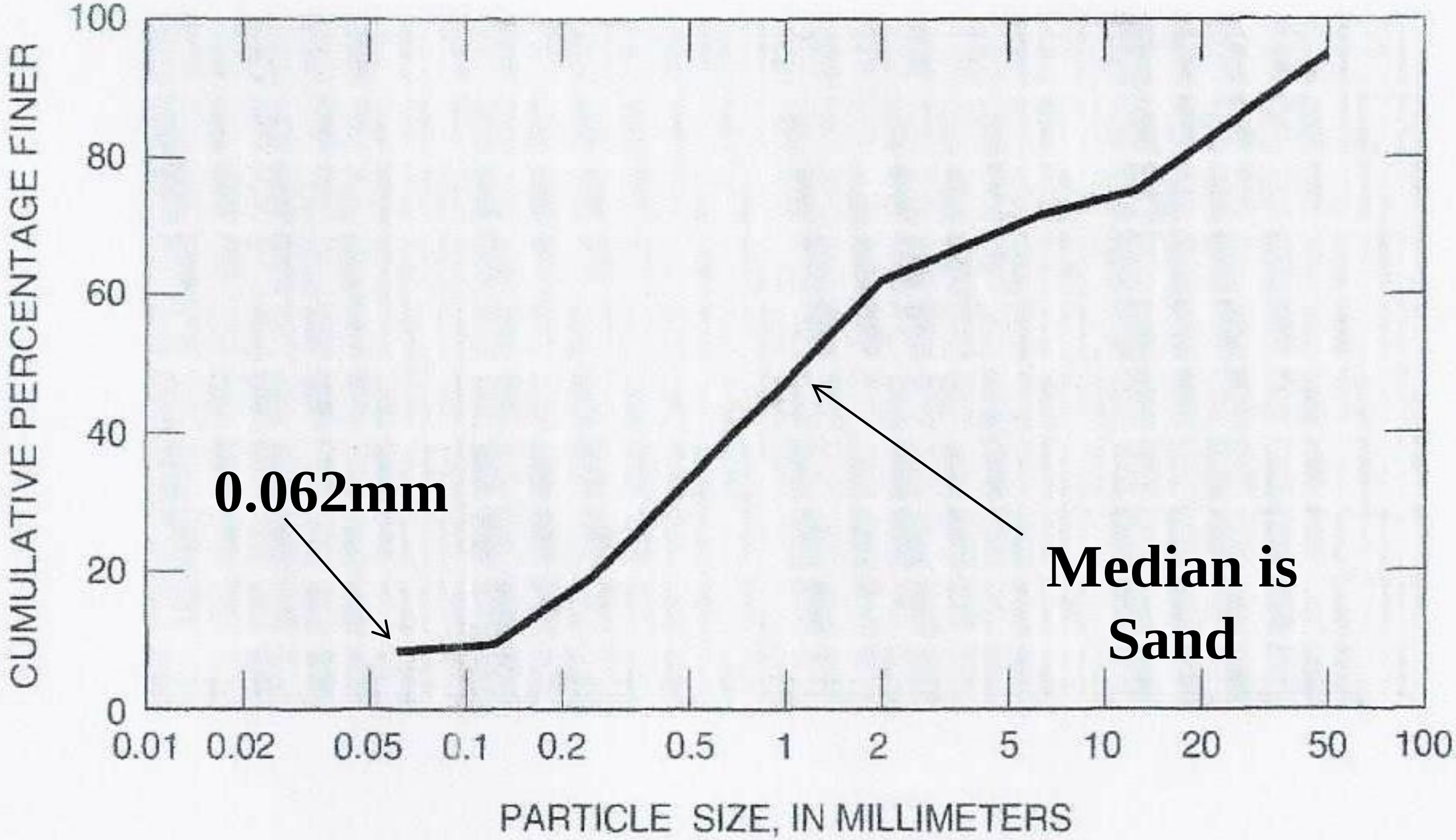


Figure 14*C*. Particle-size distribution for bed material, San Pedro River near Charleston.

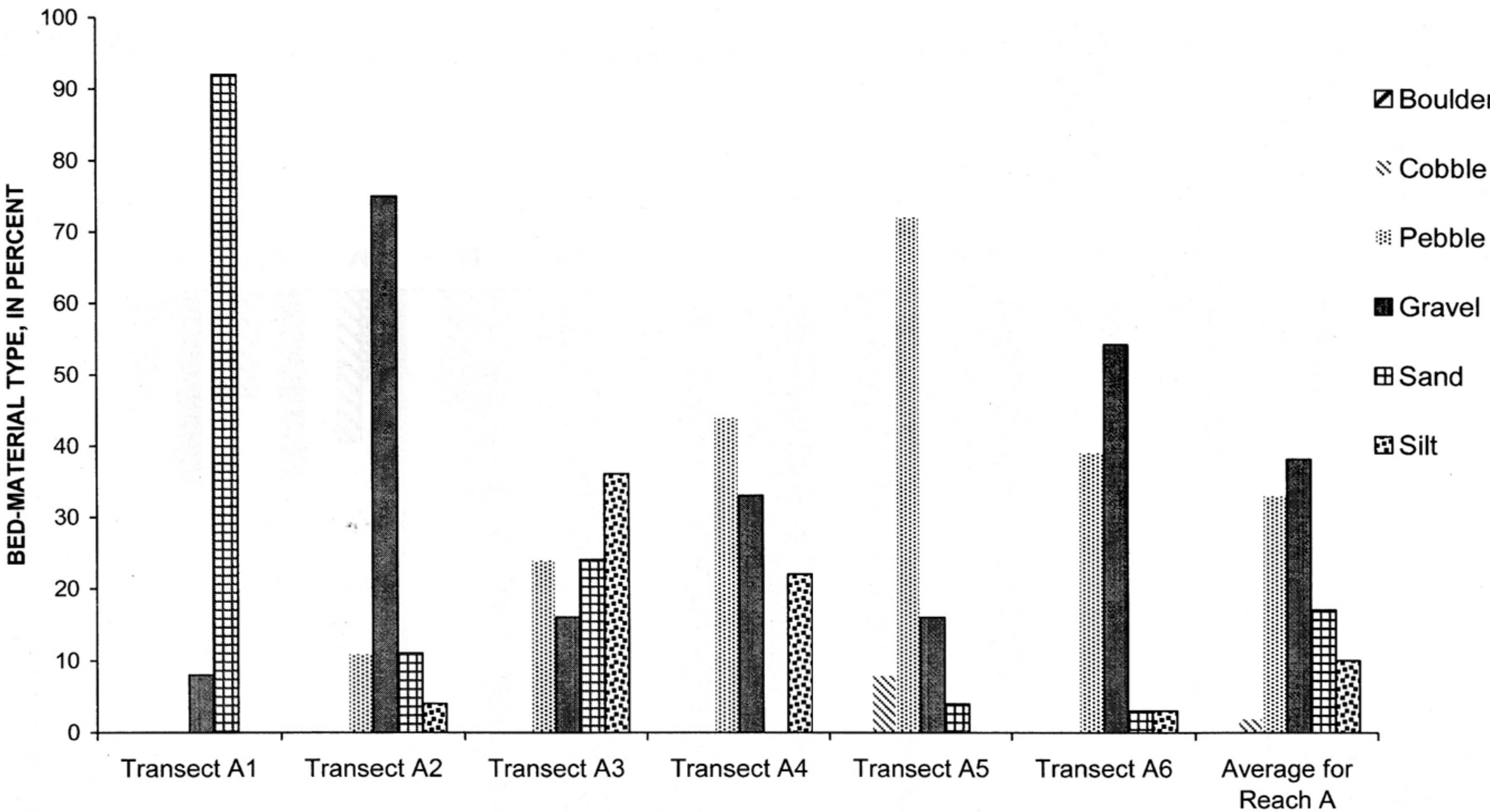


Figure 20. Bed-material types at transects 1–6 and average for reach A, San Pedro River at Charleston, Arizona, December 8, 1995.

Historic Observations

- 1849 "a clear stream, running over a **rocky** bed"
- 1854 "flows …over a light, **sandy** bed"
- 1854 "intermittent **sandy**-bottomed"
- 1867 "the Pedro is small shallow stream **sandy"**
- 1891 "an 'insignificant **sand**-bed' "
- <1895 "continuous **sand**-bed was formed"
- 1901 "The U.S. Geological Survey's Twenty-First Annual Report was the first published account to note the presence of a **sandy** channel bed"

Slope

- Slope varies a lot along a river

- Slopes at gaging stations
  - Palominas .0014
  - Charleston .0024
  - Redington .0038

- Slopes along reaches
  - Narrows to Redington .003
  - Reddington to Winkleman .004

Meanders Affect Slope

- Meanders are measured as sinuosity
- Sinuosity is the distance following the river divided by the distance “as the crow flies”
- Hjalmarson assumed 1.5
- Historic Testimony said 2.0
- Meander sinuosities also vary
- Meander sinuosity of 1.5 is the boundary between straight and braided (Leopold pg 60)

BRAIDED VERSUS MEANDERING NATURAL CHANNELS

(USGS PP 282-B RIVER CHANNEL PATTERNS: BRAIDED, MEANDERING AND STRAIGHT)

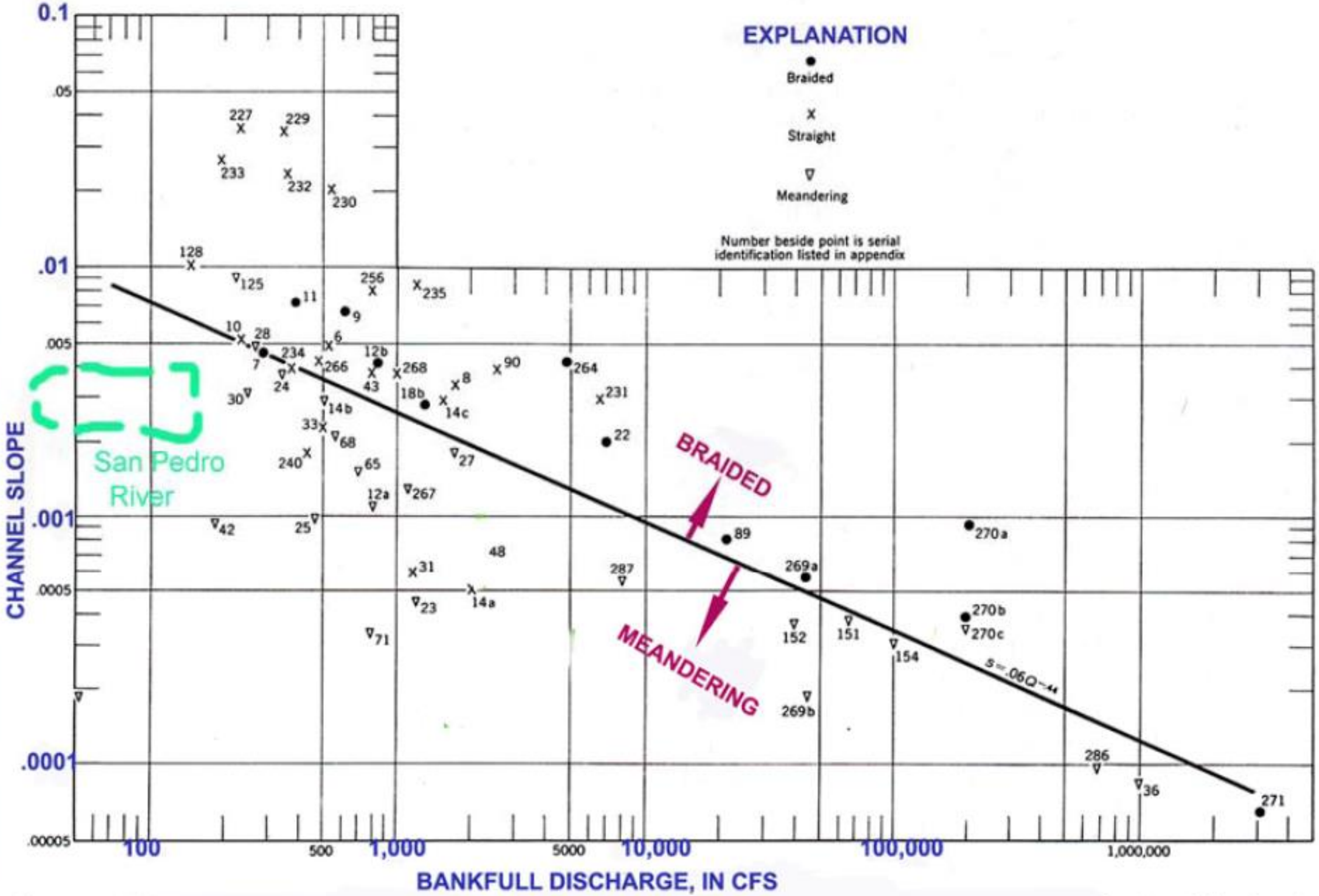
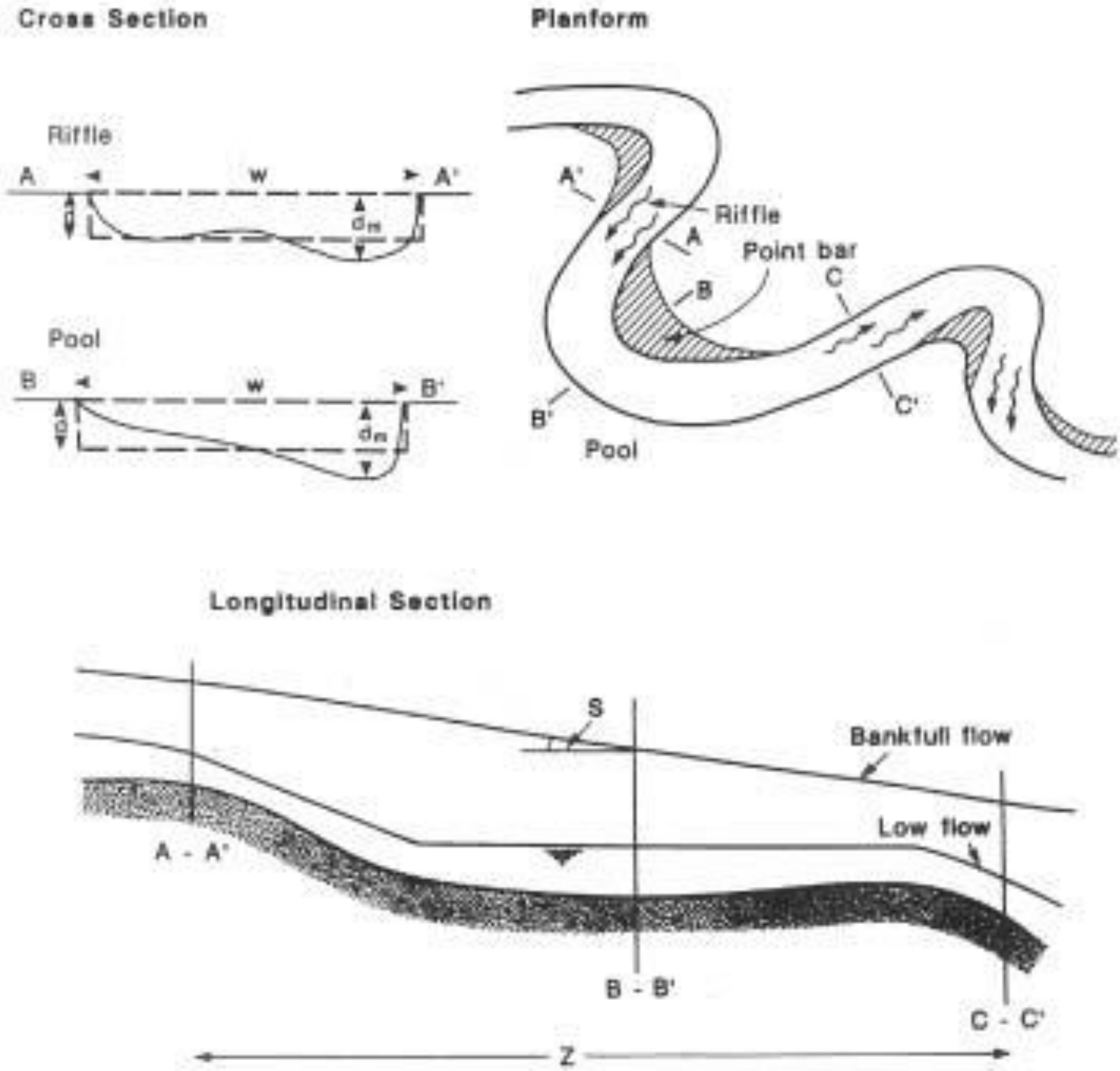


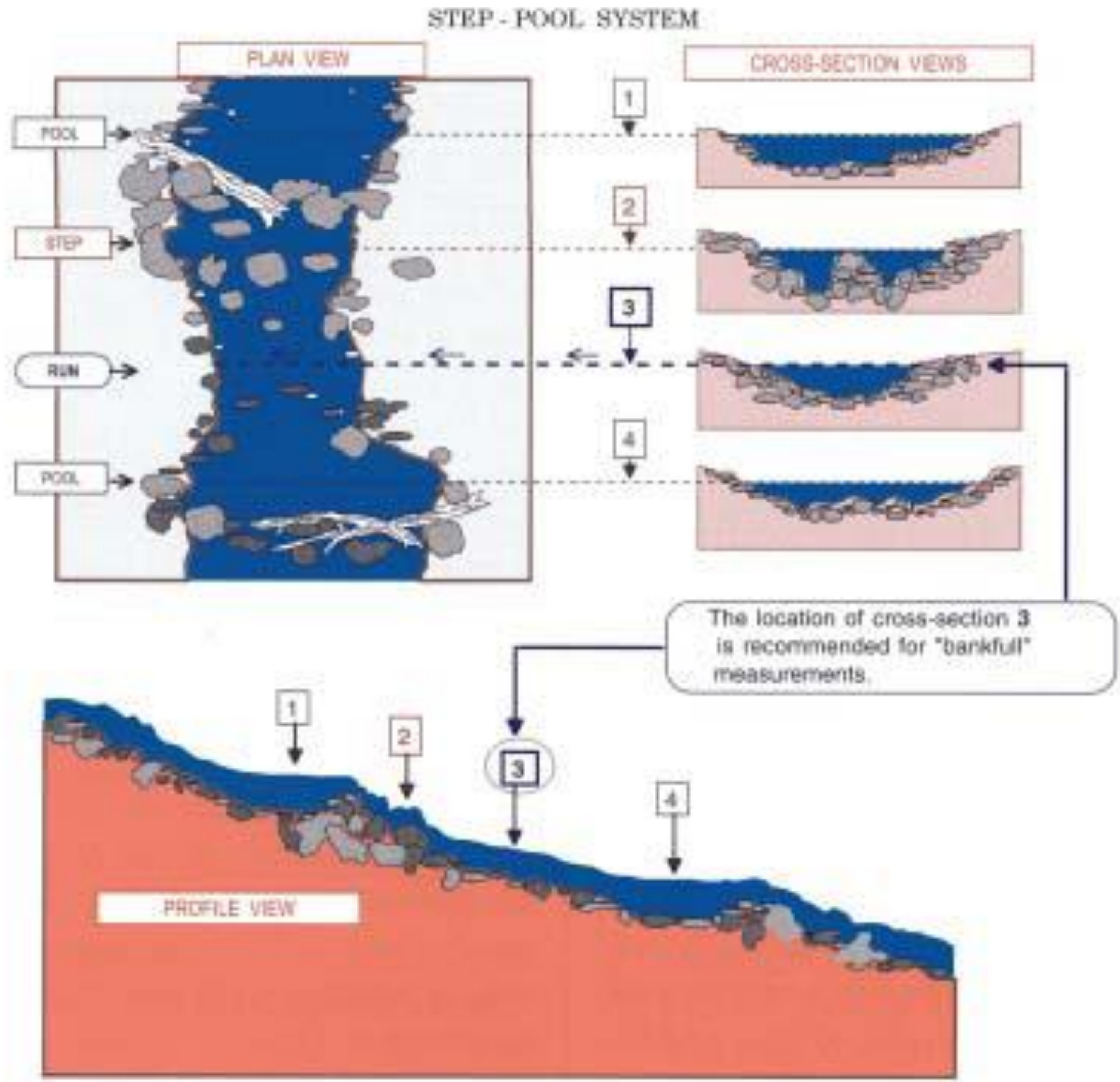
Table 4. Hydrogeomorphic traits of reaches of the San Pedro River, San Pedro Riparian National Conservation Area, Upper San Pedro Basin, Arizona

Reach number	Sinuosity (meter per meter)	Spatial extent of perennial flow in June 2002 (percent of reach)	Mean flood-plain width (meters)	Reach length (kilometers)	Cumulative distance from the United States-Mexico border, (kilometers)
1	1.41	30	214	8.1	0
2	1.37	87	186	7.6	8
3	1.43	69	223	6.1	16
4	1.18	90	244	2.3	22
5	1.16	100	216	6.5	24
6	1.36	100	156	3.0	31
7	1.37	99	123	4.1	34
8	1.58	51	177	5.8	38
9	1.13	0	61	3.1	44
10	1.17	44	128	1.9	47
11	1.12	0	138	2.1	49
12	1.58	34	355	4.7	51
13	1.16	0	276	3.9	55
14	1.65	2	232	2.5	59

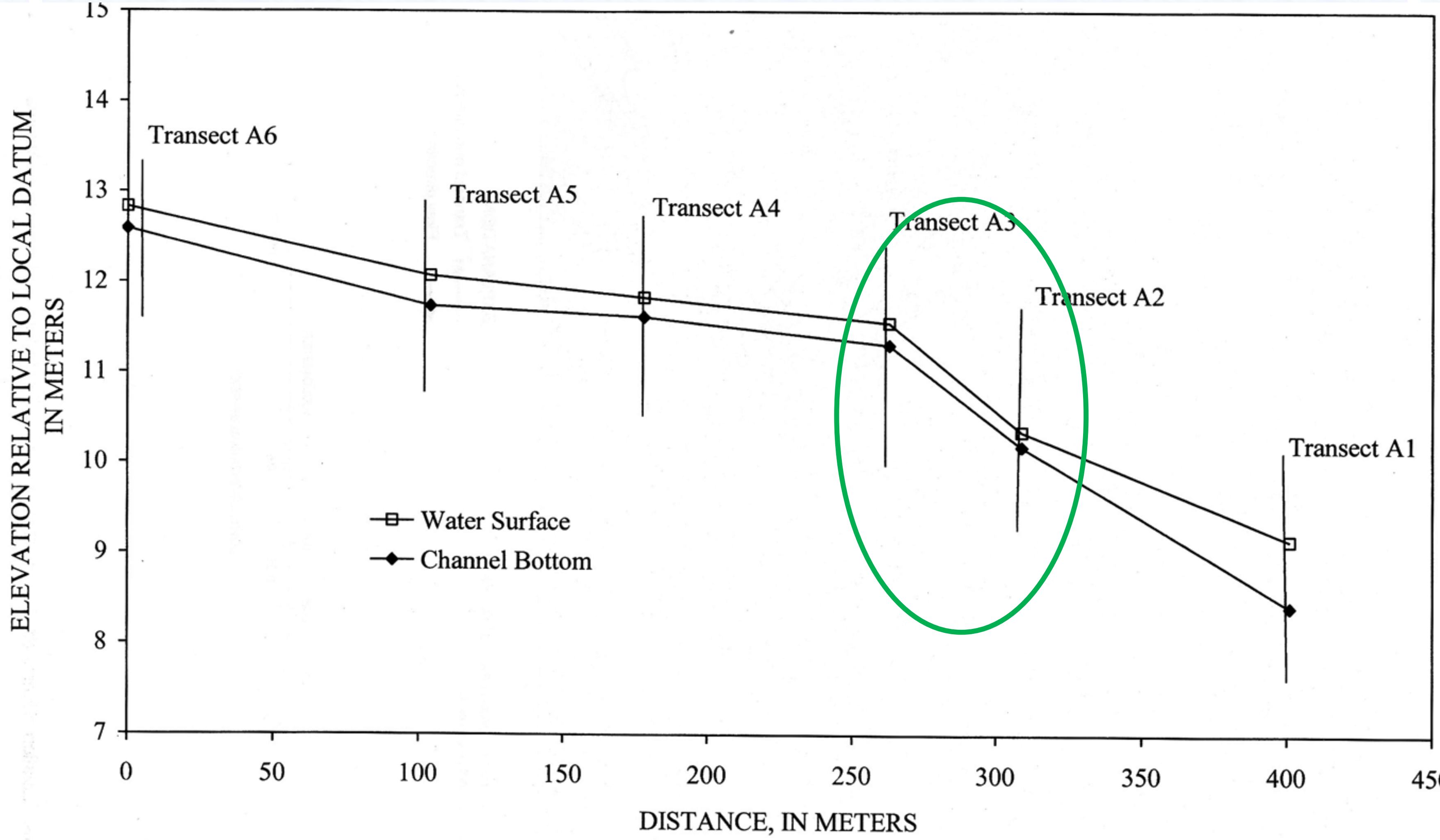
Riffles

- Very common
- They have radically different slopes than the intervening pools
- They have radically different soil structures than the intervening pools

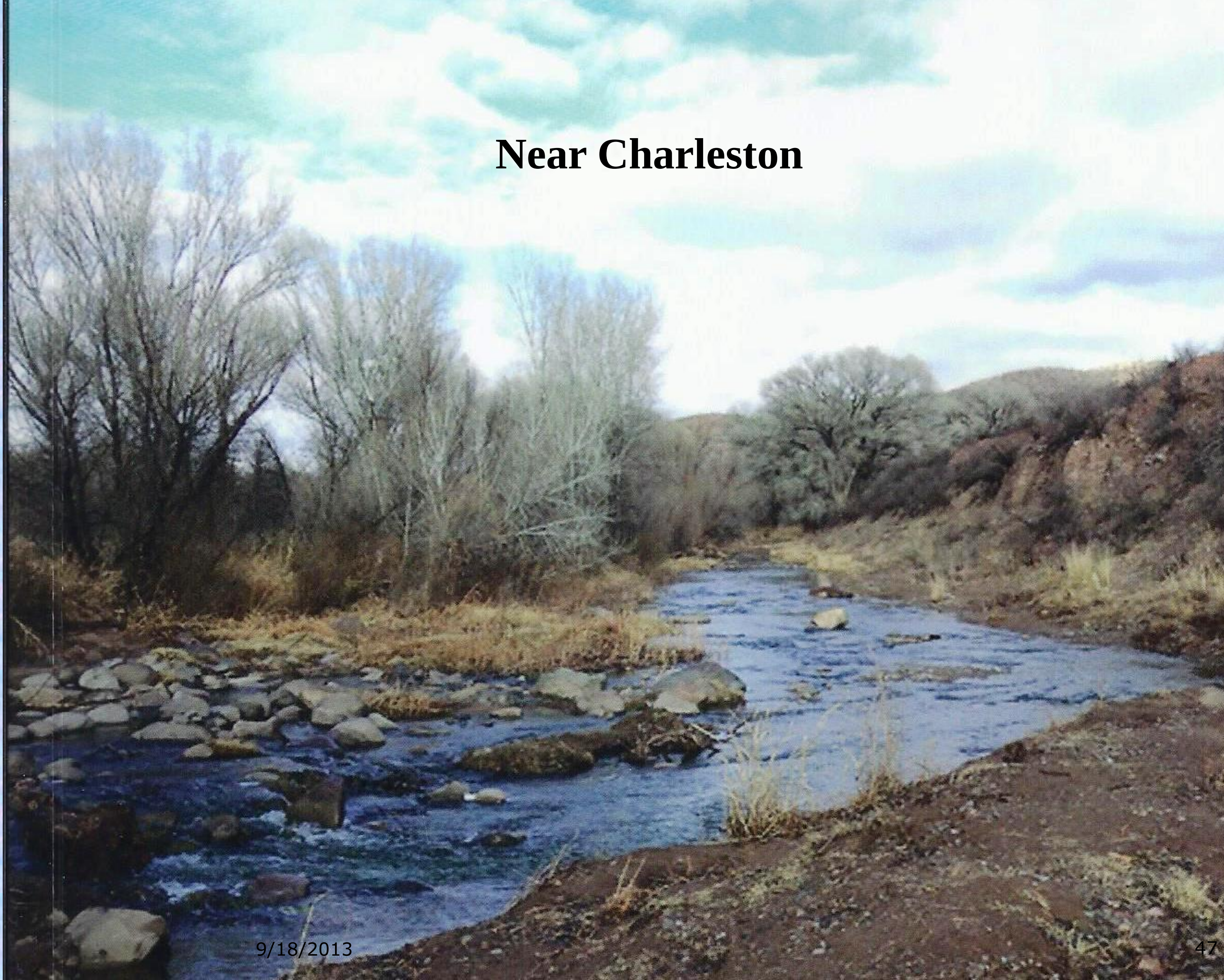

Cross Section
Planform
Riffle
A
w
A'
d_m
Pool
B
w
B'
d_m
A'
Riffle
A
Point bar
B
C
B'
C'
Pool
Longitudinal Section
S
Bankfull flow
Low flow
A - A'
B - B'
C - C'
Z


STEP - POOL SYSTEM
PLAN VIEW
CROSS-SECTION VIEWS
POOL
STEP
RUN
POOL
1
2
3
4
The location of cross-section 3 is recommended for "bankfull" measurements.
PROFILE VIEW

Near Charleston



Near Charleston



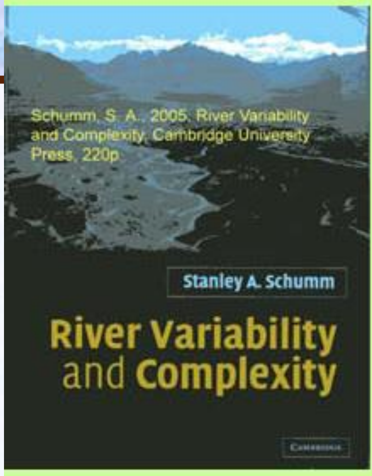
Channel Shape

1. There is no such thing as a single channel shape that is the "natural shape" for all streams

2. Many things can cause streams to change form
   - Climatic variation
   - Animal activity
   - Vegetation changes
   - Human activity
   - Tectonic activity

3. *"Everything changes and nothing remains still .... and ... you cannot step twice into the same stream"* (Heraclitus)

Schumm



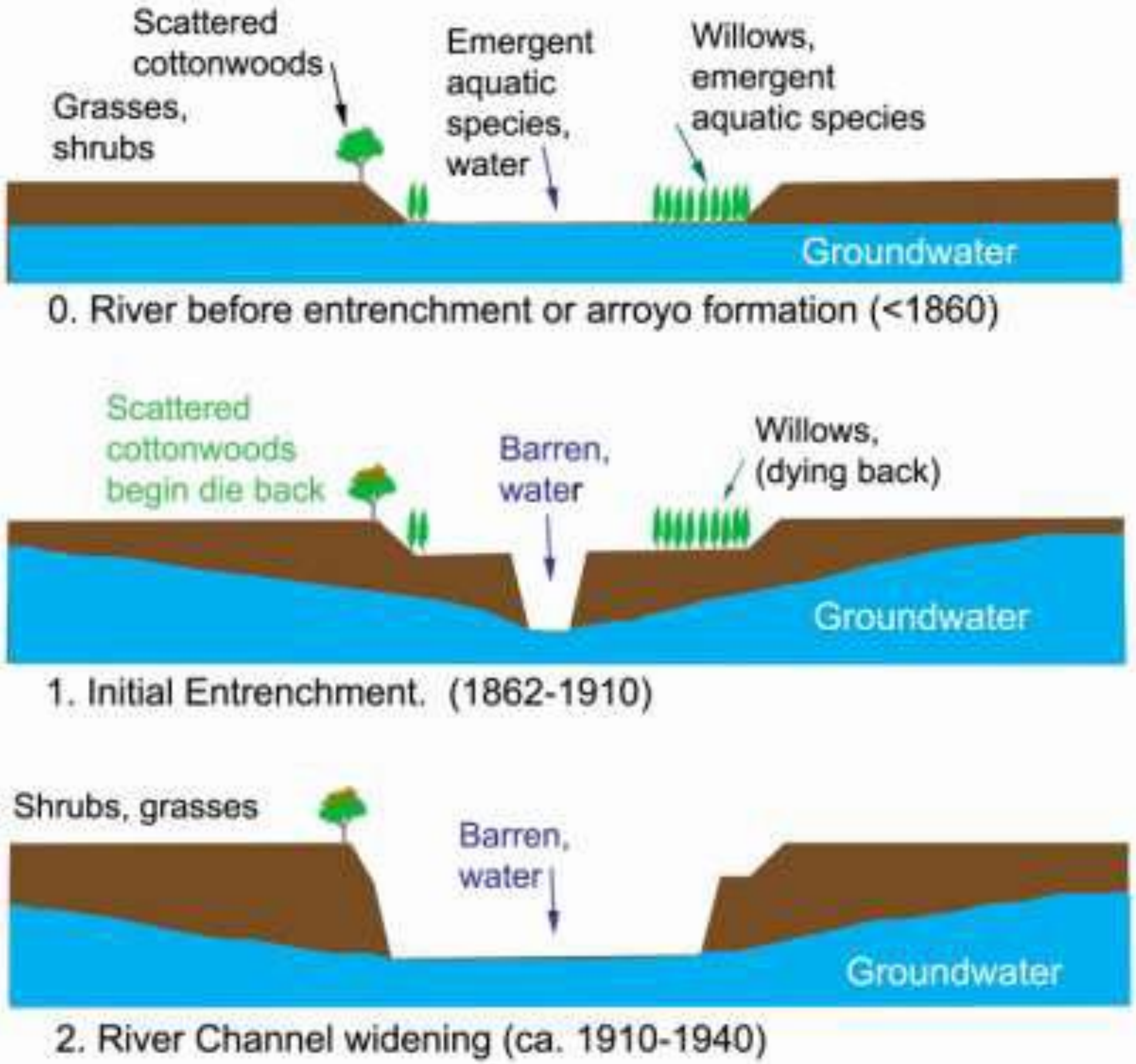
"1. there is a spectrum of river types that is dependent upon hydrology, sediment loads, and geologic history (in other words, rivers differ among themselves);

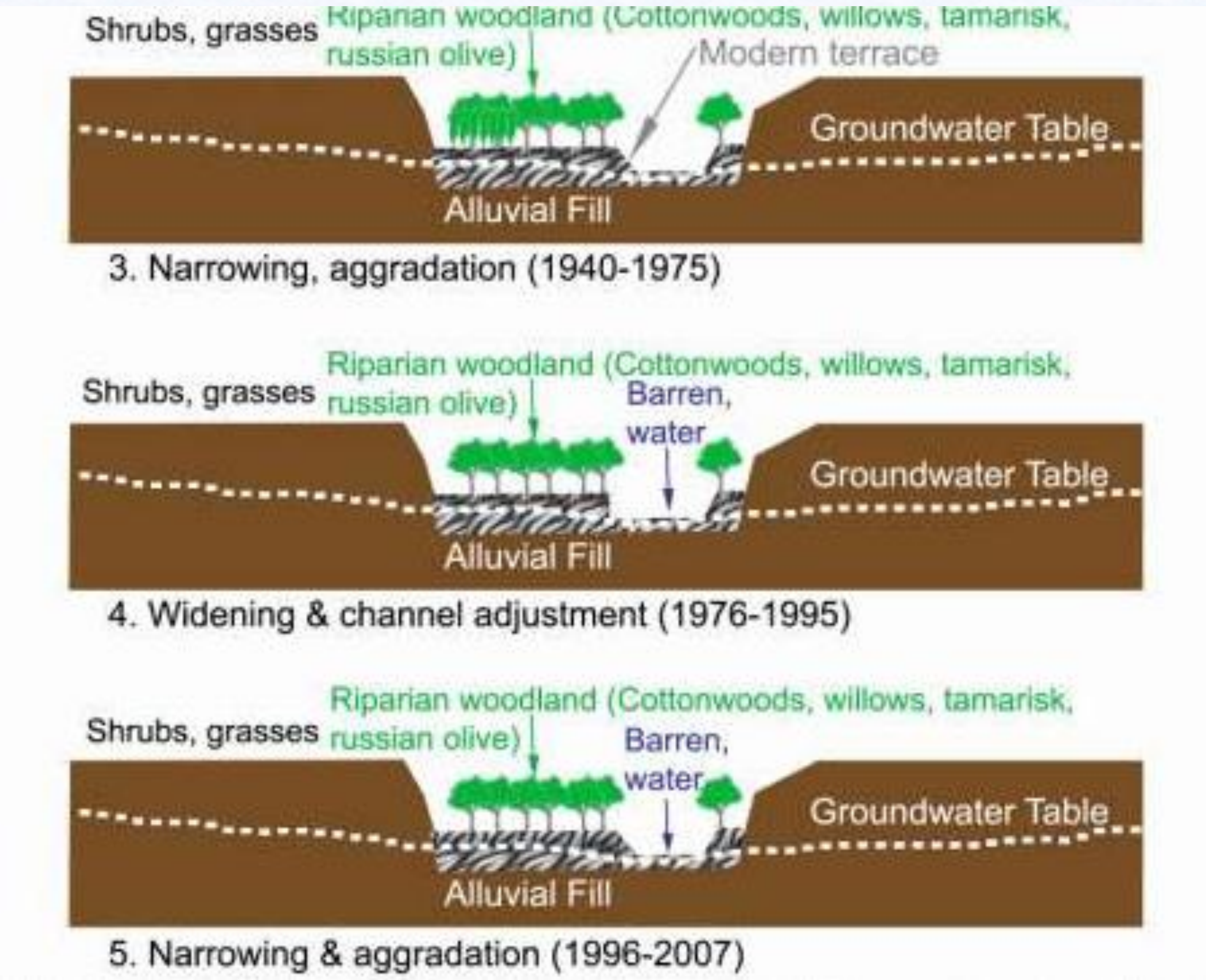
2. rivers change naturally through time as a result of climate and hydrologic change;

3. there can be considerable variability of channel morphology along any one river, as a result of geologic and geomorphic controls: (Schumm and Winkley, 1994),"

Channel Shape

- On the San Pedro there was an historic repeat of prehistoric events that are called entrenchments
- Many reasons have been suggested for the historic entrenchment
  - Cattle Grazing
  - Climatic Variations
  - Others
- Not a unique nor a human-caused event

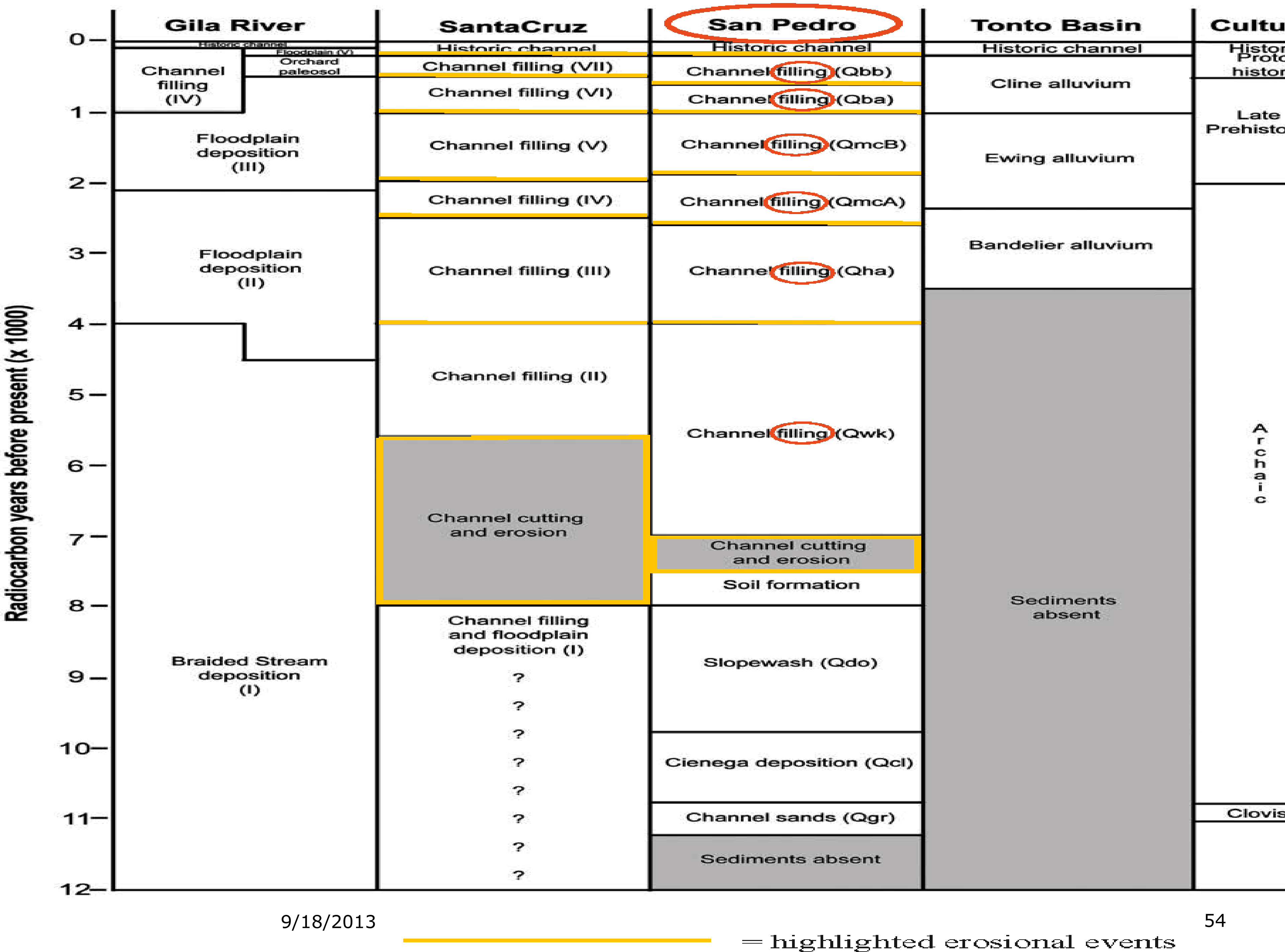

Scattered
cottonwoods
Grasses,
shrubs
Emergent
aquatic
species,
water
Willows,
emergent
aquatic species
Groundwater
0. River before entrenchment or arroyo formation (<1860)
Scattered
cottonwoods
begin die back
Barren,
water
Willows,
(dying back)
Groundwater
1. Initial Entrenchment. (1862-1910)
Shrubs, grasses
Barren,
water
Groundwater
2. River Channel widening (ca. 1910-1940)



Shrubs, grasses
Riparian woodland (Cottonwoods, willows, tamarisk, russian olive)
Modern terrace
Groundwater Table
Alluvial Fill
3. Narrowing, aggradation (1940-1975)
Shrubs, grasses
Riparian woodland (Cottonwoods, willows, tamarisk, russian olive)
Barren, water
Groundwater Table
Alluvial Fill
4. Widening & channel adjustment (1976-1995)
Shrubs, grasses
Riparian woodland (Cottonwoods, willows, tamarisk, russian olive)
Barren, water
Groundwater Table
Alluvial Fill
5. Narrowing & aggradation (1996-2007)

Entrenchments

- Prehistoric entrenchments
- Overgrazing and no entrenchment (1700-1845)
- Entrenchment during undisturbed time (1846-1870)
- Entrenchment during development (1870's-1880's)
- 1890 to Statehood



Gila River
SantaCruz
San Pedro
Tonto Basin
Cultu
Radiocarbon years before present (x 1000)
0
1
2
3
4
5
6
7
8
9
10
11
12
Historic channel
Floodplain (V)
Orchard paleosol
Channel filling (IV)
Floodplain deposition (III)
Floodplain deposition (II)
Braided Stream deposition (I)
Historic channel
Channel filling (VII)
Channel filling (VI)
Channel filling (V)
Channel filling (IV)
Channel filling (III)
Channel filling (II)
Channel cutting and erosion
Channel filling and floodplain deposition (I)
?
?
?
?
?
?
?
?
Historic channel
Channel filling (Qbb)
Channel filling (Qba)
Channel filling (QmcB)
Channel filling (QmcA)
Channel filling (Qha)
Channel filling (Qwk)
Channel cutting and erosion
Soil formation
Slopewash (Qdo)
Cienega deposition (Qcl)
Channel sands (Qgr)
Sediments absent
Historic channel
Cline alluvium
Ewing alluvium
Bandelier alluvium
Sediments absent
Archaic
Clovis
= highlighted erosional events

1700 to 1845

1. Prior to 1700, Pimas were farming the Lower San Pedro and had 100,000 Cattle

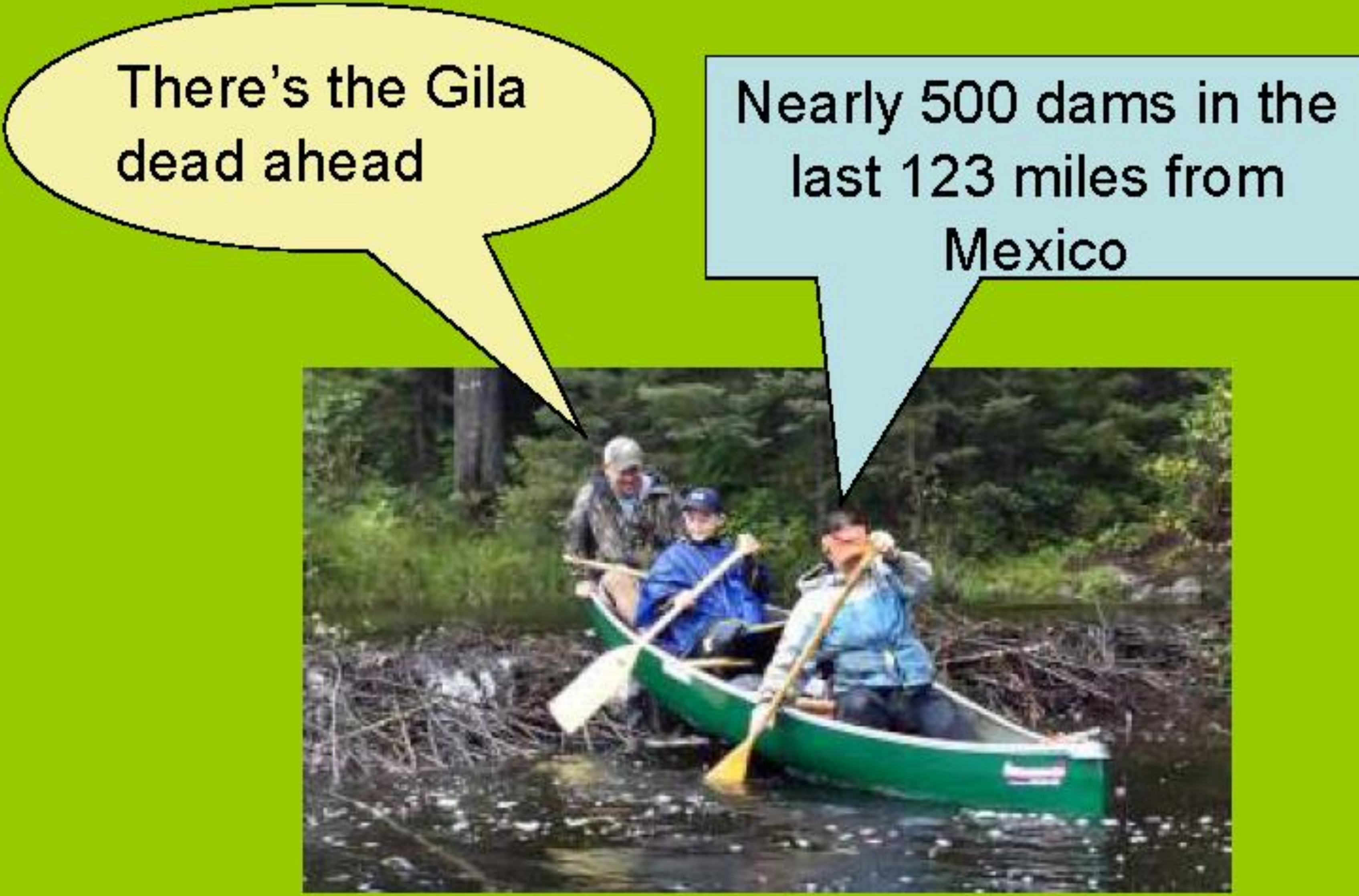
2. No record of entrenchment or destruction of the watershed

There Were Non-Flow Obstacles to Navigation

1. Without trapping, beaver dams would have been prevalent

2. Cienegas existed

3. Riffles existed



Hjalmarson, PE May 24, 2013 160

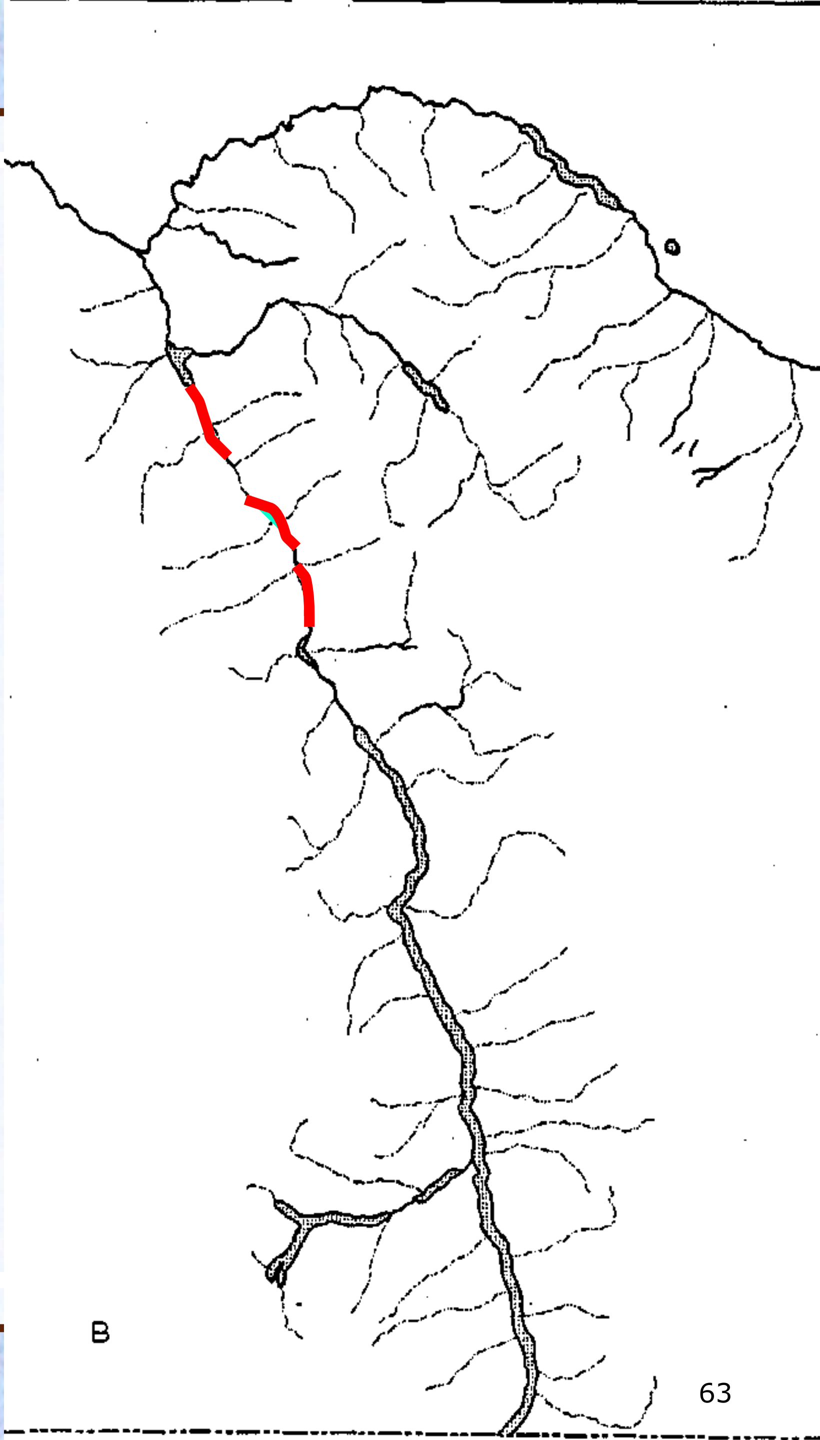
Arivaca Cienega 3/10/10

Canelo Hills Cienega

Appendix B Figure 1. Bingham Cienega sampling point, 6/9/2000.

St. David Cienega

Pre-1890 Conditions



1846-1870

1. Human influences were about a low as they can get.

2. Grasslands were in excellent condition

3. The cattle were disappearing

4. But entrenchment began

The River was Braided

- "These same streams prior to 1880 coursed unincised across alluvial fills in shallow, braided channels, often through lush marshes."
- Not all was braided

The grass was still good

- 1880’s “On any given day in the 1880's, a horseback ride along the San Pedro River would offer a visual experience that today is hard to imagine. In the spring and summer along the San Pedro one would still see acres of golden brown grasses turned to green…”

- 1882 “In June of that year,… We passed several fine ranches, and saw numbers of fat cattle and horses. This region is unexcelled for its splendid grazing and agricultural lands."

Humans did not cause the entrenchment

There were floods

1881, 1886, 1887

There was more entrenchment

The Great Flood of 1890

1. The 1890 flood occurred due to several monsoon rains in late July and early August

2. This caused extensive entrenchment

3. But not the entire river

Extensive Entrenchment

- “in August, 1890, it [the San Pedro] began carving a steep-walled trench…(Hastings 1959)”.
- “the first mention of extensive channel widening and channel entrenchment were described in newspaper accounts of the damage resulting from the flood events of August and September 1890”

But not Everywhere

- The main channel of the San Pedro River did not become incised into the floodplain in the Redington area, however, until the flood of September 1926 (J. Smallhouse, oral communication, 1996).

Destruction of the watershed 1891

"The 1890-91 winter precipitation carpeted the range with grass, so graziers were optimistic. The 1891 summer monsoon did not begin until 21 July, and thunder showers fell in their usual erratic pattern. By September, residents perceived that a drought gripped the Southwestern United States. The San Pedro River Valley range was 'absolutely bare.'"

Floods caused the entrenchment

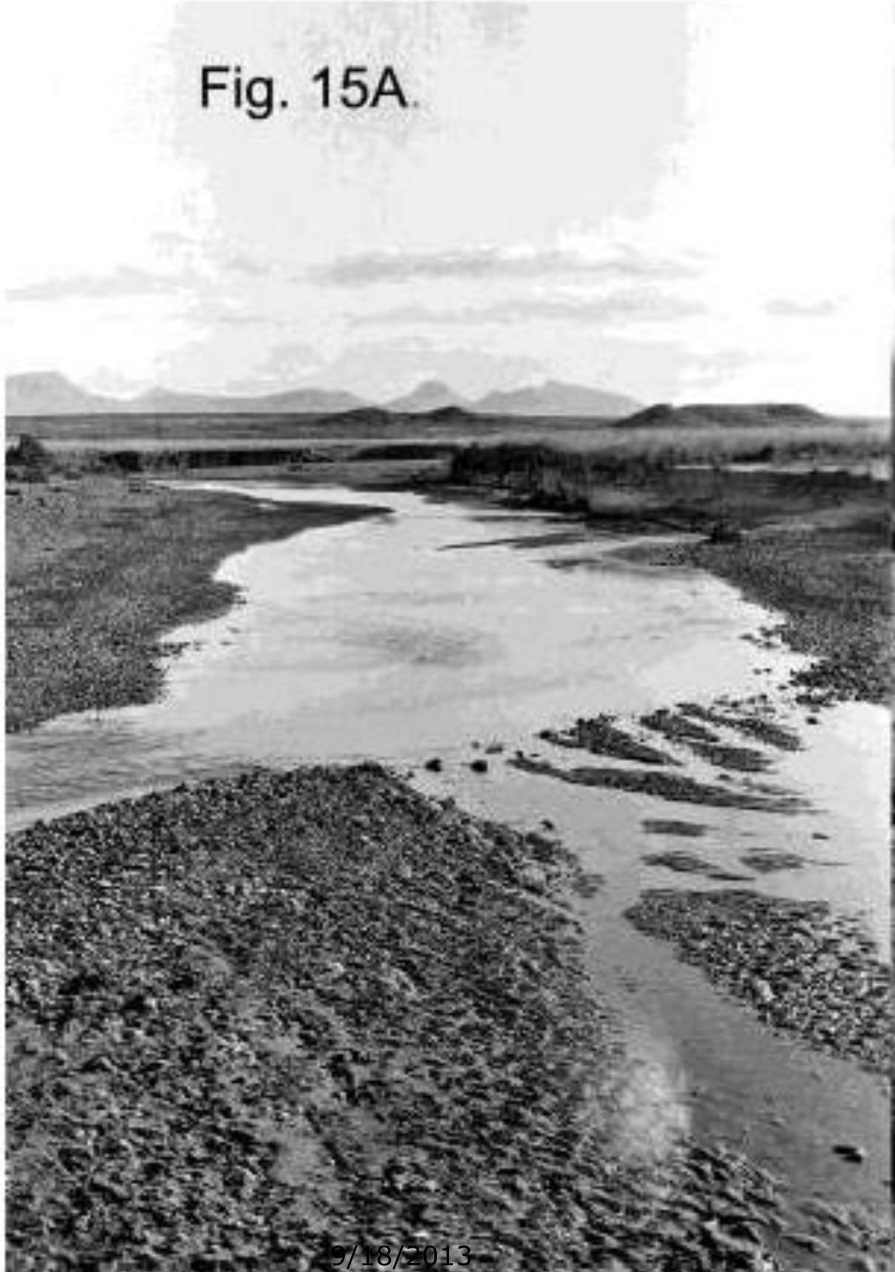
- "The cause of entrenchment is the subject of considerable debate among hydrologists, but a strong argument can be made for change of climate." Hjalmarson

- Others who agree:
  - Huckleberry
  - Hereford
  - Betancourt
  - Wood
  - Fuller

The river would not recover by 1912

1. Floods continued in 1891, 1893, 1894, 1896, 1900, 1901, 1904, 1905
2. USGS indicates that the flood of 1906 was probably greater than the flood of 1926.
3. The flood of 1926 had 100,000 cfs. Over double the 100-year flood
4. Recovery takes decades in the semi-arid Southwest

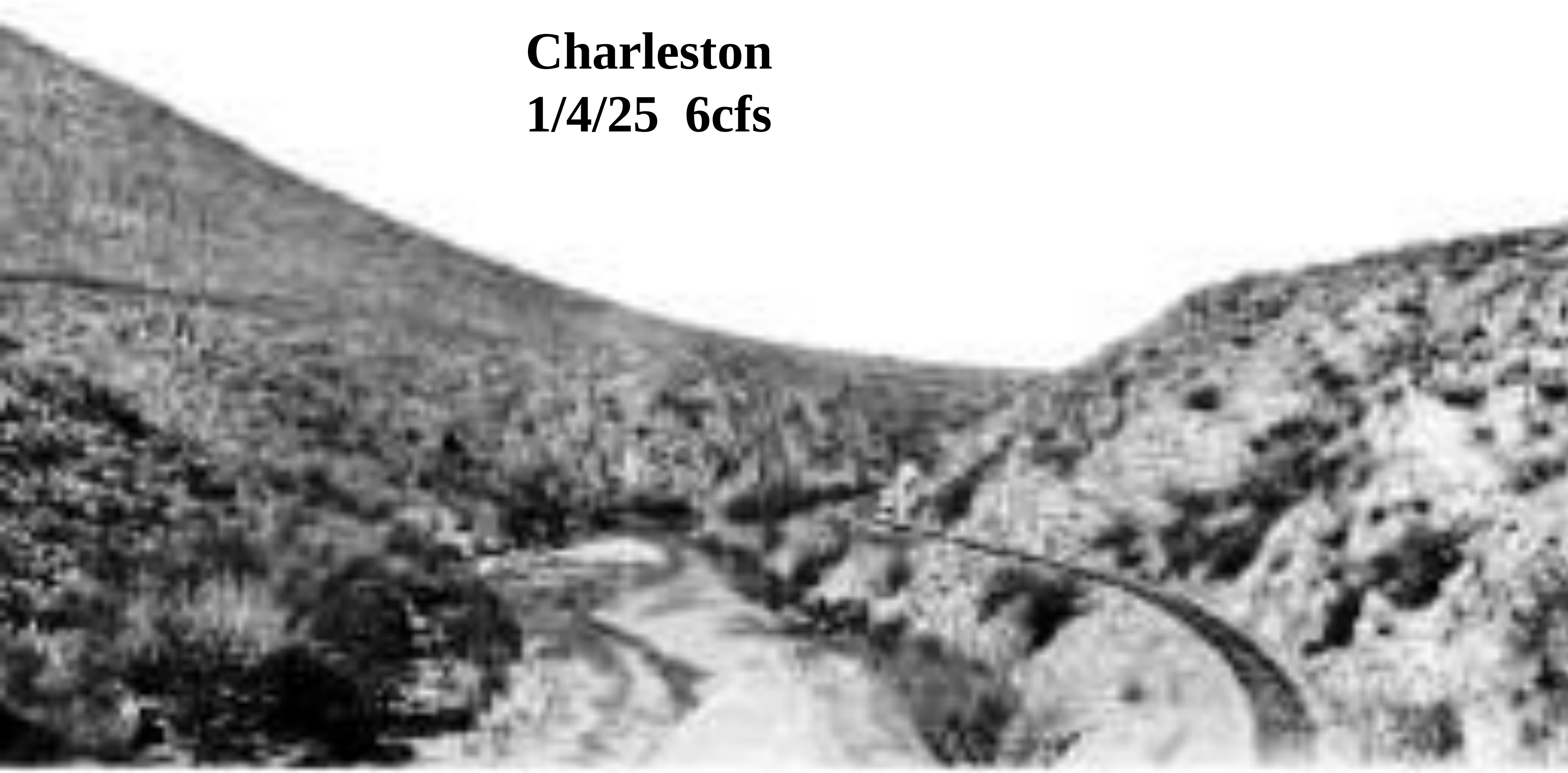
Palominas, 1930 and 1981



Condition as of 1912

- San Pedro River was mostly a braided stream
- San Pedro River was mostly entrenched with vertical sides
- Cienegas on the river were gone
- Beaver dams were gone or mostly gone
- Some of the San Pedro was in its pre-entrenchment state

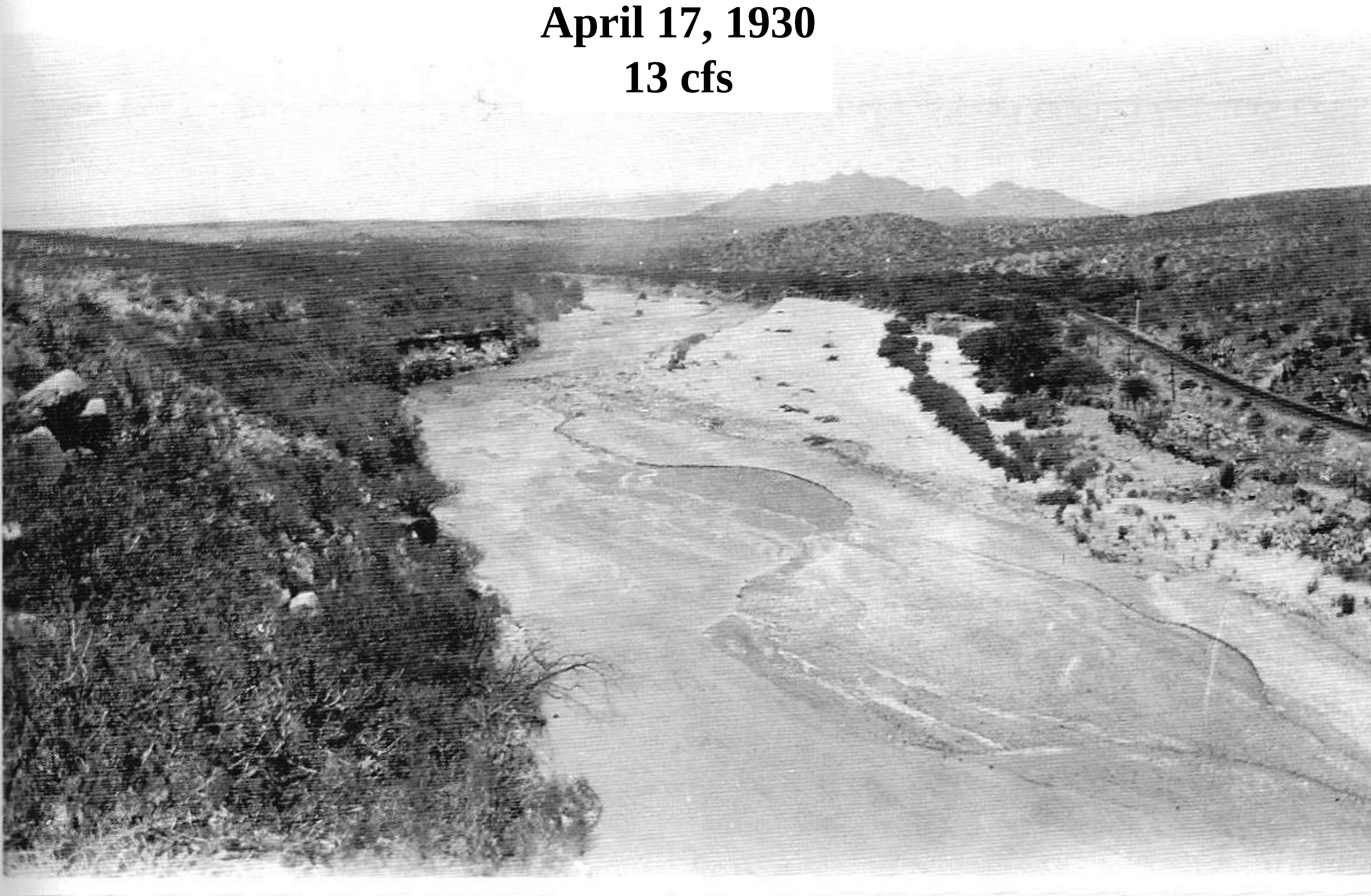
Charleston
1/4/25 6cfs



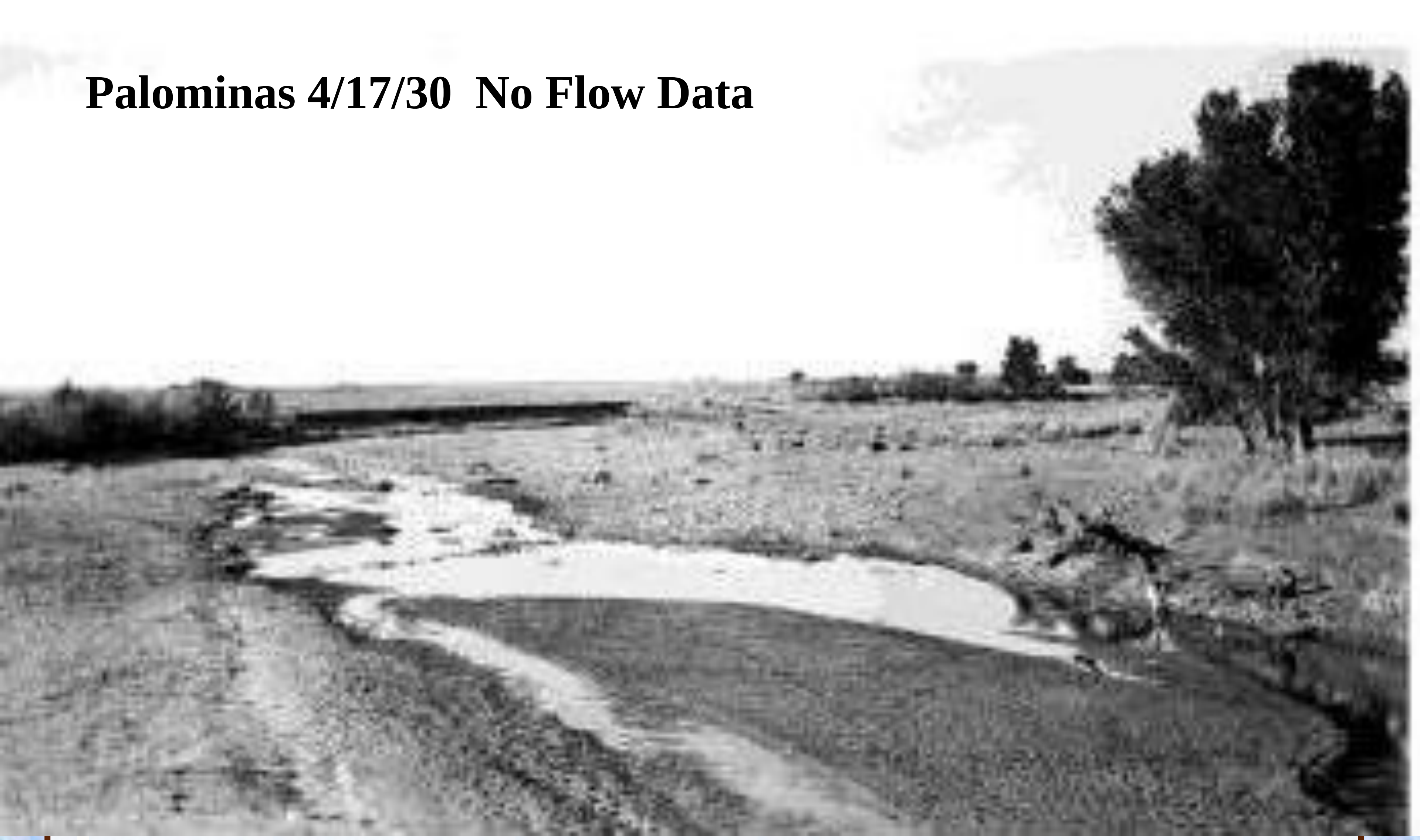
At Highway 92 on the Way to Bisbee AKA Palominas

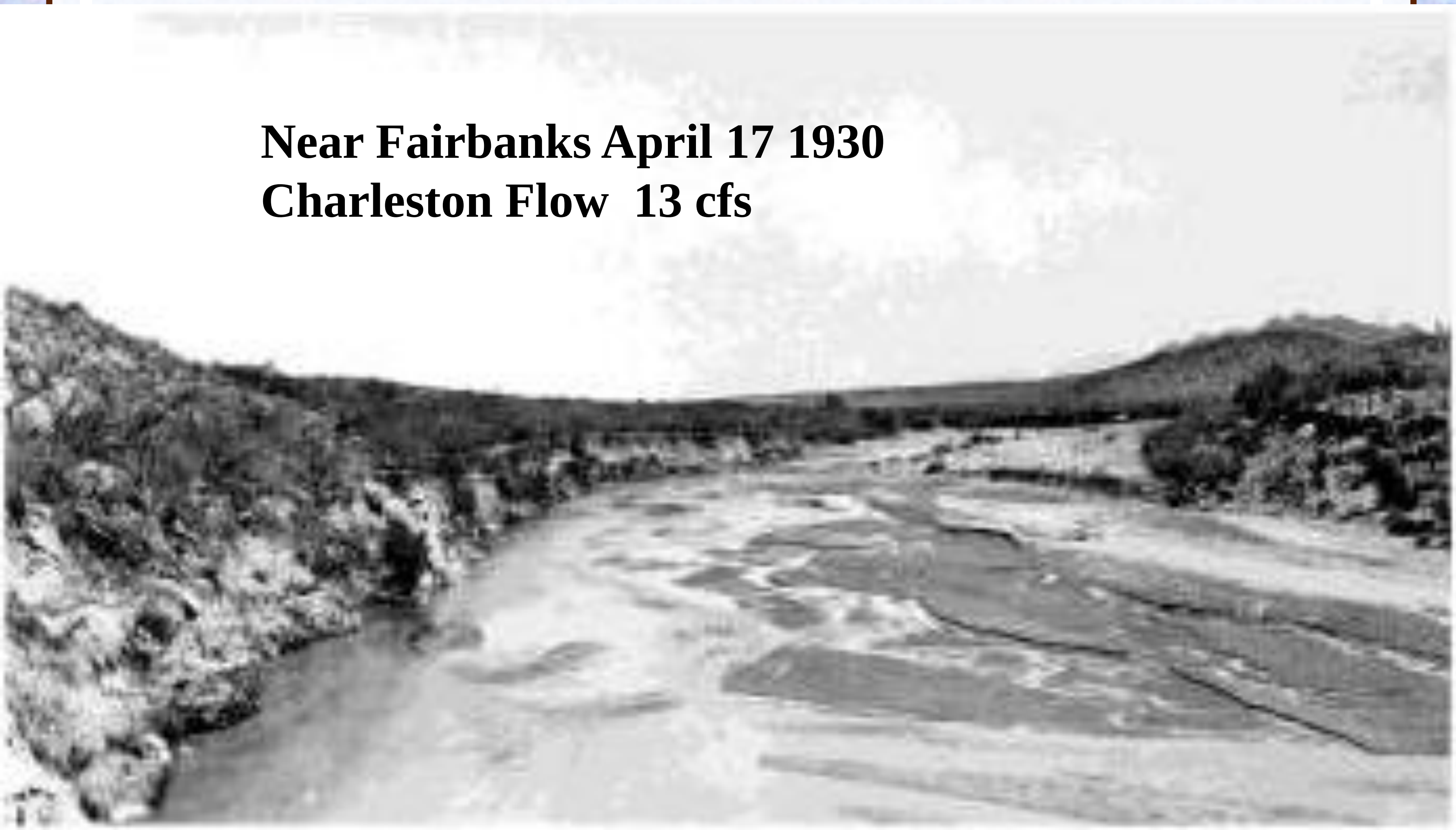
Charleston Bridge
12/14/42 16 cfs

Charleston
April 17, 1930
13 cfs



Palominas 4/17/30 No Flow Data




Near Fairbanks April 17 1930
Charleston Flow 13 cfs

What if I am wrong?

- The Floods did occur
- If the Floods had not caused the entrenchment, they would have greatly widened the channel creating some braiding
- The beavers and cienegas would still be there
- Some riffles would still exist

Two Ways to Get Depth

- What Did People See?
  - 1846 12 inches deep
  - 1849 15 inches deep
  - 1854 18 inches deep
  - 1857 12 inches deep
  - 1857 15 inches deep
  - 1858 12 inches deep
- Channel Geometry Method

Thus, for practical considerations, a typical channel mostly of medium silt-clay and some sand was used. The corresponding coefficient 'a' = (3.01) and the exponent 'b'= 0.57.

Equation 1

$$W = 3.01\ Q^{0.57}$$

Equation from: Osterkamp, W. R., 1980, Sediment-morphology relations of alluvial channels: Proceedings of the symposium on watershed management, American Society of Civil Engineers, Boise Idaho, p. 188-199.

The Channel Geometry Method has Limitations

It is used to determine flows by measuring at:

"A straight, narrow reach in which flows are approximately uniform"

For the Mean Annual Flow you should use:

"The section defined by the lowest channel bars is most commonly related to mean flows"

By reversing the use of the equation, the equation now predicts the channel widths only at certain spots in the river

Riparian vegetation bordering river meander and point bars near town of Cascabel (11/15/07)

The Equation Used is Not for Braided Channels

- Osterkamp, in 1980, presented the equation used by Hjalmarson
- He and others warned it was invalid for braided channels
- In 1983 he determined a series of differing equations based on a width to depth ratio
- For a high W/D ratio (i.e. a braided stream) he determined:

$$W = 1.24\ Q^{0.82}$$

- The exponent is much different 0.82 vs. 0.57

The 1980 Channel Geometry Method Has Several Assumptions

- Soils
  - Assumes a large amount of clay
  - San Pedro does not have much clay
- Uniform parabolic cross section
  - Historical accounts say the San Pedro cross-section was rectangular
  - This changes the 0.67 factor in the Manning's Equation to 1

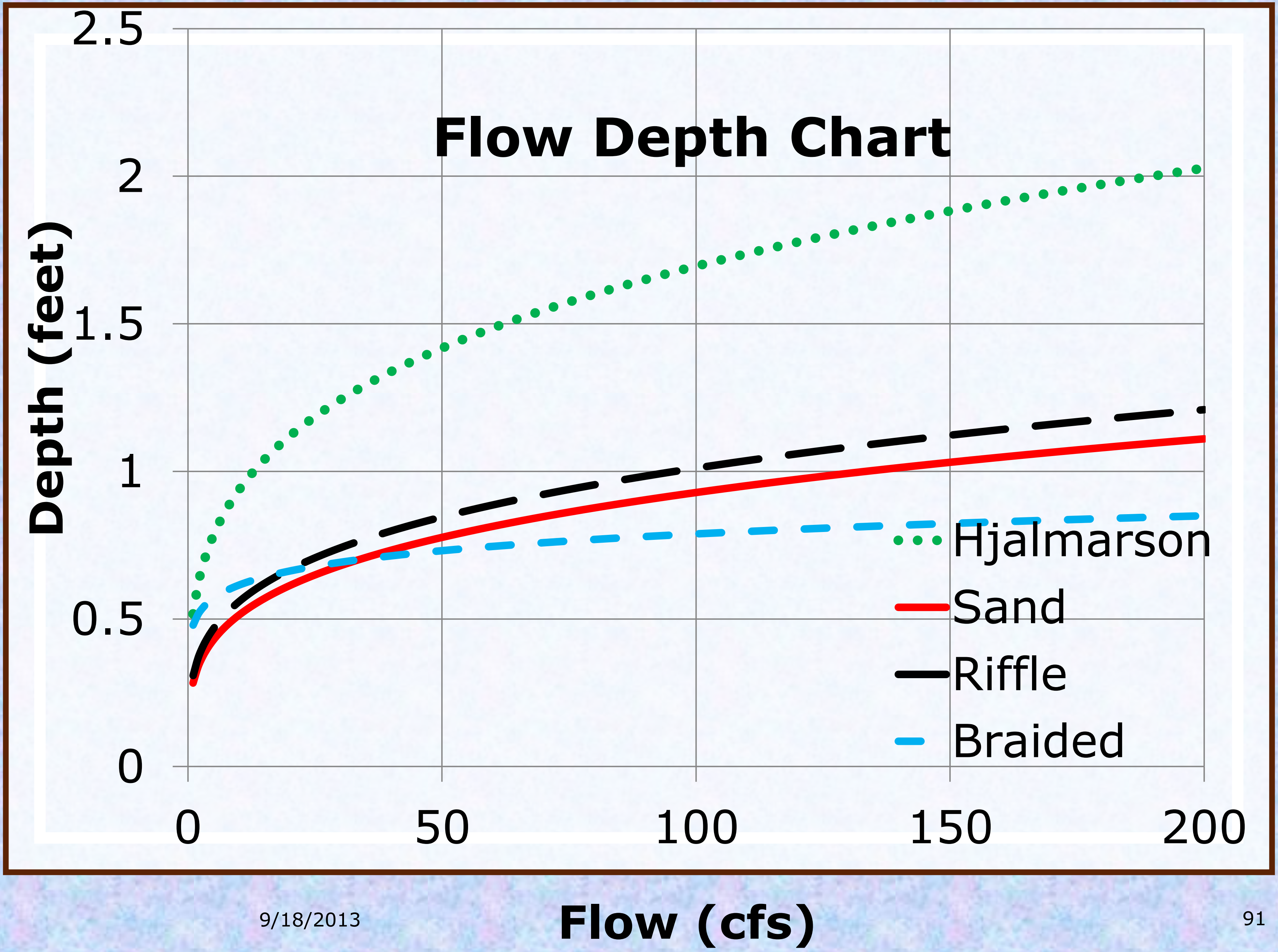
Further Assumptions

- Slopes were assumed to be relatively uniform
  - 0.21% or 0.28%

- Slopes really vary from
  - 0.14% to 2.40%

Ignores Natural Obstacles

- Riffles
- Beaver Dams
- Cienegas


Flow Depth Chart
Depth (feet)
2.5
2
1.5
1
0.5
0
0
50
100
150
200
Hjalmarson
Sand
Riffle
Braided
Flow (cfs)

Channel Geometry Method has Significant Error State of Washington Experience

[A]lthough the predicted hydraulic depth at a mean annual discharge of 1,660 cubic feet per second is 3.5 feet, 90-percent prediction intervals indicate that the actual hydraulic depth may range from 1.8 to 7.0 feet.

Navigability Criteria

- Modern Recreation
  - Bureau of Outdoor Recreation
  - Cooperative Instream Flow Service Group
- Commercial Navigation
  - Commercial Canoes in 1914
  - Washington State
  - Langbein
  - Army Corps of Engineers

Bureau of Outdoor Recreation

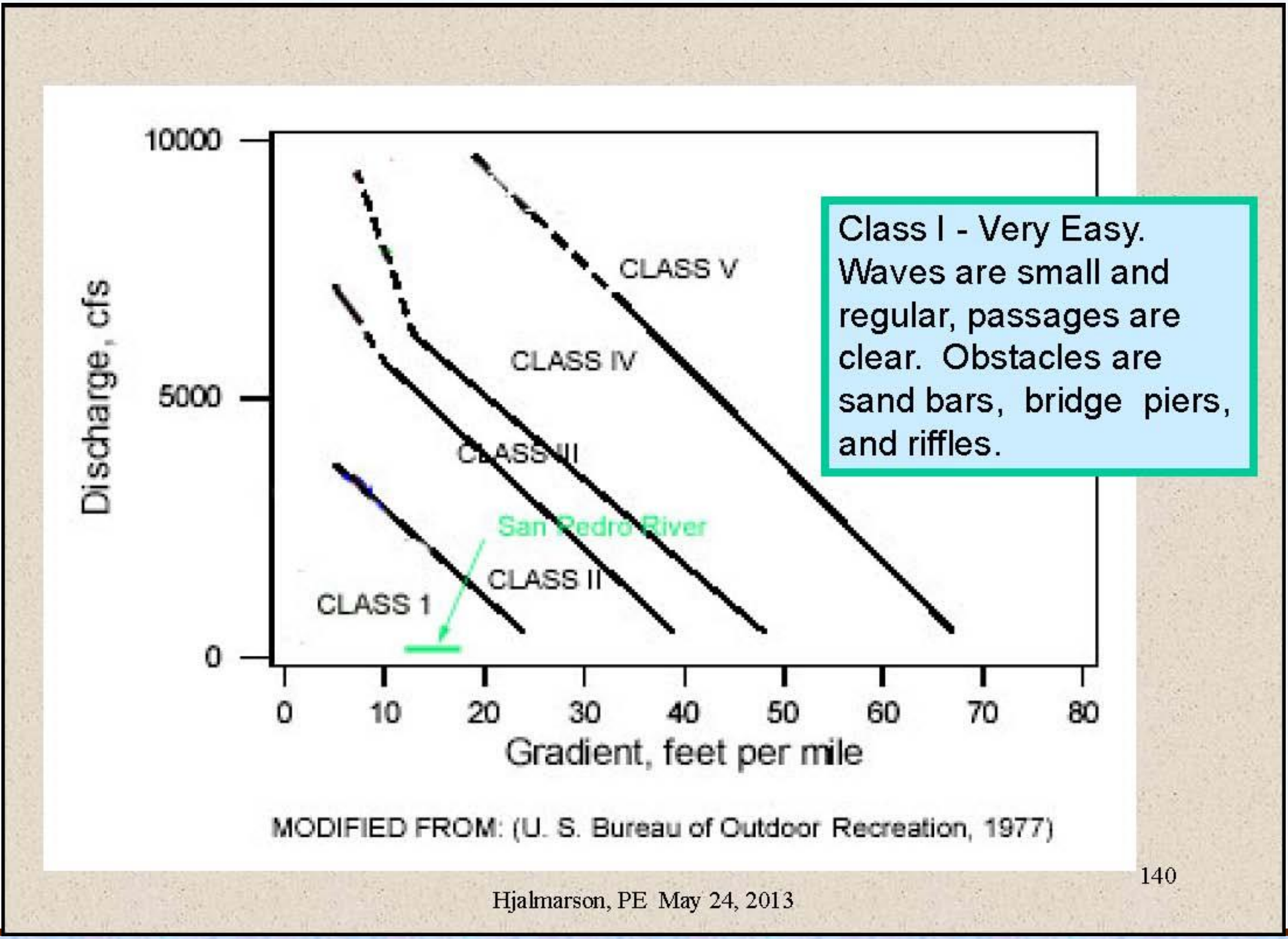
For "Tranquil" Water

A Canoe requires two feet if you want to paddle

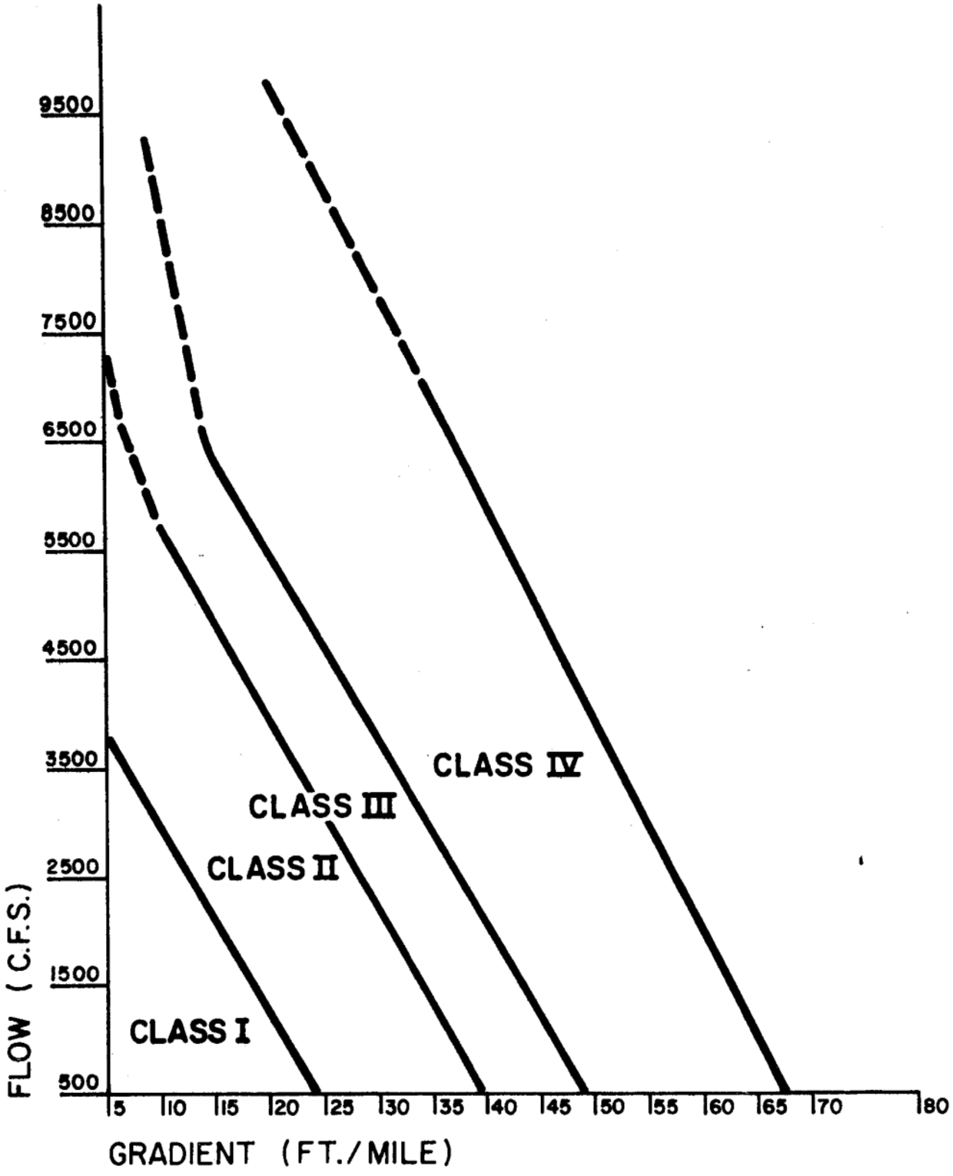
Width needs to be 25 feet

For white-water rapids you use the chart

Bureau of Outdoor Recreation



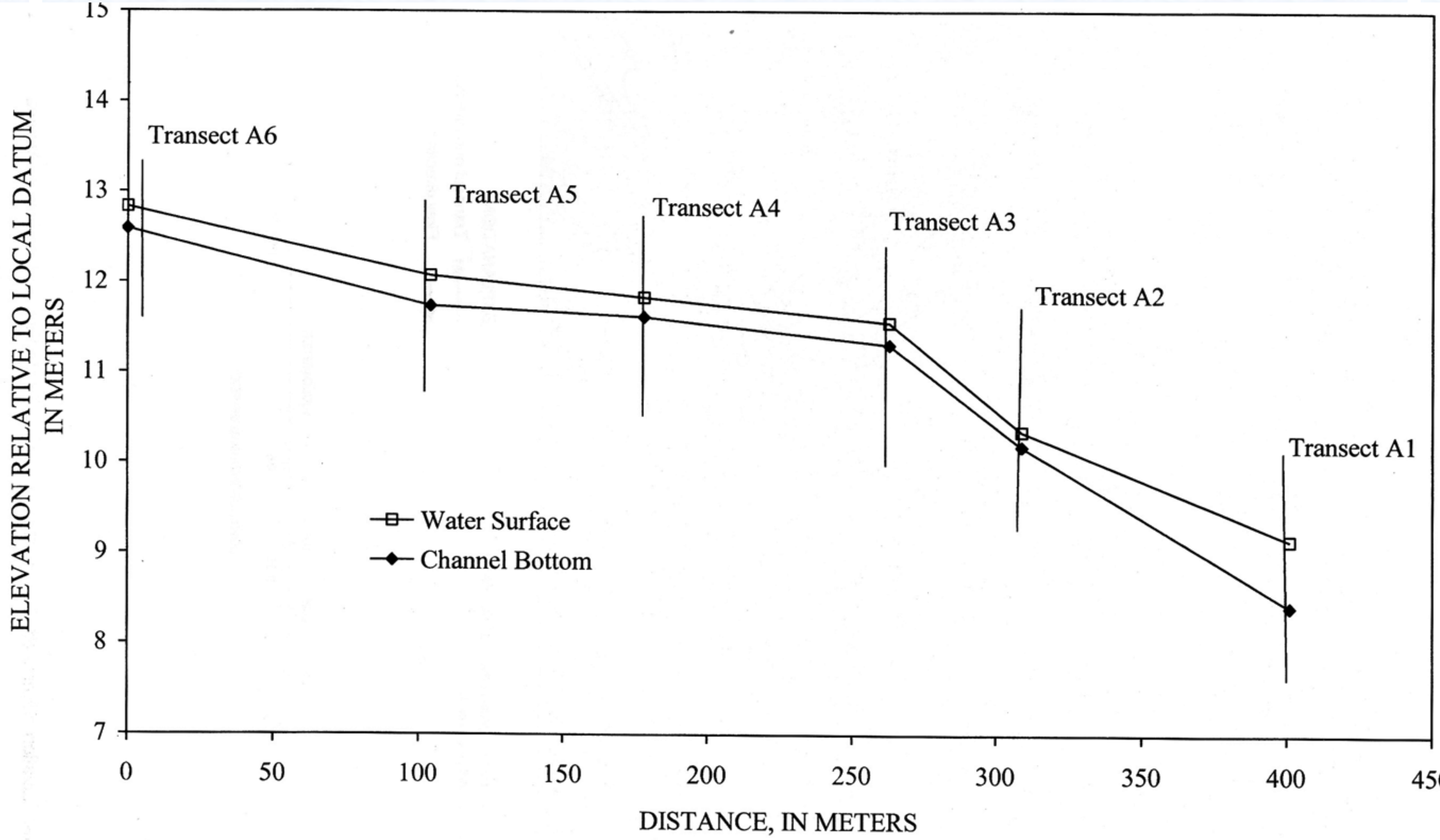
Class I - Very Easy. Waves are small and regular, passages are clear. Obstacles are sand bars, bridge piers, and riffles.



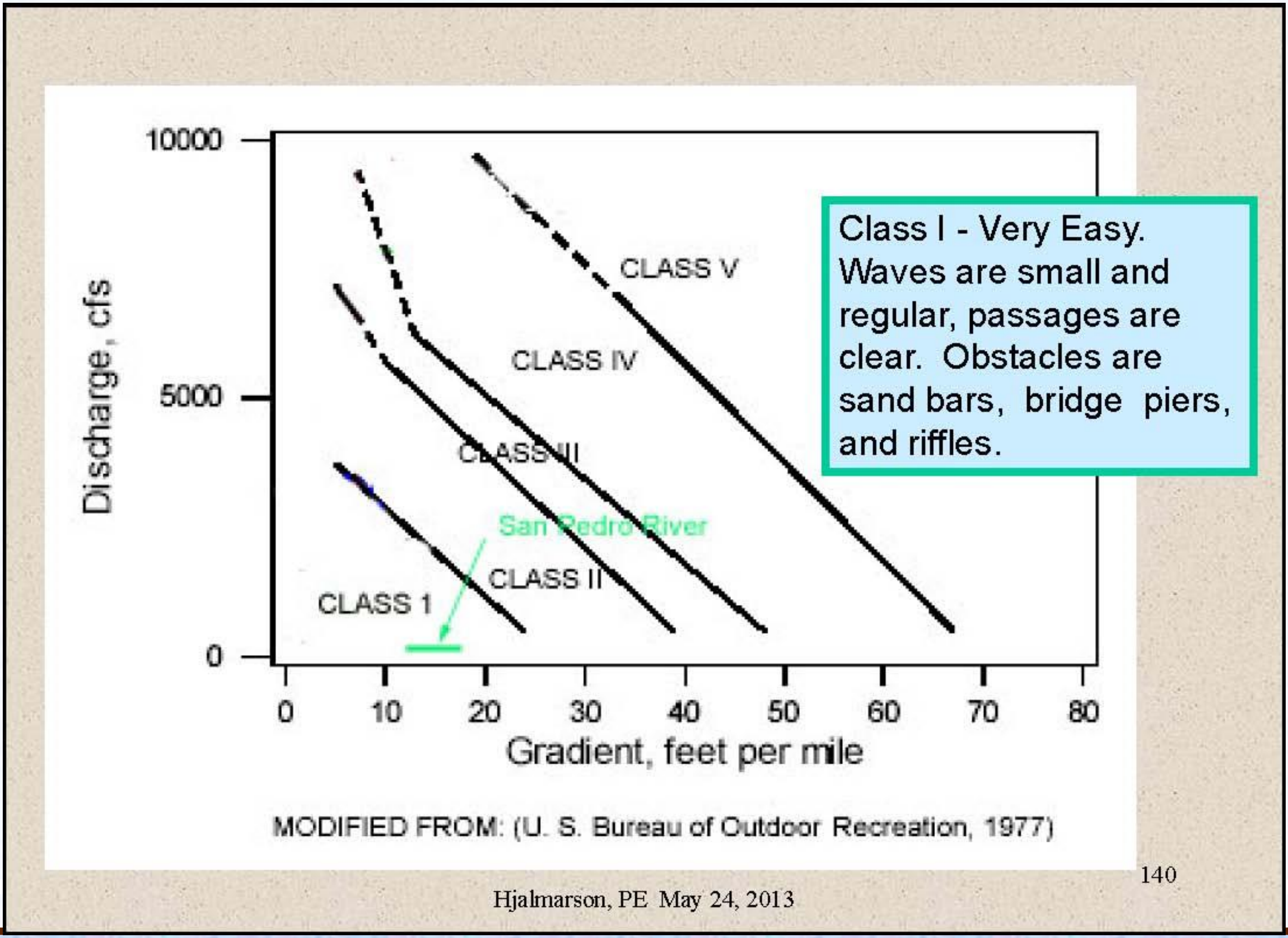
ESTIMATING RIVER DIFFICULTY
(Assumes Fairly Even Gradient)

AFTER ARIGHI AND ARIGHI, 1974

Near Charleston



Bureau of Outdoor Recreation



Class V

- Very Difficult. Rapids are long and very violent, following each other almost without interruption. The riverbed is extremely obstructed with large drops and violent currents.

Cooperative Instream Flow Service Group

- The method is for recreational boating not commercial
- “The approach is based on the assumption that a single cross section, properly located, can define a minimum flow requirement. Such a cross section is located at an area displaying the least depth across the entire stream.”

Commercial Canoe

- Carrying weight makes the canoe ride lower
- Pinkerton in 1914 said 19 inches for a freight canoe
- Army Corps says draft should only be 75% of river depth
- Requires depth of 25 plus inches

State of Washington

Table 1. Thresholds of physical river-channel characteristics determined for river flows equal to the mean annual discharge that predicts the navigability potential of a stream or river reach in the State of Washington.

[Thresholds provided by the Washington State Department of Natural Resources (DNR). **Abbreviations**: <, less than; >, greater than; n/a, not applicable]

Channel characteristics	DNR Thresholds — Navigable		
	Probably not	May be depending on balance of factors	Probably
Mean depth, D_h (feet)	$D_h < 2$	$2 < D_h < 3.5$	$D_h > 3.5$
Top width, W_t (feet)	$W_t < 24$	$24 < W_t < 40$	$W_t > 40$
Bottom width, W_b (feet)	$W_b < 18$	n/a	$W_b > 18$
Gradient or slope, S (feet/foot)	$S > 0.0047$	$0.0019 < S < 0.0047$	$S < 0.0019$

Langbein Method

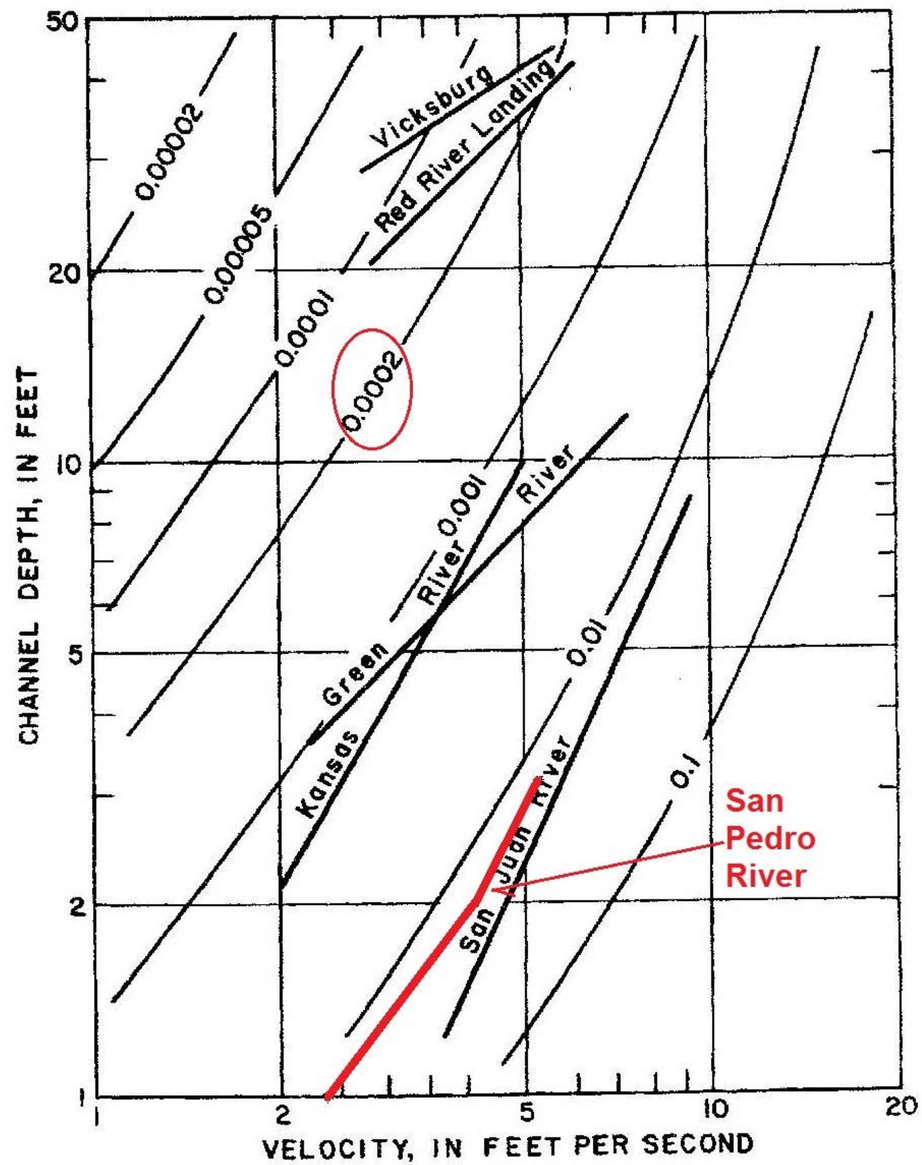


FIGURE 13.—Depth-velocity curves for several rivers in relation to minimum specific tractive force required for upstream navigation.

Army Corps of Engineers as Directed by Congress

1866	4	feet deep	Upper Mississippi
1878	4.5	feet deep	Upper Mississippi
1896	9	feet deep	Lower Mississippi
1907	6	feet deep	Upper Mississippi
1907	6	feet deep	Lower Missouri
1910	9	feet deep	Ohio

Summary of Key Flows

Depth	Hjalmarson	Gookin
1 feet	19 cfs	96-905 cfs
2 feet	191 cfs	1000+ cfs
3 feet	915 cfs	1000+ cfs
4 feet	1000+ cfs	1000+ cfs
6 feet	1000+ cfs	1000+ cfs
Width		
25 feet	41 cfs	39-41 cfs


Charleston 6.5 CFS