Navigability of the Salt River

by

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EXECUTIVE SUMMARY

The Salt River has been divided into 6 segments by Mr. Fuller. I agree with Segments 1-5. Segment 6 should be divided into 2 segments being upstream and downstream of the Old Mill Avenue Bridge. These segments I call 6a and 6b.

The decisions by the Courts lay out what is in essence a checklist. The first question is was the river navigated as the term is defined by the Courts. There is no evidence that the Salt River was navigated by the Archaic Indians or their successors, the Hohokam. The Pimas did not successfully navigate the Salt River. Fuller lists many later trips by Anglo-Americans but none of those trips meet the criteria set forth by the courts. A summary of my findings concerning the Anglo-American trips is presented in Figure ES-1.

If a river was not navigated then the next question is, was there a reason to navigate. There was clearly the need and the wherewithal to navigate the Salt River, if the Salt River had been navigable.

If there was no reason to navigate, then it is necessary to make a hypothetical hydrologic determination of navigability. The Utah Court determined, based on watercraft that were available shortly before Arizona's Statehood, that a mean depth of 3 feet is required. Ordinary and natural flows of the Salt River are significantly below a mean depth of 3 feet.

Modern day recreational boats, due to the tremendous differences in boat materials, are not meaningfully similar to the watercraft used at the time of statehood.

The Salt River had many obstacles that also prevented navigability. These included marshes, sudden floods, beaver dams, and rapids.

Summary of Problems With Historic Trips on the Salt River										
	Year	Above Ordinary Flow	Trip was Too Short	Was the Reach Boated	Did the Trip Occur	Dragged or Used Canals	Recreational	Vague Account	Succeeded	Comment
Segment 1-2										
Hayden	June 1873								No	
Segment 3										
Meadows	1883							Yes	No	Probably was the Burch Trip
Burch	June 1885			Unknown					No	Inconsistent Information
Thorp & Crawford	June 1910					Yes			No	Source Not Disclosed
Ensign & Scott	June 1919								No	Not Natural Flow
Segment 4-5										
Meadows	1883							Yes	No	Probably was the Burch Trip
Burch	June 1885								No	
Hudson	June 1893			No					No	Not on the Salt River
Thorp & Crawford	June 1910								No	Source Not Disclosed
Ensign & Scott	June 1919	Yes							No	Not Natural Flow
Roosevelt Freight	April 1905		Yes			Yes				
Segment 6										
5 tons of Wheat	May 1873		Yes							
Hamilton	June 1879	Probably					Yes			
Stewart	Oct 1880				Unknown					
Cotton & Bingham	Feb. 1881				Unknown					
Yuma or Bust	Nov 1881					Yes				
Wilcox & Andrews	Feb 1883	Probably		Partially			Yes			Slower than walking
Meadows	1883			Partially	Unknown	Yes				Probably was the Burch Trip
Burch	June 1885			No		Yes			No	Reporting is flawed
Spaulding	Dec 1888	Probably	Yes				Unknown			One person killed
Sykes	1890's	Possibly				Yes	Yes	Yes	No	
JK Day	Spring 1892					Yes				Reporting is flawed
JK Day	Unknown	Probably						Yes		
Robinson	1893							Yes		Source is questionable
Adams & Evans	Jan 1895	Probably		Partially				Yes		Source Not Disclosed
Gentry & Cox	Jan 1889	Yes								
Advertisement	May 1905				Unknown					
USRS	Dec 1905								No	
Shivley	1887	Yes							No	
Rains	April 1909	Probably	Yes				Yes			
Selly	1909				Unknown					
Thorp & Crawford	June 1910			No		Yes				Source Not Disclosed
Ensign & Scott	June 1919	Yes		No		Yes				Not Natural Flow

Figure ES-1

I. INTRODUCTION

This report was prepared on behalf of the Gila River Indian Community ("Community"). The Gila River Indian Community is a federally recognized Indian tribe and occupies the Gila River Indian Reservation ("Reservation"). This report is being prepared at the Community's request for presentation to the Arizona Navigable Stream Adjudication Commission ("ANSAC") for its use in determining the navigability of the Salt River.

The Northwest corner of the Reservation is located in central Arizona at the confluence of the Salt and Gila Rivers. The Reservation runs easterly from that confluence point, primarily along the Gila River. The Salt River is the boundary on the Northwesterly portion of the Reservation in Township 1 North Range 1 East (see location map, Figure I-1).

In addition to these major watercourses, there are several lesser washes and watercourses on the Reservation. The Vekol and Santa Rosa Washes with watershed areas to the south of the Reservation merge with the Santa Cruz River on the west end of the Reservation. The McClellan Wash enters the Reservation in the southeastern corner and meets the Gila River north of Sacaton. A variety of unnamed washes and drainage courses also carry stormwater from the Reservation's mountains to the larger watercourses.

The Gila River Indian Reservation was created by an Act of Congress in 1859. Subsequent expansions to the Reservation through Executive Orders in 1876, 1879, 1882, and 1883 brought the Reservation to a size approximating the current boundaries. Minor changes were made in the boundaries of the Reservation during the period 1911 through 1915. These changes left the Reservation with its current boundaries (see Figure I-2).

The Gila River Pima-Maricopa Indian Community was formally organized on May 14, 1936, pursuant to the Indian Reorganization Act of June 18, 1934 (48 Stat. 984) as amended by the Act of June 15, 1935 (49 Stat. 378). An amended Constitution and Bylaws of the Community was approved on March 17, 1960 and the name was changed to the Gila River Indian Community. The Community is governed by the Gila River Indian Community Council.

A. LEGAL CRITERIA

Several court cases are of importance in determining the navigability of the Lower Salt River. The first is the Daniel Ball Decision (Daniel Ball Decision).[1] The three primary cases I discuss subsequent to the Daniel Ball Decision are *State v. Arizona Navigable Stream Adjudication Commission*[2]

[1] 77 U.S 557. Daniel Ball Decision.
[2] 224 Ariz. 230. Arizona Appellate Decision.

(“Arizona Appellate Decision”), *PPL Montana, LLC v. Montana*[3] (“Montana Decision”), and the *United States v. Utah*[4] (“Utah Decision”). These decisions lay out certain key concepts that will be addressed in the chapters following.

The fundamental navigability test is a factual inquiry as to whether or not trade did occur through the use of rivers. The concept of historic navigation is addressed in chapter II.

The Utah Decision addressed the concept of susceptibility of navigation which, in essence, suggested that just because navigation didn’t occur, does not inherently mean that the river was not navigable, if there was no reason to navigate the river. The concept of whether navigation was needed is addressed in chapter III.

The pro-navigability parties have introduced considerable evidence, based on modern recreational boating to demonstrate that navigation was possible under "ordinary and natural" conditions in 1912, as defined by the Arizona Appellate Decision. Under the U. S. Supreme Court's Montana Decision, the use of modern recreational boating as a basis for navigability requires that the modern recreational boating be demonstrated to be

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[3]132 S.Ct. 1215. Montana Decision.
[4]284 U.S. 64. Utah Decision.

meaningfully similar to commercial craft used in 1912. Chapter IV addresses the question of whether modern Boats are meaningfully similar.

A basic question created by the Court cases is whether the river channel was the same in the 1800s, or today, as it was in 1912. The channel shapes are discussed in chapter V.

The pro-navigability parties have claimed that the depth of water in the rivers prove that the rivers were susceptible of navigation. The Arizona Appellate Decision provides a definition for “ordinary” and a definition for “natural”. The concept of “ordinary” primarily relates to the hydrology of the river. “Natural” has more to do with the channel itself. What is the channel in its natural condition? These two topics lead to a determination of the "ordinary and natural" depth of flow as of Statehood. These hydrologic concepts are addressed in chapter VI.

Finally, there are navigational barriers that are not covered in the above chapters. These barriers are addressed in chapter VII.

Many of the topics that are before ANSAC on the Salt River are general topics that have already been addressed in previous reports. The conclusions for those topics will be repeated with references to where the evidence and discussion was presented earlier.

B. SEGMENTATION

The Montana Decision provides guidance relating to how the river is to be segmented. I have not devoted an entire chapter to this because I have not seen that this is particularly important for the Salt River. However, the Salt River does have, based on the basic geomorphology of the reach, certain very clear and distinct reaches that probably should be considered separately.

The Salt River is best divided into seven segments. Mr. Fuller provides a map of the segments in his Salt River Navigability PowerPoint.[5] I have no problems with the first 5 segments. Fuller's map shows the Lower Salt River as one segment called segment 6. The Lower Salt River as shown on Fuller's map should be subdivided into two segments. The first segment should be from the junction of the Salt and Verde Rivers down to the Old Mill Avenue Bridge (aka Hayden's Ferry).[6] The second segment should be from the Old Mill Avenue Bridge down to the Gila and Salt River confluence. The first, or upstream, segment of the Lower Salt River I will refer to as segment 6a. The second, or downstream, segment of the Lower Salt River I will refer to as segment 6b. The line of mountains including Mummy Mountain, Camelback Mountain, Papago Buttes, Tempe Butte

[5]Fuller 2015b, Slide 48. Fuller has one typographic error on his PowerPoint slide 48. There are two segment ones and no segment 3. It is obvious from the rest of his PowerPoint that the segment 1 nearest Roosevelt Dam is segment 3.

[6]A short distance downstream from the present day Old Mill Bridge there was an even older bridge that is now gone. When I am referring to the Old Mill Bridge, I am not referring to the even older bridge that has been removed.

(aka "A" Mountain), and the South Mountains are a surface expression of a major bedrock barrier that generally separates the groundwater associated with segment 6a from segment 6b. The Old Mill Bridge is located where it is because it could be tied into the bedrock that underlies the Salt River. This is a major reason why the Old Mill Bridge withstood the floods of the 1970s and 1980s when so many others failed.

I believe that this division is necessary for a proper discussion of the base flows of the Lower Salt River. Absent the upstream dams on the Upper Salt River and the diversions on the Lower Salt River, the low flows of the Lower Salt River are impacted by the subsurface geology. When the Verde and Salt Rivers joined, their water headed westerly into segment 6a. Segment 6a is a highly porous river bed. The upper portion of segment 6a of the Lower Salt River was a losing stream.[7] When the underflow in the groundwater basin associated with segment 6a approached the bedrock barrier near the Old Mill Bridge, the water would rise back to the surface and supplement the surface flow at that location. Once the surface flow leaves the bedrock barrier near the Old Mill Bridge, it enters segment 6b and the process in 6a repeats itself. Surface water once again percolates into the groundwater. In segment 6b, this water reemerges downstream but not exclusively on the Lower Salt. Some of the water went South around

[7]Thomsen and Porcello, pg 25.

the East end of the South Mountains and some of that water reemerges on the West end of the Middle Gila River (on the Gila River shortly upstream from the Salt/Gila Confluence). Some of the underflow from the Middle Gila River, the Lower Salt River, and other smaller rivers such as the Agua Fria River reemerge below the Salt/Gila Confluence. Some of the underflow along the Lower Salt River reemerges as the water approaches the Confluence. Other factors such as consumption of water by native phreatophytes (primarily mesquite) and in later years non-native phreatophytes (primarily Salt Cedar aka *Tamarisk*) affect the amounts of water returning to the surface flow of the Lower Salt River in both segments 6a and 6b.

C. CONCLUSION

This report will primarily deal with the Lower Salt River, and emphasize Segment 6b, which is the segment on which the Northwestern boundary of the Gila River Indian Reservation lies. Many of the issues to be discussed I have already discussed at length in the reports and hearings concerning other rivers. In those cases I will limit myself to statements of my findings with citations to the detailed analysis already presented.

II. NAVIGABLE IN FACT

The primary facts normally used by the Courts to determine navigability is whether or not the river has actually been navigated for commercial purposes historically. If the river has been successfully navigated under the conditions set forth in the Court decisions, then it is navigable in fact and it is legally navigable. If the river has not been successfully navigated, generally speaking, the river is not navigable. There should be little argument that the Salt River is not navigable in fact. As Mr. Fuller stated in 1996:

> There is no evidence that sustained trade and travel ever occurred on the Lower Salt River, nor is there documented evidence that trade or travel in the upstream direction occurred on the river.[1]

The Utah Decision expanded on an exception to that rule--that is if it can be demonstrated that there was no need to navigate the river then the lack of historic navigation does not prove or disprove navigability. This rule simplifies to: was there a reason to conduct trade and would that trade have been facilitated by a water route?

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[1]CH2M Hill pg. *v*.

There are three periods of history to be considered with regard to navigation in fact. These are the Archaic and Hohokam occupancy, the Pima/Maricopa occupancy, and the European occupancy.

A. THE ARCHAIC AND HOHOKAM OCCUPANCY

The Hohokam culture extended over a large area of southern and central Arizona and was a long-lived hydraulic (based on irrigation) civilization. ANSAC has written a detailed analysis of the evidence concerning the Hohokam.[2] Most importantly, ANSAC found that no evidence was presented that the Hohokam traveled by water.[3]

The evidence indicates that the area was occupied by hunter-gatherers for thousands of years prior to the agricultural development of the Hohokam. These hunter-gatherers

> ...are called the Archaic people. They subsisted on a wide variety of plant and animal foods, moving frequently over the landscape to hunt and gather the resources available in different places during different seasons. Widespread styles of projectile points indicate that the Archaic people had wide-ranging social and trade networks.[4]

As time went by, the Archaic people began to engage in a type of farming that is now called "Ak-Chin" farming or flood farming. Ak-Chin farming does not rely on canals and diversion of large amounts of water.

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[2]ANSAC 2009, pg 23-29.
[3]ANSAC 2009, pg 27.
[4]BLM 2004, pg 1.

Instead, the farmer looks for an area that has good soil and gets thoroughly inundated during storms. Once the storm hits, the farmer(s) moves into the area and plants short-lived crops such as grain. The Archaic people will either leave the area or leave a few people to protect the food from animals. The Archaic people hunt and gather other supplies and return for the harvest. The process then repeats. Ak-Chin farming has little impact on water supplies and, what impact it does have, is felt in the wet periods not during the dry periods. Ak-Chin farming marked the end of the Archaic period and the beginning of the Hohokam period.

As populations grew, the Hohokam began development of canals and farming. Yet during the thousands of the years when the Archaic and early Hohokam societies grew, they traded. No evidence had ever been presented nor can I find any evidence of canoe or other boat-based travel by these cultures.

There is a rumor that an early archeologist named Frank Cushing may have found a Hohokam canoe near one of the Hohokam canals.[5] Apparently, there was a Hohokam site that, when different archaeologists studied it, received differing names. Archaeologists believe that the name "*Las Canopas*" was given to the site by Frank Cushing in 1887. The term *canopas* translates to water-worn river rock. However, some archeologists

[5]Hackbarth, pg 2.

hypothesize that, if Mr. Cushing misspelled the name he gave the site and it should have been written "*canoas*" instead of "*Canopas*", then it might be a reference to a prehistoric canoe found by Cushing. If true, this indicates that the Hohokam may have traded internally, using their canals. It tells us nothing about use, if any, of the Salt River.

B. PIMA-MARICOPA OCCUPANCY

No one is certain when the Pimas originally entered the Middle to Lower Salt River Valley. The Pimas believe they were descendants of the original Hohokam who survived whatever disaster collapsed the Hohokam civilization in the mid 1400s. Certainly much of the Pima culture mirrored the Hohokam culture. We know however that by 1699, the Pimas were established in the region.[6] The Maricopas came into the area later, formed a confederation with the Pimas, and primarily settled in the area around the confluence of the Salt and Gila Rivers. Originally the Pimas practiced Ak-Chin type farming, and traded for a considerable period before beginning their classical canal farming. Even when farming by canals, as documented in my Gila River report, the Pima and Maricopa impact on the river flows would have been minimal. Despite contemporaneous records, the only case where a boat was used was the one failed attempt of a military party

[6] ANSAC 2009 pg 31.

to ferry across the Salt River. The Pima-Maricopas did trade but chose to walk or run rather than use the rivers for boating.

The Pimas and Maricopas did trade with distant parties. Much of this trade is documented in my Gila River Report.[7] The Pima and Maricopas traded as far away as Santa Fe.[8] They hosted annual trade fairs.[9] "The Pima knew the value of trade."[10]

The Lower Salt River was part of the aboriginal land of the Pima-Maricopa Confederation. In the early 1800s, due to an ongoing war with the Apaches, the Confederation retreated to the Middle Gila River and the portion of the Salt River in the immediate vicinity of the Salt-Gila Confluence. This was done to allow a better grouping and enable a quicker response to Apache raids. Bartlett recorded that in 1854 the retreat of the Pima-Maricopa Confederation had already occurred.[11] In 1872, many of the Pimas returned to the portion of the Lower Salt River that is now the Salt River Pima-Maricopa Indian Reservation to use the available water.

I believe the lack of boating by the Pimas is very important. Fuller wrote in 1998 about the Colorado River. He indicated that "[b]oats were

[7] Gookin 2014b, Chapter IV pg. 4-8.
[8] DeJong, pg. 11,
[9] DeJong, pg. 14,
[10] DeJong, pg. 19,
[11] Bartlett, pg 215.

used on the Colorado River long before the arrival of the Spaniards."[12] Fuller goes on to explain how the various boats were built. The reason he can make these statements is that, as Fuller points out later on the page, the Spaniards recorded the information when they explored the area.

The Spaniards also visited the Pimas and never recorded the use of boats or canoes. These early Spaniard visits occurred before the Pimas built canals to irrigate. In the early period, before the Apaches arrived, the Pimas lived by the Salt River. The Rivers were in their undepleted condition. There is no evidence of boats. The Pimas would have seen the boats floating on and across the Colorado River during their trading. The Maricopas had originally been located on the Colorado River and, after losing a war with other local tribes, migrated up the Gila River and entered into a confederation with the Pimas.

C. EUROPEAN OCCUPANCY

The first explorers to the area were the Spaniards. Fuller indicates that the Spaniards "... proceeded up the Colorado River probably not much farther than the mouth of the Gila River ... in smaller ship's boats of various types - rowboats or canoes."[13] The rivers were undepleted at that time. If the Lower Gila River was not capable of being navigated, then it is

[12]Stantech, pg 20.
[13]Stantech 1998, pg 21. .

improbable that as you move upstream the river would become navigable. The Salt River was only about 75%[14] of the flow of the Lower Gila River.

The balance of this section deals with the activities of pre-development conditions along the Salt River during the mid to late 1800s. Fuller proposes extremely liberal criteria for categorizing a boating event as a successful trip and a basis for navigability. Specifically, Fuller indicates that if the boat makes it, one-way, to the downstream point, intact, although patched, with a passenger, only somewhat the worse for wear, and with a portion of the cargo still remaining, then the voyage was a success.[15]

Fuller also indicated that as long as there is a record that somebody intends to do something and there is no record that they either did not attempt the action or failed in their attempt, you must conclude that it succeeded.[16] When I took logic, I learned that this type of argument is called an *argumentum ad ignorantiam.* I do not mean this as an insult. It is the name applied to this specific type of logical fallacy. The *ad ignorantiam* argument is an "appeal to ignorance". Specifically it is "the fallacy that a proposition is true simply on the basis that it has not been proved false... .

[14]U.S. Bureau of Reclamation, pg.192, 194.The virgin average flow of the Salt River was about 1,423,800 million acre-feet per year. The Middle Gila's virgin average flow was about 546,800 million acre-feet per year. 1423800/(1423800+546800)=72% which I rounded up to 75%.

[15]Fuller 2014b, slide 121.

[16]ANSAC 2014a, pg 496 and Fuller 2014b, slide 123.

This error in reasoning is often expressed with influential rhetoric."[17] Fuller indicates that assuming success in the absence of evidence is "good science."[18] That is absurd. Good science requires repeatable experimental proof. In science, the absence of evidence means the absence of a reasonable hypothesis. Current day science operates on the "scientific method" which is driven by evidence and not absence of evidence.

I believe that for a trip to be considered proof of navigability, it must meet additional standards established by the Courts. The individual cases are discussed below.

1. Efforts to Navigate on the Upper Salt River

Fuller presents six accounts of attempted boating in the Upper Salt River (segments 1-5). None of the accounts involve segments 1 and 2 except for the 1873 Hayden attempt that Fuller admits was a failure. I will use the shorthand labels and dates that Fuller uses in his PowerPoint as headings.[19]

Hayden (June 1873)

Mr. Hayden attempted to use a canoe on the Salt River in order to develop his plan of floating logs down the Salt River. As Hayden tried to canoe back to Phoenix in his canoe, he first lost all his supplies due to

[17] philosophy.lander.edu.
[18] ANSAC 2014a, pg 496.
[19] Fuller 2015b, slides 208-211.

"...rapids and boulders." As Hayden progressed through, the Salt River Canyon became too narrow for the canoe. Hayden had to abandon the canoe and walk home.[20] This trip was a failure.

Meadows (1883)

Fuller misstates the account in his PowerPoint. The flat boat was not able to clear the rapids. The individuals rolled rocks into the river to raise the water high enough to allow the boat to float off.[21] This account was published 26 years after the event. It seems likely that it is really referring to the same trip as the Burch trip, which I discuss next. If Meadows is a separate event, it does not prove a navigable river due to its failure and the lack of information to show the flow was normal.

Burch (June 1885)

The log from the trip was reprinted by the Daily Phoenix Herald.[22] The log indicates that "...the "'box canyon of Salt river,' below the mouth of Tonto Creek, has never been explored from the river's course..."[23] This trip also included Jim Meadows[24] who had allegedly already made the trip only two years earlier in 1883 and had to have known better.

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[20]Arizona Weekly Miner, no page.
[21]SFC Engineering Company, pg 34.
[22]Daily Phoenix Herald 6-5-1885, no page.
[23]Daily Phoenix Herald, no page.
[24]Daily Phoenix Herald, no page.

On the trip, the boat did manage to pass over "swift and dangerous rapids" and "Cascades and falls, occasionally from four to six feet high,..." [25] The boat then got stuck on a large rock, capsized and they lost "much of their supplies".[26]. The narration does not seem plausible, specifically the article stated, "the fish were so thick the boat floated on their backs."[27] The article also indicates that "[t]hey expected every minute to strike a waterfall...". If this was Mr. Meadows' second trip, then Meadows would have had some idea of where the waterfalls were and should have known that you can hear them ahead of time. This trip, according to the news articles, was to prove that logs could be floated from the Four Peaks area or the Sierra Anchas area to Phoenix or Tempe, depending on the article. I would infer from the various articles that Segment 3 was not involved,[28]although the accounts are not clear or consistent. No evidence is presented that the trip did succeed in its goal of causing successful log floats to Tempe (or Phoenix). This does not prove a navigable river.

Hudson River Company (June 1893)

A canvas boat was tried and overturned, the occupants were thrown in the river, and when the boat was recovered, the boat's structural integrity

[25]Daily Phoenix Herald, no page.
[26]Arizona Gazette 6-6-1885, no page.
[27]SFC Engineering Company, pg 35.
[28]Based on my examination, using Google Earth, of the locations of the two different areas listed as a source of the logs to be floated.

had been compromised. The article says that the trip was from some diversion dam to the exit from Tonto Basin. This trip occurred on Tonto Creek, not the Salt River.[29] This trip should be deleted or called a failure.

Ensign and Scott (June 1919)

Mr. Ensign made a trip in June 1919. Since Roosevelt Dam had been built by then, the trip would have been made at a time of very high flow, because the dam would have been releasing large amounts of water to meet the high demands of the farmers downstream. Portages were required and the canoe flipped several times.[30] This trip was not in its natural condition and was a failure.

Roosevelt Freight (April 1905)

The referenced article indicates that a road was needed because of the transportation problems. The people headed up to the Roosevelt Dam site and had to carry some of the supplies and haul the boats up the river. The trip was only 4 miles. The trip sounds very similar to the Supreme Court's admonitions that 1) "Mere use by initial explorers or trappers who may have dragged their boats in ... the river... is not itself enough."[31] and 2)

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[29]The Arizona Republican June 2, 1893, no page.
[30]Fuller 2015b , slides 196, 197.
[31]Montana Decision pg 21-22.

"...neither can that susceptibility be so brief that it is not a commercial reality."[32] This example does not demonstrate navigability.

<u>Thorpe & Crawford (1910)</u>

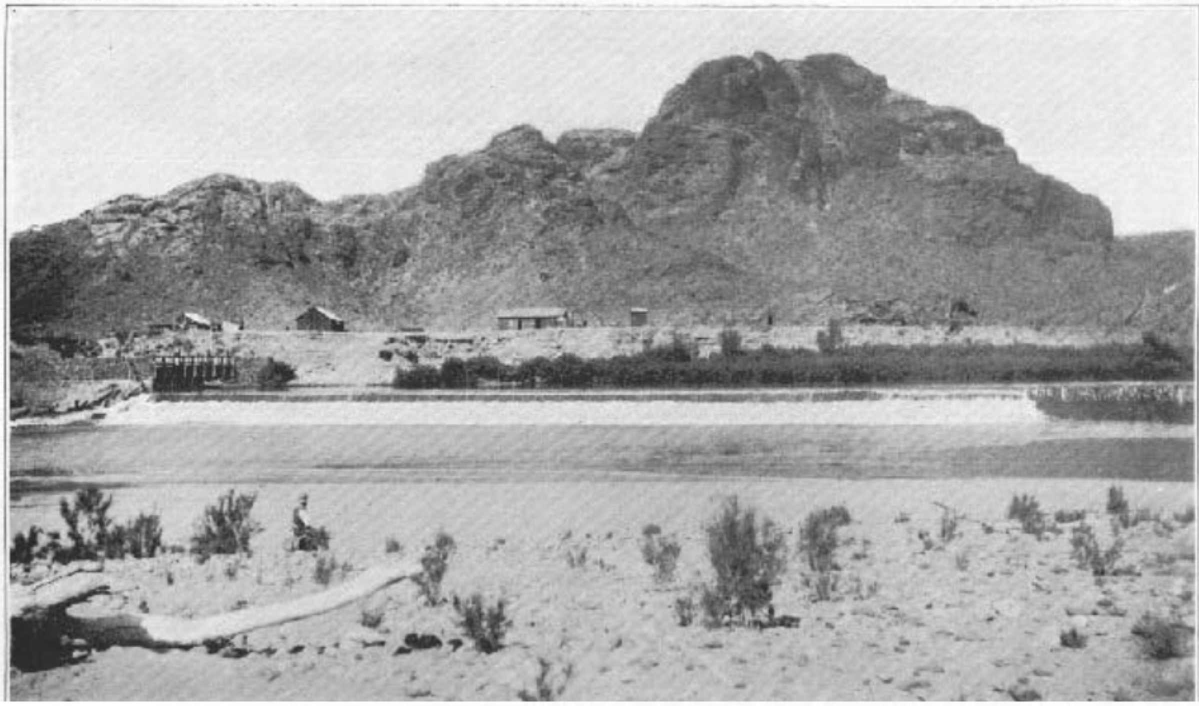
According to Fuller, this trip required portaging and dragging the boat which, as just discussed, does not demonstrate navigability. The boat was damaged.[33] The indicated source (Arizona Republican 6-28-1910) was not disclosed. The only source that discusses a trip in 1910 reported that the individuals wrecked their boat and were barely able to walk out alive.[34] This trip was a failure.

2. Before Significant River Depletions on the Lower Salt

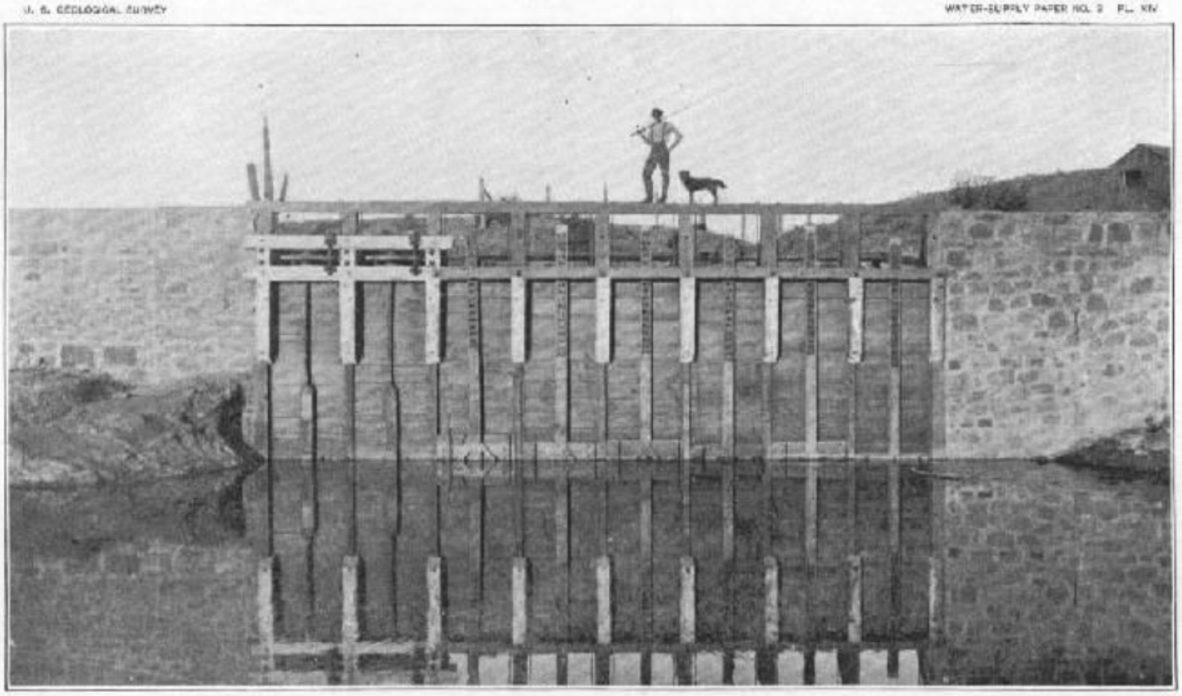
The flow of the Lower Salt River was reduced by the influx of Americans. When did the period that did not have a significant impact on river flows end? It is hard to put a specific year on what was a continuous process. While the process of irrigation development was continuous, we do have a major obstacle that occurred in 1885, the Arizona Dam (Figure II-1). This large diversion dam built downstream from, but near to, the Salt and Verde Confluence had a major impact on remaining river flows in the Lower Salt River. Any effort to navigate the Lower Salt River after 1885 must be examined in detail to determine its veracity. This is not to suggest

[32] Montana Decision pg 24.
[33] Fuller 2015b, slide 195.
[34] Bisbee Daily Review.

U. S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER NO. 2 PL. XI



U. S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER NO. 2 PL. XIV



ARIZONA CANAL HEADGATES.

Arizona Dam - Top Arizona Canal Headgate - Bottom

Figure II-1

Source: Davis 1897

that the Salt River was in its pristine condition before the Arizona Dam was completed. Construction of the first non-Indian canal on the Lower Salt River was started in 1867. Beaver dams were gone or mostly gone by the mid 1800s, as the Arizona Appellate Court stated:

> "...evidence of the River's condition after obstructions cause a reduction in its flow is likely of less significance than evidence of the River in its more natural condition, and may in fact have "minimal probative value,"....[35]

When I was starting my engineering career, I worked on litigation performing the background research to document the value of this region in 1883.[36] As I read many newspapers and books from that period, I found many "facts" that were either great embellishments or out and out lies. For example, when the Arizona Canal was being built, the writers of the era wrote that there was going to be constructed a man-made drop that would rival Niagara Falls in its scope and majesty. Figure II-2 shows the Arizona Falls. You can hear the falls if you go to 56th Street and Indian School Road in Phoenix. There is a small park on the Northeast corner and, in that park, there is a moderate sized building. The Arizona Falls are inside the building. Researching the 1800s is much like using the Internet today. Most computer literate people can find sources to prove virtually anything. You

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[35]Arizona Appellate Court paragraph 31.
[36]I worked on Indian Claims Commission Docket 228.

FALLS ON ARIZONA CANAL

Figure II-2

have to learn to evaluate the source and the reasonableness of what is being reported.

Fuller indicates there were seven attempts before completion of the Arizona Dam which I describe next.

Five Tons of Wheat (May 1873)

This navigation attempt is best called a ferry and, in fact, started at the Hayden Ferry location and went a very short distance along the Salt River to the Swilling Canal. The balance of the trip was on a manmade canal, the Swilling Canal. The river portion of the trip was immediately downstream from the dividing point between segment 1a and 1b and went down to 56th Street.[37] Using Google Earth, I measured the distance as being under 2 miles. As the U.S. Supreme Court indicated "...neither can that susceptibility be so brief that it is not a commercial reality."[38] This trip would seem to meet this requirement. This little sub-reach on the Salt River is not indicative of the overall Lower Salt River due to the underflows being pushed to the surface. This trip does not prove navigability.

Hamilton (Jan 1879)

The source cited (Arizona Republican 10-2-1920) does not discuss Hamilton. It does mention Stewart's trip. I believe Fuller meant the Arizona

[37]ANSAC 2005, pg 5.
[38]Montana Decision, pg 24.

Sentinel on January 25, 1879.[39] If I am right, Fuller's slide 208 should be corrected to be January 1879 and not June 1879. The $10 cost of the skiff is $231.65 in 2015 dollars[40] plus an unknown amount for labor. Hamilton indicated that his boat would require 2 feet of water if goods were to be transported. Hamilton indicated that the channel needed to be modified on the Gila River to eliminate a dangerous boulder in the middle of the River. No streamflow records are available for 1879. Fuller does show that the average flow for a typical January is about triple the median daily flow. I realize this is mixing statistical values. The point is that January, while not as good as February to April, is normally a wet month. Based on the very limited temperature data available it appears that the snow melt occurred early in 1879. The average maximum temperature in Yuma was 80^0 , 90^0 , and 100^0 in January, February, and March respectively. Littlefield points out that within two weeks of the boating trip, the Gila River was "considerably swollen".[41] The trip was apparently made on the rising stage of an early snowmelt. Although Hamilton indicates that goods can be transported, there is no evidence that he ever did attempt that commercial trip. The conclusions were unsupported speculation. The trip seemed to be

[39]Arizona Sentinel January 28, 1879.
[40]in2013dollars.com
[41]Littlefield, pg 127.

recreational. The trip demonstrates that you could float an unknown portion of the Salt River one-way in a good month-if you are not engaged in trade.

One interesting fact that occurs over and over in these early newspaper accounts is that there is a schedule published with stagecoaches, railroads and sometimes Colorado River boat trips. There is also an advertisement for the stage coach and a ferry on the Colorado River.[42] What we do not see are schedules or advertisements for boats up the Gila (or Salt) River. It is not, as is claimed by the pro-navigability parties, that there was nothing to transport. In 1879, the goods transported were worth almost $2,000,000 ($1,942,403)[43].This translates to $44,995,000 in 2015 dollars.[44]

Stewart (October 1880)

The article provides no evidence the trip started or finished. Fuller acknowledges that the success is unknown.

Cotton and Bingham (February 1881)

According to Fuller's source, they "will leave to-morrow." Fuller presents no evidence that the effort was tried or that it succeeded. The success column should be changed to unknown.

Yuma or Bust (November 1881)

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[42]Arizona Sentinel January 25, 1879, pg 3-4.
[43]Hamilton pg 151.
[44]in2013dollars.com.

This is the “Yuma or Bust” effort to navigate that consisted of the boaters pushing the boat down the Salt River.[45] This seems to mirror one of the U.S. Supreme Court's cautions. "Mere use by initial explorers or trappers who may have dragged their boats in ... the river... is not itself enough."[46] The travelers apparently did not complete their trip.[47] The trip was one-way, yet the boat was 20 feet long.[48] It is unlikely that such a large boat could be routinely abandoned and still have a way to have a "highway of commerce" be workable. This trip was a failure.

Willcox & Andrews (February 1883)

This trip only went as far as the Jointhead Dam. The trip apparently occurred during February which is normally the month with the third greatest flow. We know that it rained the night before their final effort. The records of precipitation at Fort Apache which is located in the Salt River Watershed showed 2.46 inches of rain fell that month.[49] We can surmise that the boat was not heavily loaded since they apparently had no tent because the rain bothered them.[50] The trip took 18 hours on the water to

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[45]Fuller 2003b, pg IV-7.
[46]Montana Decision pg 21-22.
[47]CH2MHill , pg 3-20.
[48]CH2MHill , pg 3-20.
[49]USGS 1897, pg 23.
[50]Arizona Gazette, February 14, 1883.

travel about 33 miles or 1.8 miles per hour.[51] This means this trip would have been faster walking. It appears from the tone of the article to be recreational. This trip does not support navigability.

Meadows (1883)

As discussed in the Upper Salt River section earlier in this chapter, the Meadows trip did have major problems on the Upper Salt River. Also as discussed above, the Meadows trip was probably the same trip as the Burch trip. This trip only went as far as the Jointhead Dam unless it went to Tempe in 1885. This description was 25 years after the fact which may explain the discrepancies between the Burch and the Meadows trip. I believe this trip should be eliminated from the list.

3. After Significant River Depletions on the Lower Salt

In 1885, a major event occurred, the completion of the Arizona Dam and the Arizona Canal. This diversion could divert 1,000 cfs into its canal. The water rights in the Lower Salt River expanded dramatically following the Arizona Dam's and Arizona Canal's completion. The Arizona Canal normally diverted all the water and returned the water their farmers did not want into a waste way 2 miles down. This tells me that anybody floating the river had to either 1) do it while Arizona Dam was spilling, 2) carry the boat

[51] Based on 8 miles from Fort McDowell to the Salt/Gila Confluence, twenty miles to Jointhead and an estimated 5 miles to Phoenix Canal. Sources: Google Earth, ANSAC 2005, pg 27 and USGS, pg 50.

for at least two miles, or 3) use the canals. Choice 3 seems to have been the favorite.

Burch (June 1885)

As discussed in the Upper Salt River section earlier in this chapter, the Burch trip did have major problems on the Upper Salt River. This trip is probably the same trip as the Meadows trip. The trip started on June 2, 1885.[52] They arrived on June 4, 1885.[53] The trip is reported to have taken six days.[54] June 2 to June 4 is three days maximum. Different destinations (Phoenix or Tempe) are reported in the news articles.[55] The Burch party must have used a canal because the trip occurred in June and no flood is recorded in June 1885.[56] It is very unlikely that the Burch trip used the Salt River in segment 6. As discussed in the Upper Salt River section on the Burch trip earlier in this chapter, the newspaper reporting of the Burch trip is pretty bad. The trip was a failure and did not occur in segment 6.

Spaulding (December 1888)

The Spaulding trip is the one canoeing event that actually failed to meet Fuller's criteria of no deaths. The death occurred when the two individuals were lifting their canoe over the brush Mesa Diversion Dam,

[52] Arizona Gazette June 3, 1895.
[53] Arizona Gazette June 5, 1895.
[54] Arizona Gazette June 5, 1895.
[55] CH2M Hill, pgs 3-21 and 3-22.
[56] Durrenberger and Ingram, pg 4.

which was below the Arizona Diversion Dam, and a gun accidentally went off. I do not feel that this death was a canoe failure due to water depth but it was a canoe failure caused by the existence of a brush diversion dam. Diversion dams below the Arizona Diversion Dam (i.e. on the Lower Salt) were brush dams and very similar in nature to a beaver dam. Brush dams and beaver dams are cut branches piled in such a way as to impact the flow of water. The difference lies in the existence of a canal to remove the water. A beaver dam usually has water near the top; a diversion dam has sand and silt deposits near the top. In Spaulding's case, the canoe was having its cargo removed to enable Spaulding and his companion to *lift* the canoe over the brush diversion dam. It is important to note that Spaulding's team did not try to drag the canoe over the brush diversion dam as modern day recreational canoeers do over beaver dams. If Spaulding's team was carrying a commercial cargo in addition to their personal supplies, the commercial cargo would also have to be unloaded and reloaded. The commercial materials being transferred would be a significant hindrance if, as the Chapter VII discussion on beaver dams points out, there were numerous beaver dams on the route.

The other problem with the Spaulding historical example of canoeing is that Spaulding covered a very short portion of the Salt River. Spaulding's team left Fort McDowell and ended the trip at the Mesa Canal Diversion

Dam. This canoe trip was a distance of 13 miles, 8 miles on the Verde[57] and five on the Salt.[58]

The Spaulding trip occurred in December 1988. The flow at Arizona Dam varied from a low of 1,665 cfs to a high of 43,489 cfs with a mean of 6,698 cfs.[59] The upper limit for normal flows is slightly under 3,000 cfs. The trip very probably did not occur during normal flow. The Spaulding trip did not prove navigability.

<u>Sykes</u> (1890s)

This is a non-contemporaneous account of a trip that may have occurred at some time during a winter of an unknown year. We know as documented in the next two entries for J.K. Day, that there were many days with flows well in excess of normal flow. Sykes' canoe trip was purely recreational; they had to carry or drag the boat over dry reaches and also capsized the boat.[60] The trip does not prove navigability.

<u>J.K. Day (1892)</u>

This is based on an article that has problems. First, the two Day brothers left on September 1, 1891 and arrived in Yuma on March 27, 1892 on a trip reported as being almost 6 months instead of the almost 7 months

[57]ANSAC 2005, pg 27.
[58]ANSAC 2005, pg 6 and USGS 1897, pg 51.
[59]USGS 1897, pg 37.
[60]ANSAC 2014a, pg 197-198.

those dates suggest. The article indicates they arrived in Yuma with a large quantity of beaver and otter. Their boat was small. The amount of supplies a typical trapper carried with them was impressive.

> Each man's equipment generally included a rifle with an extra lock, one hundred flints, twenty-five pounds of powder, one hundred pounds of lead, a powder horn, a double shot bag, a butcher or skinning knife, a tomahawk or shingling hatchet and several traps....[61]

It is true that guns had improved by the 1890s but, if anything, the large amount of ammunition would have weighed more due to their casing than the individual components listed above. Given that the Day brothers would have each carried all that along with some food, camping supplies and their furs, it becomes pretty obvious that at some point these "'trappers appear to have waded or walked' through the river, dragging their boats rather than floating them, ..."[62]. Such a trip has "no bearing on navigability".[63] There are additional reasons to believe the Day brothers did not ride in the boats. The language in the article about the Salt River only says they entered the Salt River. It does not talk about the trip through the Salt River and for good reason. The Salt River would have had many dry spots and perhaps some puddles in that time period. The estimated maximum daily flow for the first month of the trip (September 1891) on the Verde River was 1,231 cfs. The

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[61]Davis, Jr., pg 6.
[62]Montana Decision, pg 22.
[63]Montana Decision, pg 22.

next six months had flows varying from about 800 cfs maximum to under 500 cfs minimum.[64] These flows are based on data at the head of the Lower Salt River Valley, i.e. Arizona Dam. Some of these values were estimated from flows in 1900 by the USGS. According to Judge Kent in the Kent Decree, diversions were pretty much a free for all. "[T]here was no effective attempt to enforce it [the Kibbey Decree] or to distribute water according to its terms." [65] When the Day Brothers got to the Arizona Dam, the Arizona Canal could take at least 1000 cfs of the flow[66] and the brand new Crosscut Canal that tied the rest of the north side listed in the Kent Decree to diversions made at Arizona Dam could take an additional 375 cfs. The decreed demand, if it were enforced, was 1,632 cfs on the north side alone.[67] If any water was returned to the river by the Arizona Canal at its wasteway, the water still had to get by the Highland Canal (capacity 100 cfs), the Mesa City Canal (175 cfs), the Tempe Canal (114 cfs), and the San Francisco Canal (52 cfs).[68] These canals had at least 441 cfs capacity and

[64]Davis, A.P., pg 14, 27.

[65]Kent Decree, pg 6.

[66]USGS 1897, pg 51. The reason I say at least is that 1000cfs was the initial capacity. In 1889 the Crosscut Canal was built (375 cfs capacity) (also USGS 1897, pg 51) that connected the Arizona Canal to the Grand Canal, the Salt River Canal and the Maricopa Canal.

[67]Kent Decree, table 10 converted from miner's inches to cfs at 40 miner's inches per cfs. This did not include the "B" rights that may have been farming in 1891-2.

[68]USGS 1897, pg 51-53.

had a decreed demand of 1,218 cfs as of 1891.[69] With only 500 to 800 cfs available before any diversions happened, and an ability to divert two to three times that amount of water, what water is left for floating the boat?

The Day brothers traveled during the winter months. Why do I believe the canal companies would divert all the water in the river? There are very good reasons to divert in the winter. In the Salt River, many crops such as vegetables and grains do best through the winter months. Farmers would have also had alfalfa or other hay crops that just love water. Finally, there was leaching of salts and banking the water in the ground when they could get it, so that the soil would start the growing season wet. The USGS estimated in a study for building dams on the upstream rivers that the demand for water in the months of November to February was 55% of the demand in the peak months of May and June.[70] The total Decree demand was 2,850 cfs. With a 55% winter demand, that indicates a water requirement of about 1,500 cfs (rounded down) or almost twice the flow available on the best day. The Salt River was probably muddy to dry in most spots. More likely than wading or walking through the river, the Day brothers took the canals. J.K. Day and his brother did not navigate the Salt River in 1892.

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[69]Kent Decree, table 10 converted from miner's inches to cfs at 40 miner's inches per cfs. This did not include the "B" rights that may have been farming in 1891-2.

[70]Davis, A. P., pg 31.

J.K. Day-(Unknown)

I changed the dates in this heading to unknown because, when you read the article all we know is that Mr. Day, with or without his brother or other people, left in unknown years, unknown months, and traveled on unknown days arrived in Yuma on unknown dates taking rivers or canals or walking or possibly navigating the rivers. Assuming, Fuller's assumption that Day did the trips in the four immediately preceding winters, then Day was lucky in that the 1888-1889 winter had mean flows of 6,698 cfs in December, 5,947 cfs in January, 8,745 cfs in March and 3,975 in April.[71]There were many, many days when the flows were greater than the approximately 3,000 cfs Fuller indicates for the upper limit of the "ordinary and natural flows" .[72] In March, the minimum flow for the month was over 3,000 cfs. The winter of 1889-90 had average monthly flows far in excess of 3,000 cfs and a February maximum of 143,288 cfs.[73] The winter of 1890 to 1891 had average monthly flows over 3,000 cfs beginning in November and going through February.[74] March and April are not recorded. All of the above floods were from snowmelt not monsoons. That means they rose and fell comparatively slowly and gave the Day brothers plenty of

[71]USGS 1897, pg 37.
[72]Fuller 2015b, slide 228.
[73]USGS 1897, pg 37.
[74]USGS 1897, pg 37.

opportunity to pick nice high flow days for their transit. The other trip supposedly occurred in the winter of 1887-1888. We have no flow records for that period. The rain gage at Fort Apache in the upper end of the watershed suggests there were significant periods of high flow. Beginning in September 1887, the monthly rainfalls were 2.23 inches, October 0.55 inches, November 1.83 inches, December 0.57 inches. In 1888, January rainfall was 1.42 inches, February 1.83 inches, and March 2.92 inches.[75] The information is too sparse to prove anything.

Robinson (1893)

The report is supposedly an account of Robinson's trip. The source is unknown since Robinson was shot to death after reaching the Colorado River. This trip occurred in an unknown month of 1893 from an unknown point in Phoenix using an unknown type of boat with an unknown cargo. The trip is being retold 16 years later by an author whose apparent source is somebody from Guaymas who was told by the sole survivor. How the story got back to the newspaper reporter in Bisbee is unknown. This trip demonstrates nothing regarding navigability.

Adams & Evans (January 20 to February 17, 1895)

[75] USGS 1897, pg. 23.

This report is unclear as to where on the Salt River it started. January and February are not months of low flow as indicated by Fuller.[76] According to Fuller, the average flow in January and February are the 4th and 3rd wettest months generally. However, we do have maximum minimum and mean flows for those two months in 1895. January 1895 had a maximum flow of 46,806 cfs on the Salt River alone and 33,000 cfs on the Verde. The sum of the two rivers had an average flow of 9427 cfs. The minimum flow was 1271 cfs. February 1895 had a maximum flow of 9897 cfs and average flow of 3061 cfs. The minimum flow was 951 cfs.[77] January and February 1895 were a very wet two months with many of the flows in the flood range. The source documents referenced by Fuller have not been disclosed. Without seeing the source documents, I can conclude that best they can demonstrate is that you can navigate during floods.

Gentry & Cox (January 1889)

This trip was obviously at a very high flow. The report says the river was flowing at 15 mph[78] (22 feet per second). This occurred in January 1889. The maximum flow that month was 23,456 cfs. The mean flow was

[76]Fuller 2015b, slide 185.
[77]Davis, A. P., pg 15 and 27.
[78]CH2MHill, pg 3-22.

4590 cfs. The minimum flow was 1,565 cfs.[79] Again, this demonstrates that you can navigate during a very high flow or flood.

Advertisement (May 1905)

As Fuller points out in this summary, we have no knowledge of whether or not anything happened.

USRS (December 1905)

This voyage was shipwrecked twice. Fuller acknowledges it to be a failure.

Shively (March 1905)

This trip may have occurred in March 1905 apparently on or right after the 24th (the article's date) and before the 29th.[80] The reason I say "may have occurred" is that the article seemed tongue in cheek. On the days of the trip, the measured flows of the Salt River at Roosevelt varied from 9,895 cfs to 6,000 cfs. On the Verde, the flows at the Fort McDowell gage varied from 5,594 cfs to 2,770 cfs. The flows of the Gila at Dome were from 16,000 cfs to 9,500 cfs.[81]These flows are far greater than the ordinary flow. . Some of the letter from Shively that was reprinted by the newspaper was hard to understand.[82] Apparently, on day one, Shively's ship was

[79]Davis, A.P., pg 15 and 27.
[80]CH2MHill, pg 23.
[81]Murphy and others, pg 44, 46-47.
[82]The Arizona Republican April 3, 1905.

partially submerged for part of the time. "The captain reported having encountered rough water and for a time the boat was semi-submarine." [83] After that start the boat capsized, one of the two boatmen nearly drowned and they lost "most all".[84] The flows were not ordinary. The trip did not succeed.

Rains (April 1909)

Some kids stole a boat in late April 1909. They went joy riding on a stolen boat for a total of 9 miles over two days fighting "shoals and rapids."[85] Fuller calls it travel, it should be classified as recreational, criminal recreational, but recreational. We do not have flow records for 1909 but April is, on average, the second wettest month of the year. The trip was recreational and it did not go far enough to be a "commercial reality" if it wasn't recreational.

Selly (1909)

Fuller admits that we have no idea what was done with the boats. He also is not sure where this boat builder was.

Thorpe & Crawford (June 1910)

[83]The Arizona Republican March 29, 1905.
[80]The Arizona Republican April 3, 1905.
[85]The Arizona Republican April, 29, 1909.

Thorpe & Crawford turned off at Arizona Dam and used the canals for reach 6. It is wrong to consider this trip for reach 6. Other issues with the account are presented above when discussing segments 1-5.

Ensign and Scott (June 1919)

Claiming that segment 6 was navigated is wrong. Granite Reef Dam was built by 1919 and Ensign and Scott floated down the Arizona Canal[86] which diverted from the Granite Reef Dam. Ensign and Scott did not boat down segment 6 of the Salt River. Other issues with the account are presented above when discussing segments 1-5.

[86] Fuller 2015b, slides 196, 197.

III. SUSCEPTIBLE OF NAVIGATION

There are two components to the navigability doctrine (for title purposes). These are: was it navigated or was it susceptible of being navigated. As chapter II discussed, there is no evidence that the Salt River was successfully navigated under the standards set by the Courts. The second component is was it susceptible of navigation? The Utah Decision expanded on this second component. The Utah Decision decided that if it can be demonstrated that there was no need to navigate the river, then the lack of historic navigation does not prove or disprove navigability. This rule simplifies to: was there a reason to conduct trade and would that trade have been facilitated by a water route? In the Utah Decision, the reason navigation was not undertaken in some areas was that there was nobody there with whom to trade.

Mr. Fuller asserts numerous reasons why people did not trade on the Salt River. I am grouping Fuller's reasons into the following categories.

A. Navigation was not needed

B. Navigation occurred but was not reported

C. There were too few people for navigation to occur

D. Too many problems with the river to navigate it

E. Other

A. NAVIGATION WAS NOT NEEDED

Fuller states that it is "[f]aulty [l]ogic [to assume that] [i]f the river was navigable people would have regularly boated it."[1] Fuller goes on to explain that trains provided a cheaper, faster, and safer way to travel.[2] The effectiveness of the trains really does not enter into this legal/factual situation. The Arizona Appellate Decision wants us to look at the river before the river has been significantly impacted by diversions. On the Salt River, the major diversion dam that caused significant impacts was, on the lower Salt River (segment 6), the construction of the Arizona Diversion Dam. The Arizona Diversion Dam was built in the early 1880s. The Arizona Diversion Dam was the first diversion dam that could dry up the river and was a big reason that the first adjudication of water rights on the Salt River (the Kibbey Decision) occurred. Therefore, we should limit our discussion of trade to the period before the 1880s on the Lower Salt River (segment 6).

Prior to the railroad, there were three ways to trade or travel; walk, use an animal (horse, mule, etc.), or use a boat. The Hohokam and early Pimas did not have the horse and walked. By the time the Anglo-Americans arrived,

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[1]Fuller 2015a, slide 68.
[2]Fuller 2015a, slide 71.

there was animal power to ride or to pull wagons. The Anglo-Americans used animal power.

There were good reasons to use boats instead of animal power IF the Salt River had been navigable.

> In 1800, the only practical way to travel and trade across long distances was along the nation's natural waterways. As a result, settlement clung to the nation's coasts and rivers. A few roads connected major cities, but travel on them was difficult and time consuming.[3]

Wagons were an inferior alternative to boats. This had already been established in the Eastern United States. The cost of wagon transport was so high that the state of New York dug a 363 mile canal (the Erie Canal). "For eight years of wet, heat, and cold, they felled trees and excavated, mostly by hand and animal power, mile after mile."[4] The Erie Canal was 4 feet deep and 40 feet wide. Before the Erie Canal was built, it cost 27.5 cents per ton per mile by wagon. Afterwards, going by barge, it cost 1.6 cents per ton mile. The transit time to traverse the route of the Erie Canal went from 45 days before the canal was started to 5 days after it was done.[5] After the Erie Canal there was an entire network of canals constructed for navigation.

[3] America on the Move.
[4] Erie Canalway National Heritage Corridor.
[5] Ulvog.

On the Colorado River, it was realized in the early 1850s that boats were a superior option. A boat could "carry more to the post in twenty-four hours than a hundred wagons could transport in a week".[6] In the early 1860s

> Johnson's steamers did a bonanza business carrying men and supplies to all the new mines opened up along the river and in the interior. He secured a virtual monopoly on the trade, for even though two new wagon roads were opened across the desert from Los Angeles, the overland teamsters demanded $250 a ton, while Johnson could land freight from San Francisco for less than half that price.[7]

As shown on Figure III-1 there were several locations where forts were located that required supplies. Although references are easily found to ships that came down the Pacific Coast, around the Baja of California, and up the Colorado River to supply military posts on the Colorado River, there are no records indicating that the forts in the Salt River Watershed were supplied by river deliveries.[8] Shipping was available on the Colorado River since 1852.[9] Figure III-2 shows the numerous ports on the Colorado River and the absence of ports on the rest of the rivers in Arizona. Despite the ease of heading east along a navigable river, the Army found that:

> ... [t]ravel inland from the [Colorado] river still required a difficult and time-consuming journey by horse or stagecoach, one made worse by the poor condition of the few existing roads.[10]

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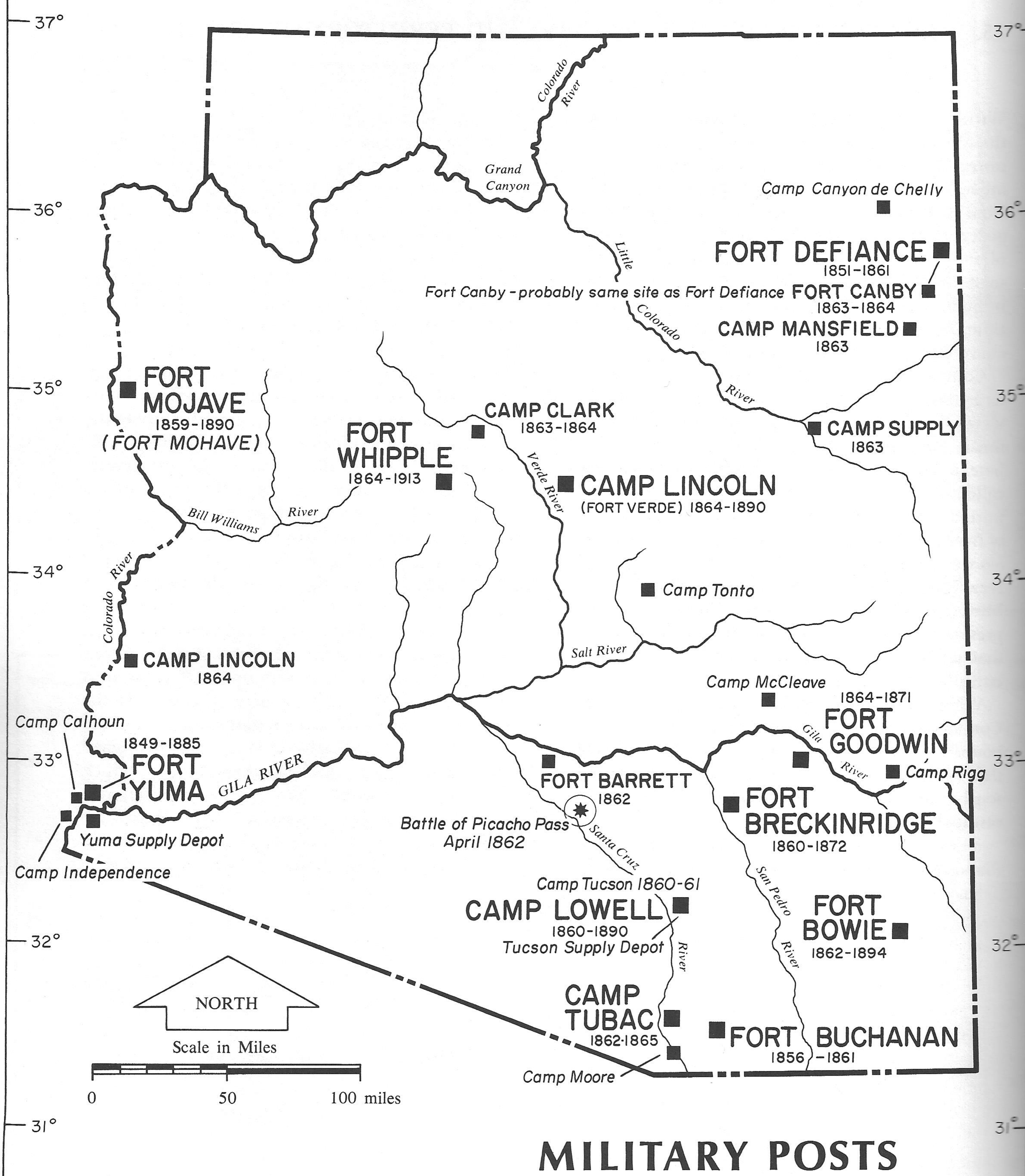
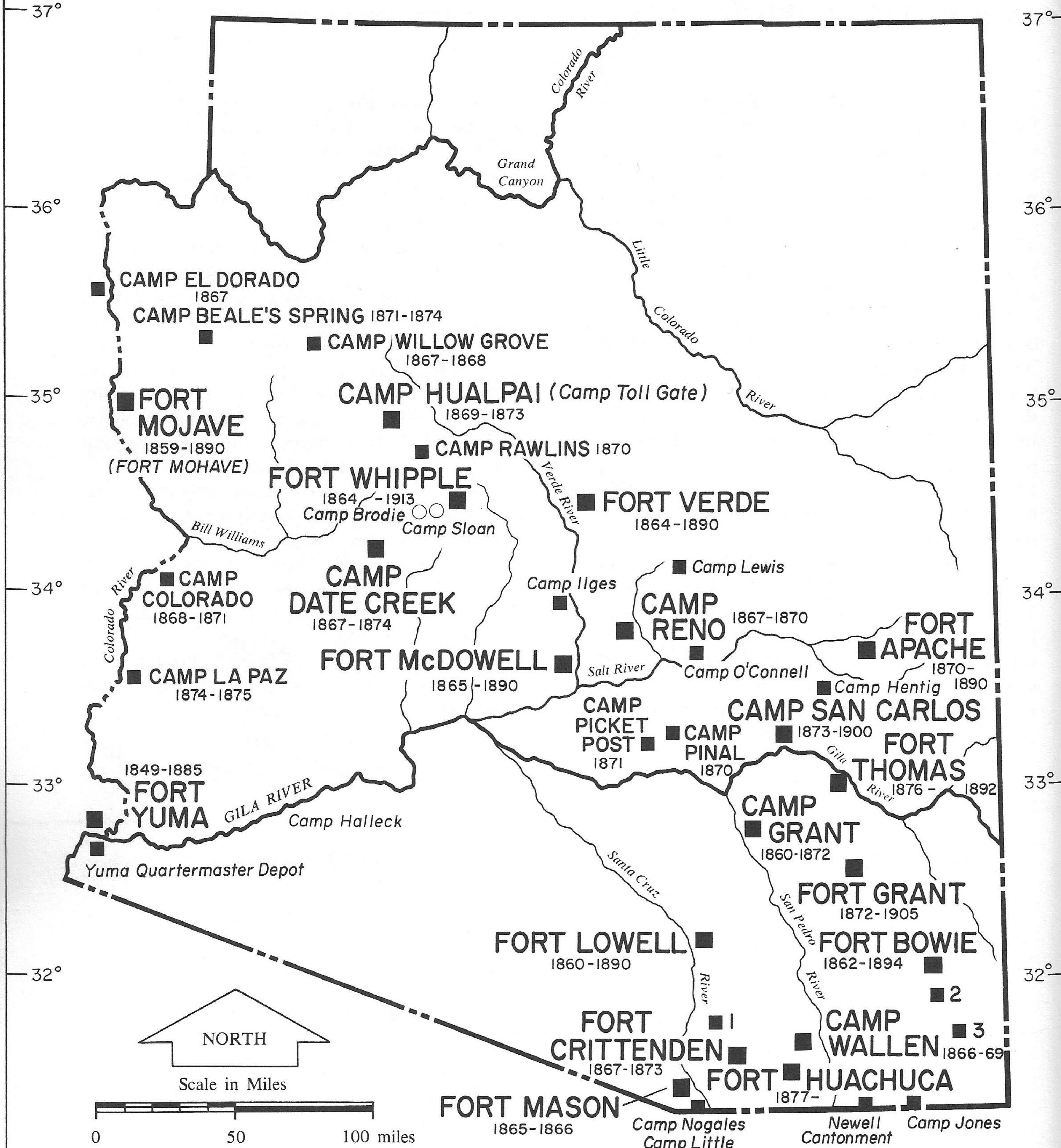
[6]Lingenfelter, pg 8.
[7]Lingenfelter, pg 37.
[8]Walker and Bufkin, map 39.
[9]Lingenfelter, pg 9.
[10]Pry and Andersen, pg 14.



MILITARY POSTS
1849-1864



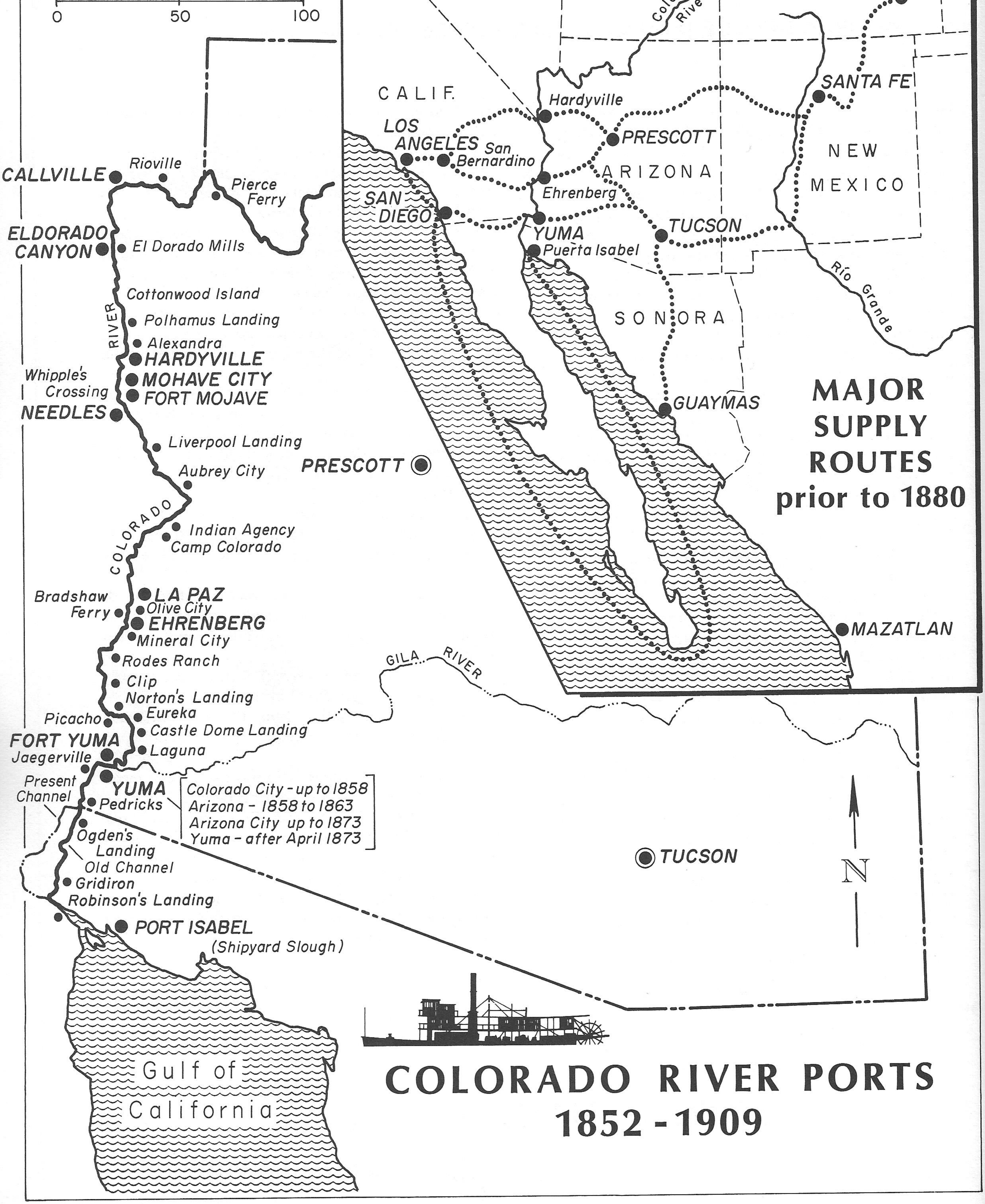
Legend

1 - CAMP CAMERON 1866-1867

2 - CAMP CRAWFORD 1886

3 - CAMPS RUCKER, SUPPLY, POWERS & PRICE
1879, 1878, 1878, 1881

MILITARY POSTS
1865 - 1920


0
50
100
CALLVILLE
Rioville
Pierce Ferry
ELDORADO CANYON
El Dorado Mills
Cottonwood Island
Polhamus Landing
Alexandra
HARDYVILLE
Whipple's Crossing
MOHAVE CITY
FORT MOJAVE
NEEDLES
Liverpool Landing
Aubrey City
PRESCOTT
RIVER
COLORADO
Indian Agency
Camp Colorado
Bradshaw Ferry
LA PAZ
Olive City
EHRENBERG
Mineral City
Rodes Ranch
Clip
Norton's Landing
Picacho
Eureka
Castle Dome Landing
FORT YUMA
Jaegerville
Laguna
GILA RIVER
Present Channel
YUMA
Pedricks
Colorado City - up to 1858
Arizona - 1858 to 1863
Arizona City up to 1873
Yuma - after April 1873
Ogden's Landing
Old Channel
Gridiron
Robinson's Landing
PORT ISABEL
(Shipyard Slough)
TUCSON
N
Gulf of California
CALIF.
LOS ANGELES
San Bernardino
SAN DIEGO
Hardyville
PRESCOTT
ARIZONA
Ehrenberg
YUMA
Puerta Isabel
TUCSON
SANTA FE
NEW MEXICO
Río Grande
SONORA
GUAYMAS
MAZATLAN
MAJOR SUPPLY ROUTES prior to 1880
COLORADO RIVER PORTS 1852 - 1909

The railroad provided, what the Gila River and its tributaries never did, sustainable commercial transport that "laid the groundwork for the development of Arizona's modern economy."[11]

The alternative to boating in Arizona, before the 1880s, was walking or animal-pulled wagons. Fuller indicates that the railroad arrived in Arizona in 1871[12]. In actuality, the first railroad to enter Arizona was in 1877.[13] In 1877, the Southern Pacific Railroad came from the Pacific Coast and ended at Yuma. As the railroad was extended from Yuma, it followed the Gila River until it turned to the south to serve Tucson. Railroad service to Phoenix did not occur until 1887.[14] In 1887, therefore, the train could have preempted trade on the Salt River. By the early 1880s, the flows of the Salt River had been badly depleted anyway.

One other factor that proves the need for transportation along the Gila River is how the territory expanded once the railroads arrived.

> The arrival of the railroad truly opened southern Arizona. Intensive farming and ranching, and substantial new city and town development date to the completion of the railroad. It provided a way to ship out agricultural and mining products, and to bring in imported foodstuffs and finished products which formerly had been

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[11]Pry and Andersen, pg 20.
[12]Fuller 2015a, slide 63.
[13]Walker and Bufkin, maps and pgs 46 and 47. Also Pry and Andersen, pg 19.
[14]Walker and Bufkin, slides 46 and 47. Also Pry and Andersen, pg 20.

> subject to hideously expensive and always uncertain overland freighting.[15]

When the Railroad reached Yuma, the people in the Lower Salt River Valley (segment 6) had even more reason to ship goods down the Salt River. In 1877, Yuma, which had been a port city since the 1850s, was now tied into an even cheaper method of shipping, the railroad. So did they start building boats, or improve the river for navigation on the Salt River? No.

> In 1877, with the Southern Pacific poised to enter the Territory at Yuma, Arizona legislators finally brought the Territorial government into the road-building business. The Territory's first project was a wagon road between Phoenix and Globe. ...[16]

Globe is located about 30 miles from the Salt River. If the Salt River was navigable, you would have expected boats to be used to transport the supplies and products. You would have further expected the Territorial government to spend its money on improving the Salt River for boats and building the much shorter road from the Salt River to Globe. To get goods from Phoenix to Yuma "...Maricopa County sold $15,000 in bonds to pay for the construction of wagon roads from Phoenix to several destinations. This included ... a road to Yuma... ."[17]

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[15]Berry and Marmaduke, pg 235-236.
[16]Pry and Andersen, pg 20.
[17]Pry and Andersen, pg 22.

Again, if the Salt River was navigable, the money would have been better spent on boats and improvements on the Salt River. In both cases, the government entity did not fund navigation but funded roads.

Since the railroad paralleled much of the Gila River, it would have been an easy thing to get off the train at some point on the Gila River, hop on a commercial boat and go to Phoenix IF the Gila and Salt Rivers were navigable. Instead, the railroad passengers got off at the closest stop (to Phoenix), which was Maricopa, and rode a stagecoach for 35 miles north to Phoenix.[18]

It is not faulty logic to indicate that people would boat a navigable river. In addition to the cost advantages, people generally would have preferred boats. The descriptions of what it was like to drive a wagon over the early so called roads were awful.

> One Army wife who took the road [the General Crook Trail] soon after its opening, Martha Summerhayes, vividly recalled the experience many years later: "For miles and miles the so-called road was nothing but a clearing, and we were pitched and jerked from side to side of the ambulance as we struck large rocks or tree-stumps; in some steep places, logs were chained to the rear of the ambulance, to keep it from pitching forward onto the backs of the mules."[19]

B. NAVIGATION OCCURRED BUT WAS NOT REPORTED

[18]Pry and Andersen, pg 20.
[19]Pry and Andersen, pg 19.

There is a lot more to a newspaper than news. Newspapers carry advertisements. If the Salt River had been a "highway of commerce", there would have been advertisements for travel by boat. On the Colorado River below the Black Canyon, there is a lot of evidence and records available to demonstrate the navigability of the Colorado River. Mr. Lingenfelter wrote an entire book on it.[20] In Lingenfelter's book, he shows a sampling of the advertisements that newspapers carried, announcing rates and the location of their booking offices.[21]

C. THERE WERE TOO FEW PEOPLE FOR NAVIGATION TO OCCUR

The basic gist of this argument is that there were an insufficient number of people to know how to build a boat[22], or know how to pilot a boat.[23] There are four problems with that. The first problem is that the development of Yuma and the Colorado River shows that river navigation occurs with a very small population. The second problem is the existence of Yuma. The third problem is that the people had boats and used them during floods, which is one of the trickiest times to float a boat and survive. Finally, we know the U.S. Census populations did not report all the people.

[20] Lingenfelter.
[21] Lingenfelter, pg 57, 59, 79, 98.
[22] Fuller 2015a, slide 63, 69.
[23] Fuller 2015a, slide 69.

After the United States acquired control of the Colorado River, the U.S. Army sent troops to the Colorado River Valley to exert military control over the area. "In mid-November 1852 the first Colorado steamboat was finally launched on the muddy waters."[24]

The populations living along the banks of the Colorado River can only be estimated. In 1850, California had one county, San Diego County, which bordered on the Colorado River. San Diego County had 798 people.[25] The San Diego County population included the people located on the Pacific Coast in and around the natural port that became San Diego. Arizona had no census coverage in1850.[26] In the 1850s "...Arizona had very few residents who were not Native Americans and hardly anything that passed for an economy."[27] Given the very low population, how did the commercial navigation of the Colorado River occur? Fuller in 1998 provided us the answer "getting supplies in ore [sic] out and supplying the forts offered new opportunities for boating entrepreneurs"[28] i.e. they moved there. In 1864-5, central Arizona went through a similar process of establishing forts on the Gila River and its tributaries. The difference was that despite the pristine nature of the Salt River at that time, the Army used wagons instead of boats to ship the goods.

[24] Lingenfelter, pg 9.
[25] U.S. Department of Commerce, pg 21.
[26] U.S. Department of Commerce, pg 15.
[27] Pry and Andersen, pg 11.
[28] Stantech, pg 24.

The second problem with this theory of too few people for navigation is the existence of Yuma. Yuma is located at the junction of the Gila River and Colorado River. "Yuma was the chief port from which supplies were hauled by wagon to all of Arizona south of the Gila and Salt rivers."[29] As a port city, Yuma would have had the people who knew how to build and pilot ships on Western rivers. If boat production was required elsewhere, the product could be imported by sea. If the Lower Gila and the Lower Salt were navigable, the boating entrepreneurs of Yuma would have built or acquired the boat and navigated it up to the Phoenix area.

The third problem of too few people for navigation is that people had boats and did use them particularly during floods. Fuller stated in 1998, "... they [boats] were clearly available for use when needed in situations such as flood rescue, ..."[30]

Finally, up until 1890, U.S. Census values did not include Native Americans.[31] While the Indians were counted in the 1890 census, the census had two problems. The 1890 census included only some of the Indian Reservations and those values, which in 1890 were 28,623, were left out of the county populations.[32] The Pimas and Maricopas had large populations

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[29]Walker and Bufkin, pg 39.
[30]Stantech, pg 25.
[31]U. S. Department of Commerce. Bureau of the Census, pg. *vi.*
[32]U. S. Department of Commerce. Bureau of the Census, pg. 14.

until the starving decade of 1895 to 1904. As far back as 1858, the Pima-Maricopa population was 4,117 people, far more than the population of Yuma when navigation started there.[33]

D. TOO MANY PROBLEMS WITH THE RIVER TO NAVIGATE IT

Fuller indicates that the "Flow depth", "Cost", and "Speed of Travel"[34] were problems. I agree, but if the river is too shallow or they could not beat out the cost and speed of wagons, then it indicates the river was non-navigable. Fuller indicates that the boat won't carry the goods that are needed or you can't risk capsizing.[35] If there are no goods that can be carried in a specific boat, then the entrepreneur should be using a different boat. If no boat was available to carry any type of cargo, then the river was non-navigable. Fuller indicates that "[g]oing upstream is too much work or expense."[36] This is discussed in Chapter IV. Succinctly put, you need to use a raft that can be destroyed at the downstream end.

E. OTHER

Several other reasons were mentioned that might have a bearing on vacationing at certain times of the year "It’s too cold." etc.[37]. That is true for

[33]Russell, pg. 21.
[34]Fuller 2015a, slide 68.
[35]Fuller 2015a, slide 70.
[36]Fuller 2015a, slide 70.
[37]Fuller 2015a, slide 69.

many recreational activities. The answer is you make your money or take your trip on the good days.

IV. MODERN RECREATIONAL BOATING

Evidence has been presented by the pro-navigability parties of current-day recreational boating on the various rivers as proof that portions of the rivers would have been navigable at Statehood. This concept was discussed by the United States Supreme Court in its Montana PPL decision. The standard set by the U.S. Supreme Court is that the reliance on such evidence was wrong "as a matter of law". The U. S. Supreme Court did indicate however that:

> [a]t a minimum, therefore, the party seeking to use present-day evidence for title purposes must show: (1) the watercraft are meaningfully similar to those in customary use for trade and travel at the time of statehood; and (2) the river's post statehood condition is not materially different from its physical condition at statehood.[1]

This chapter addresses the first criteria presented by the U.S. Supreme Court.

In 1996, Fuller asserted that modern recreational boating, due to changes in modern materials and improved durability, allowed areas to be boated that could not have been boated in 1912.

> Commercial recreational rafting started in the 1930s, but developed in the 1970s, on the Colorado River (especially upstream in Utah) and later on the Salt, Gila, and Verde Rivers.

[1]Montana Decision, pg 22-23.

> *The development of durable small boats* - plastic, fiberglass and other modem types of canoes and kayaks, inflatable boats for single paddlers and for groups - all *contributed to the rising popularity of river running in Arizona especially on rivers not previously considered boatable, or boatable only very rarely because of low water* [italics added].[2]

Fuller had more than his own opinion to rely on. The Arizona State Parks, quoted by Fuller, stated:

> There is a bit of revolution in river running going on in the state that makes it hard to give definitive information. Boaters who aren't content to resign themselves to a few days of fun per year on most of the state's rivers have started using durable plastic canoes and single person inflatables to run them at levels *well below what in the past has been considered boatable*. These seemingly stubborn individuals may end up dragging their boats over a riffle too shallow to float once in a while but to pay that small inconvenience for the reward of a day in the river is well worth it in their eyes.[3]

Fuller further stated:

> When determining boatability, the intended kind of boat and purpose need to be considered. A river that is boatable by a neoprene raft or fiberglass canoe may not be boatable by wooden rowboats, for example.[4]

Certain aspects of each type of watercraft, their materials, the legal standards of navigability, the characteristics of the River, and other factors can be considered best on a watercraft by watercraft category. I have broken the watercraft discussions into the following categories:

A. Wood Rafts

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[2]Stantech, pg 32.
[3]Stantech, pg 36.
[4]Stantech, pg 33.

B. Inflatables

C. Canoes

D. Rowboats

A. WOOD RAFTS

When I refer to wood rafts, I am including flatboats and skiffs in the term wood rafts. Wood rafts' distinguishing characteristic is that this water craft makes one-way commerce possible on some rivers. The basic concept of one-way commerce is briefly discussed in the "Defenders" decisions when the Arizona Appellate Court found that a statutory presumption requiring two-way travel was not supported by the Case law.[5]

As a matter of historic fact, other rivers have been used for one-way commerce with certain types of rafts. The one-way approach is to build a watercraft that is so cheap that it is feasible to load the watercraft up with goods, float downstream, sell your goods, destroy the boat, sell the boat for firewood (or whatever you can), and return to the point of beginning by an alternative method (such as walking). Fuller points out how the "Sweep Scows" were used in this manner on the Salmon River.[6]

While allowing one-way commerce, rafts also have significant disadvantages. Since they are built to be destroyed at the downstream end,

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[5]Arizona Appellate Court, Feb 13, 2001, paragraphs 32 and 33.
[6]Fuller 2014c, slides 9-10.

the structural integrity is usually weaker than other water conveyances. Rafts are also not streamlined vehicles and have ~~a~~ limited control. I have tried to come up with an authoritative definition of what differentiates a wooden raft from a wooden boat. I did not find an authoritative one but as one boater put it "One [the boat] goes pretty much where YOU want and the other [the raft] goes pretty much where IT wants." As Fuller states in discussing rafts "these boats are difficult to control".[7]

This lack of control and structural strength makes the raft highly susceptible to natural obstacles. Fuller indicates that barges (a type of raft that is intended to be pushed or pulled by a separate boat) cannot handle rapids.[8] Fuller shows at slide 78 what he means by a barge.[9] Barges are modern metal boats. If barges cannot survive rapids, then I believe it safe to say wooden rafts couldn't either.

Wood rafts would hit a major problem with beaver dams. Modern canoes can slide over the top of them. Old canoes could with some time and effort be portaged around beaver dams. Wood rafts are very heavy. Wood rafts do not have open frames but are solid wood.

[7]Fuller 2014c, slide 31.
[8]Fuller 2014c, slide 79.
[9]Fuller 2014c, slide 78.

In the navigability presentations, there has been no evidence that I have found that indicates that wood rafts are being used in modern day recreation. The early uses were generally failures. There are certainly a lot of inflatable rafts used today but not wooden. Inflatables are discussed in the following section.

B. INFLATABLES

The inflatable boat or inflatable raft was not practicable at Statehood. At that time, synthetic rubber was unknown. Rubber had been known for a considerable length of time and was used for pontoon bridges as far back as the 1800s. Pontoon bridges are not the same as boating. A pontoon bridge is built by finding a spot where the criteria for that bridge are met, floating the boats across, tying them together, and placing a road (wood planks or metal constructions) on top of them. Pontoon bridges do not face the hazards of navigating a river and are essentially a ferry. Pontoon bridges do not carry commerce up and down the river but, like a ferry, across the river.

In the evidence presented to support this option of inflatables, the primary reliance is on advertisements. There are three reasons to doubt the reliability of advertisements. First, is that they are advertisements with unsupported claims and brief testimonials. There is no technical data provided.

Second is the inflatable rafts are made of rubber and the ads do not show black rafts. Rubber went through a major technological advance in 1904 when it was discovered that adding carbon black to the rubber made dramatic changes to the strengths of the rubber. Prior to the production of carbon black laced rubber, rubber was white. If you look at very early pictures of tires, they were white. When the carbon black was added, the rubber becomes black.

> Carbon black is the predominant reinforcing filler used in rubber compounds, and it is required to impart the necessary durability and strength to these products for longer lifetime and greatly improved performance. Carbon Black distributes and absorbs stress applied to a rubber component and improves its tensile strength, tear strength and abrasion resistance.[10]

The difference carbon black made was tremendous. "... [A]dding about 50% by weight of carbon black increases the road-wear abrasion of the produced tire by as much as 100 fold and improves the tensile strength of the tire by as much as 1008%. For the uninitiated, the tensile strength is the amount of force needed to pull something to its breaking or bursting point."[11] The concept of reinforcing rubber with carbon black was

[10] Aditya Birla Group.
[11] Hiskey.

discovered in 1904.[12] This does not mean that rubber boats with carbon black were instantly available prior to 1912. It takes a while to go from discovery, to validating the discovery, patenting the discovery, to financing, designing the production process, building the production facilities, then production, and finally marketing. There are certainly additional steps that I missed. Based on the advertising, it appears that the Carbon Black Rubber Rafts must have been available sometime after Statehood.

The third reason to doubt the reliability of advertisements was production problems.

> Around 1900 the advances of rubber manufacturing made it possible to build more durable rubber inflatable boats. But these crude craft had inherent defects and they tended to split at the seams and folds due to less than optimal manufacturing of the rubber.[13]

"[T]hese [inflatable] boats were awkward, difficult to maneuver, and not very durable...."[14] Even after carbon black was applied to inflatable rafts, rafts required numerous additional developments before it really became a reliable alternative after World War II.[15] Fuller explained that the

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[12]Rubber Division American Chemical Society, item 82.
[13]Hoops, pg 4.
[14]Stantech, pg 32.
[15]Hoops, pg 5-7.

"[u]se of inflatables, however, did not become common until the development of artificial rubber in the 1940s."[16]

In researching the Internet, it is easy to find inflatable boating being used today. The materials that have permitted this are due to a century of research and development and are generally made from synthetic materials that can take the rigors of river boating.

> When you compare the modern inflatable to earlier boats made of cotton and natural rubber you find that you are looking at an entirely different animal.[17]

I found no examples of inflatables being used on the Gila River and its tributaries near the time of Statehood or before Statehood.

C. CANOES

The canoe has been presented as the answer to the problems of navigability. Fuller and others have testified to navigating the Gila, the Upper and Lower Salt, the Verde, and the San Pedro Rivers in modern times. The two types of craft used are the modern rafts, discussed above, and the canoe. The pro-navigability parties claim that canoes could have navigated the virgin flow rivers with similar success since the only difference is durability. This difference is then ignored.

[16]Stantech, pg 22.

[17]Hubbard, pg 28. It is necessary to use the table of contents on the website and select page 28 from the table of contents.

Durability is one of the most critical aspects to be considered. The United States Forest Service in the 1995 navigability hearings presented photos[18] showing what happens to canoes that lack the sufficient durability to navigate the waters in question.

Fuller knows the materials make a major difference. In his 1998 report, Fuller has a table listing "Boat types in Arizona before 1913". In the column entitled "Primary Historic Uses in and Near Arizona," Fuller stated that canoes were for "Lakes and calm rivers for fishing, recreation, travel."[19]

The difference in durability between then and now has been dramatic. In my Santa Cruz navigability report, I pointed out the tremendous difference between the strengths of wood and fiberglass.[20] Fuller, in 1998, stated that fiberglass made the Verde, Gila and Salt, popular.[21] Yet even this advance does not always provide the strength needed (Figure IV-1). Other types of canoe have been suggested.

1. Aluminum

In 1998, Fuller stated that the aluminum canoe was invented in the late 1940's.[22] A few aluminum boats, not canoes, were built in the early 1900s for use in the ocean but they fell victim to several problems. First,

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[18]U. S. Department of Agriculture. Forest Service. Photos.
[19]Stantech, pg 31.
[20]Gookin 2014a, chapter 7 page 2.
[21]Stantech, pg 28.
[22]Stantech, Appendix B-3 under "Canoe".

Photo No. 4 - Fiberglass Canoe, 1991

Photo No. 7 - Fiberglass Kayak, 1980

Fiberglass Canoes Figure IV-1 Source: USDA aluminum cost 35% more than steel.[23] A second problem occurred when the boats were placed in salt water; aluminum boats suffered from "severe corrosion in salt water"[24]. Although I could not find any sources that indicated that this problem also existed in fresh water, it was because I could not find any evidence of aluminum canoes being used in fresh water at all, in or before 1912. Corrosion is a phenomenon that occurs in all water, fresh or salt. “Small metal boats, unlike tankers and container ships, are not designed with an appreciable corrosion allowance."[25] Cathodic protection is necessary even in steel water pipes for municipal water supplies. Third, the state of the production process at that time was such that "[i]mperfect manufacturing processes and a lack of understanding of all aluminum properties and capabilities hampered wide dissemination of this metal in shipbuilding."[26]

The aluminum canoe was very tough. "Aircraft Technology has given canoeists nearly indestructible canoes ... ."[27] The tensile yield strength of aluminum is 40,000 psi.[28] Like fiberglass, aluminum canoes cannot always meet the requirements of the Upper Salt River (Figure IV-2).

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[23]UC RUSAL, sheet 45.
[24]UC RUSAL, sheet 45.
[25]Kasten Marine Design, Articles page.
[26]UC RUSAL, sheet 45.
[27]All About Canoes. Aluminum Canoes.
[28]ASM.

Photo No. 1 - Aluminum Canoe, 1975

Aluminum Canoe Figure IV-2 Source USDA

Aluminum canoes were invented and introduced by Grumman Industries using technology from World War II.

> The Grumman was the first true recreational canoe. It's maintenance-free, stable, user-friendly and relatively cheap.[29]

2. Canvas

There are several instances where Fuller provides pictures of canvas canoes that are used for ferrying or very localized fishing. There is a market for canvas although it has been subordinated to newer materials such as Royalex discussed below. Simply looking at pictures of the near Statehood canvas canoes and canvas canoes today shows several differences. (Figure IV-3) The canvas canoes shown by Fuller were a canvas sack that was loosely attached to a frame that kept the canvas sack open for the user to sit in. The old canvas canoes obviously lack any hydrodynamic considerations and must've been very hard to maneuver. Canvas canoes today, hold a firm shape due to the use of differing chemical formulas. As the Wooden Canoe Heritage Association stated:

> One note about filler formulas. The materials that were used in the early 1900's may not be the same as materials with the same names today. In addition, canvas is certainly different today than it was in 1900, … .[30]

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[29]Mihell.
[30]Miller.

Modern Canvas Canoe Source: Old Town Canoe

Old Canvas Canoe Source: Fuller 2015a Slide 149

Figure IV-3

Fuller acknowledged the limitations of the Canvas Canoe back in 1998 when he stated in his table of boats available that the canvas canoe that was listed in the Sears Catalog of 1910 was for "[h]unting in calm water".[31]

3. Wood

The wooden canoes of 1912 were different than most wood canoes today. The Sears catalog has been submitted to show that canoes were available for sale.[32].Reading the text, it is apparent that all three are rowboats. Specifically, the boats come with oar locks. The middle picture, however, looks like a canoe. It is impossible to tell what the stern looks like on the right hand boat. Even if these boats are easily convertible to canoes, they are almost totally made from soft wood with two layers of paint providing the coating.

> Canoes made solely of wood are readily available in today's market. They are perhaps the most aesthetically appealing of all canoes, but, with looks, usually comes price. ... The time and expertise necessary to fashion wooden planks into a wooden hull is such that these boats are prohibitively expensive, *not to mention fragile*. Wood canoe building kits are available for ambitious home handy persons to build "stripper" canoes which are similar to the all-wood canoes of the past, except that the thin planks of cedar *are covered with transparent layers of fiberglass.* Though homemade strippers are cheaper than

[31]Stantech, pg 37.
[32]Sears, Roebuck and Co., pg 934.

> commercial ones, *they are still fragile and suitable only for careful paddling in quiet water* [italics added].[33]

The Sears canoes were made out of cedar. This is a soft wood. As Fuller pointed out in his discussion of the rapids of the Grand Canyon:

> ...they were constructed of lightweight cedar which was far too fragile for the Grand Canyon and some were even broken in transit before they reached the river.[34]

But as the ASLD's exhibit points out, Mr. Baldwin who ran the whitewater tours for the Salt River stated, concerning the Salt River:

> You think of rafting in Arizona, and you think of going down the Colorado River through the Grand Canyon....But we've got something just as challenging ...in our own backyard.[35]

The USDA Forest Service, who manages much of the Upper Salt River above the dams, explains the viability of boating in a wood or canvas boat.

> There are a relatively small number of days per year when the water level itself would have been suitable to allow a canvas, metal, or wooden boat to attempt to travel down this river, even if its gradient would have allowed it. The theoretical "window of opportunity" could occur in almost any month of the year, but it is impossible to predict and thus impossible to plan ahead for. There are entire years when the water never reaches those levels. The Salt River Project's streamflow gages also show that this river can go from a few hundred cubic feet per second (c.f.s.) to over 100,000 c.f.s. in a few short hours. To have been caught on this river making the required multi-day trip, while

[33]All About Canoes, Wood canoes.
[34]Stantech, pg 27.
[35]Bearden-Mason.

> attempting to use this wild river as a highway of commerce, would have been disastrous. Luckily, there is no record that anyone was stupid enough to try such a trip during or before 1912, nor for many years afterwards.[36]

The Sears catalog shows the cost of boats ranging from 13 feet to 16 feet.[37] Reading the text of the catalog shows that they are boats although the middle picture sure looks like a canoe. The prices vary from $22.75 to $30.50 plus shipping. The Sears shipping cost is $23.20[38] for shipping to Phoenix. Pinkerton in 1914 indicated that freight canoes were over eighteen foot.[39] The cost for the 16 foot boat/canoe is, in today's dollars, is $1,282.[40] The importance of this is that shipping by boats or canoes are not feasible or affordable if it is one-way only.

Many sources agree that the wood canoes are fragile.

> Lightweight, wood, canvas, cedar strip, and birch bark canoes paddle like a dream, ... There *[sic]* hulls can be damaged very easily ... Unless you have a trust fund, or have headed up five internet startups that have IPO'ed, you probably are not going to take a natural material canoe into whitewater. These canoes are ideal for flat water touring, ... [41]

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[36]U.S. Department of Agriculture. Forest Service, pg 3.

[37]Sears, Roebuck and Co., pg 934.

[38]Sears Roebuck and Co., pg. 18. The Sears catalog page with the boats (pg. 934) says the "Freight Rate on Boats Is Four Times First Class". The biggest of the boats that looks like a canoe (the boat on the right) on page 19 is 170 lbs. First Class to Phoenix is $2.90 per 100 lbs. (pg 19). First Class is for the 16 foot boat/canoe 170 pounds is $5.80. Four times First Class is $23.20.

[39]Pinkerton, chapter 2, 3rd paragraph from the end.

[40]I used a CPI calculator to inflate the price from 1913 to date. Apparently the CPI started in 1913. $53.70 in 1912/1913 is worth $1,282 today.

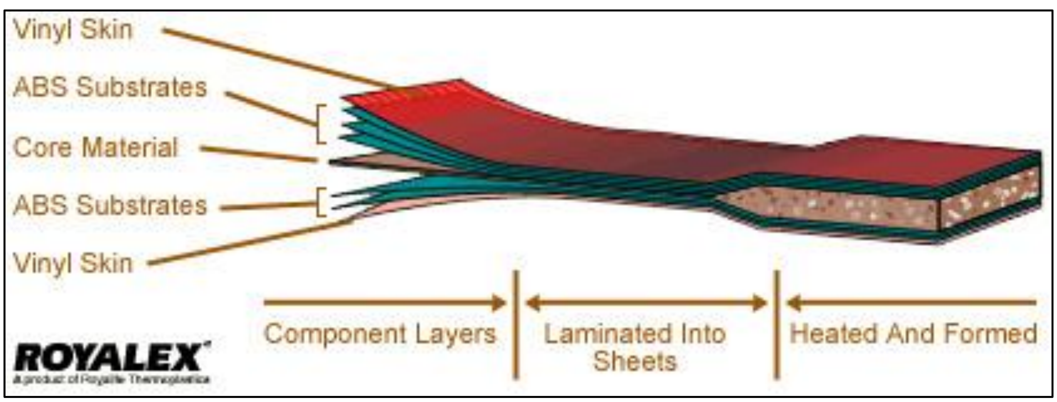
[41]OutdoorPlaces.Com

Even though they are fragile today, wood canoes are stronger than they used to be.

> Wood ... has constantly been the least durable. On the other hand, modern-day canoe builders making use of wood to build their boats have access to scores of things that did not exist even 20 years ago. Water-tight epoxy films, varnishes, along with contemporary manufacturing methods have made today's canoes quicker, lighter in weight, plus more durable then [*sic*] ever previously.[42]

4. Royalex

After the development of the aluminum and the fiberglass canoes, the industry developed numerous alternatives. These alternatives were created for various reasons; cost, looks, durability, weight, handling ability, and some other reasons I probably did not find. I have not attempted to evaluate all the types of materials that now exist. One type of canoe deserves a detailed evaluation, the Royalex. A graphic of this material is displayed to the left.[43] A Royalex canoe



[42]Brooks, item 3.
[43]Old Town Canoe Co.

was used by Fuller[44] to demonstrate the navigability of canoes on various portions of the rivers.

> Royalex is an exceptionally abrasion- and impact-resistant material that springs back from hard collisions. It provides excellent insulation from cold water, and is quiet to paddle. Royalex consists of a closed-cell foam core sandwiched between layers of ABS plastic, then topped off with a tough, vinyl skin.[45]

The capabilities of Royalex are pretty amazing. One website, "The Mad River Canoe," is a retailer for many types of canoes. They have a frequently asked questions section in which they discuss the durability of Royalex. The bold capitalized portion of the following quotation is the "frequently asked question."

> **ISN'T ROYALEX INDESTRUCTIBLE? WHY WOULD IT NEED A REPAIR?**
>
> ABS Royalex® is an incredibly durable material but it is not indestructible. Back when Royalex® started to show up in canoes, it was *nothing short of a revolutionary advance* in canoe materials. Its functional durability put it in a class by itself compared to other available technologies of the time such as aluminum or fiberglass or wood.
>
> Canoe manufacturers could be forgiven if they got a little too carried away with this almost magical material. *Images of canoes sailing off factory roofs or falling from airplanes and surviving* contributed to the growth of Royalex®'s reputation for being "indestructible" [*italics added*]. [46]

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[44] ANSAC 2014b, Volume 1 pg 77.
[45] REI. Consider the Materials > Royalex.
[46] Mad River Canoe.

The Old Town Canoe Company also discusses Royalex's capabilities.

> Royalex's unique molecular configuration has much to do with resiliency: *a Royalex canoe can be folded in half by a bridge abutment or boulder, and then return to its normal shape with minimum hull distortion.* With its light weight, it is often the choice of recreational and whitewater enthusiasts [*italics added*].[47]

The All About–Canoes website, which is quoted above to the effect that wood canoes were fragile, states: "... these [Royalex] canoes can be bent, folded and generally abused with only minimal hull damage. ... they're nearly indestructible."[48]

It is the characteristics of Royalex that permits users to traverse the whitewater so easily.

> A swamped Royalex canoe will often come through the toughest rapids unscathed and pop back into near-perfect shape even after being folded around a midstream boulder.[49]

"Royalex is the choice for remote rivers and mean rapids, simply because no other material takes abuse so well."[50]

Fuller needs to hold onto his Royalex canoe. A factory in Warsaw, Ind. that is the sole source for Royalex material is closing due to a buyout in 2013 by Avon Lake. An article in Plastics News reports:

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[47]Old Town Canoe Co.
[48]All About Canoes, Royalex canoes.
[49]Jacobson, pg 40.
[50]Jacobson, pg 40.

> Whitewater adventurists are bemoaning the loss of Royalex, which has been used to make *nearly indestructible* multi-laminated ABS and vinyl canoes for at least 40 years. Retailers are concerned about the sport losing moderately priced Royalex products that are popular with educated, entry-level canoers [i*talics added*]. [51]

The one thing that is amazing, given the incredible durability of the Royalex, is that the Verde River was so rough that Fuller managed to break the seat in a Royalex canoe when he floated down the river.[52] As the Mad River Canoes website indicates, Royalex is not indestructible, merely nearly so. This near indestructibility also provides an explanation as to how and why Fuller believes that rivers with class V rapids and waterfalls can be boated without portage.

The failures and lack of use of canoes on the various rivers reinforces the conclusion that canoes were not a viable option before or around Statehood. The references to canoes that I could find in the exhibits are discussed next.

5. Historic Use of Canoes

To demonstrate the practicality of using canoes in the Gila River and the Salt River, we should look to what the people did with canoes as far as commercial activities. In the Utah Case, the Special Master spends a

[51]Kavanaugh.
[52]ANSAC 2014b, Volume 1 pg 96.

considerable time in discussing all the commercial activities and the boats that were used in the same time period.[53] I tried to OCR the case to search and see if the Special Master thought canoes were used for commerce. For some reason most of the words would not OCR. Fortunately for me, Fuller did the work for me in 1998. Fuller listed the types of boats discussed by the Special Master twice.[54] In both lists, canoes are not mentioned.

In researching the use of canoes in Arizona prior to and around Statehood in the numerous exhibits submitted to ANSAC, I could only find 7 instances in which canoes were alleged to be used anywhere for any purpose on the Gila River and its tributaries. These are the Hayden trip, the Spalding trip, and the Ensign Scott trip already discussed in chapter II. All three were unsuccessful. I found four other instances of canoe use on the Gila River and its tributaries during pre-Statehood times. I discuss these next.

Pattie (San Pedro) Pattie did use a canoe to set traps and ferry across the San Pedro River. As already documented, this occurred during a flood period that was not an ordinary and natural condition.

[53]Gookin 2014a, Chapter 7 pgs 5-6.
[54]Stantech, pg 23 and 42.

Boy in a Canoe In Fuller's PowerPoint, he shows a canoe being used by a boy in still water. There is no indication that it was used for anything but floating in still water.[55]

Forts on the Verde River In Fuller's testimony on the Verde River, he pointed out that there were a couple of canoes used by the U.S. Army.[56] Rather than use the canoes to bring supplies, mail, or other materials from the Colorado River, up the Gila, Salt and Verde Rivers to the forts, the U.S. Army limited the use of canoes to ferrying across the Verde or Salt River and nearby fishing. I believe this is a very significant Anglo-American situation for the Salt and Lower Gila Rivers that occurred before Anglo-American development, as suggested by the Arizona Appellate Court.

Camp McDowell, which later was named Fort McDowell, was established near the junction of the Salt and Verde Rivers in 1865. In addition, there was Camp Clark founded in 1863, and Camp Lincoln founded in 1864. Fuller, in his testimony on the Verde River made the observation “I don't know how you could offer an opinion on navigability and not having looked at the river in person."[57] Fuller has a valid point but rivers change. We cannot look at the rivers as they were in 1912 or anytime

[55]Fuller 2015b, pg 153.
[56]Fuller 2014a, slides 110, 129. ANSAC 2014b, Volume 1 pg 145, 155.
[57]ANSAC 2014b, Volume 1 pg 91.

prior. Looking at a river today does not tell us a lot about how it was a century before.

The U.S. Army was on the site at the time and there was minimal human disturbance at the time. The first diversion on the Salt River was in 1867 by which time the U.S. Army had a boat at the lower crossing of the Salt River for ferrying during floods.[58] The U.S. Army chose to move the materials from the Colorado River up to Camp McDowell, later Fort McDowell, by wagon.[59] The U.S. Army had already decided to ship the supplies from the West Coast around the Baja and up into the Colorado River. Further, the U.S. Army had considerable access to various types of boats and river pilots since the U.S. Army had just finished fighting the "War of the Rebellion" or as it is more commonly called the Civil War. The Civil War was fought on the major Southeastern Rivers using all kinds of river craft. The U.S. Army provided a canvas canoe to Fort McDowell for ferrying the Salt River during floods, apparently bringing the canvas canoe by wagon to the Fort. The U.S. Army apparently knew better than to navigate the Gila and Salt Rivers.

Kentucky Canoes

[58]CH2MHill, pg iii.
[59]CH2MHill, pg 3-1.

The Arizona State Land Department submits two brief articles about people going up the Salt River.[60] Reading the context of the two articles it is pretty clear they are talking about the Salt River that exists in Kentucky.

Canoes were not a "customary mode of trade and travel on water" on or before Statehood.

D. ROWBOATS

The modern rowboat has the same considerations as a canoe when it comes to materials i.e., the newer materials are better. "A river that is boatable by a neoprene raft or fiberglass canoe may not be boatable by wooden rowboats."[61] The rowboat has a different design than a canoe. It is wider and less maneuverable. It generally needs at least two people, one to row and one to steer. The oars are locked into an oar lock; this requires more width than a canoe. According to modern recreational boating standards, a rowboat requires twice as much water depth as a canoe.[62] They are not even listed as an option for whitewater boating in modern times.[63] Fuller, in his list of "Boat types in Arizona before 1913" indicated

[60]Evening Public Ledger and The Arizona Republican July 31, 1920.
[61]Stantech, pg 33.
[62]Cortell 1977a, pg 12 and Hyra pg. 3.
[63]Cortell 1977a, pg 15-22.

that the "Primary Historic Uses in and Near Arizona" for rowboats was for "Lakes and calm rivers... . "[64]

E. CONCLUSION

Modern canoes, boats, and rafts are not "meaningfully similar" to those in customary use for trade and travel at the time of Statehood.

[64]Stantech, pg 31.

V. GEOMORPHOLOGY

Evidence of current day recreational boating on the various rivers has been presented by the pro-navigability parties as proof that portions of the rivers would have been navigable at Statehood. This concept was discussed by the United States Supreme Court in its Montana PPL decision. The standard set by the U. S. Supreme Court is that the reliance on such evidence was wrong "as a matter of law". The Court did indicate however that:

> [a]t a minimum, therefore, the party seeking to use present-day evidence for title purposes must show: (1) the watercraft are meaningfully similar to those in customary use for trade and travel at the time of statehood; and (2) the river's post statehood condition is not materially different from its physical condition at statehood.[1]

The Arizona Appellate Court suggests that there is a single “natural state” that can be used for any period of time that humans are not present.[2] This chapter addresses the condition of the Salt River for the period in the early to mid 1800s suggested by the Arizona Appellate Court, the 1912 condition, and the modern condition as discussed by the U.S. Supreme Court.

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[1]Montana Decision, pg 22-23.
[2]Arizona Appellate Decision, pg 28-29.

Rivers change, with or without humans. What the river was, before and during the Hohokam occupation, is different than what the river was in the early to middle 1800s. Neither of these is the same thing as what the river would have been in 1912 in its natural state nor its current state.

Rivers are variable. Arizona rivers are more variable than most rivers. Mr. Hjalmarson pointed out that he would expect flows to be extreme and variable in predevelopment conditions. This was, from listening to the testimony, a very strong opinion and a correct opinion. As Hjalmarson pointed out: "A one-word description of Arizona rivers is variable." [3]

During the hearings on the Gila, San Pedro, and Santa Cruz Rivers, it was very important to recognize the distinction in time. Those rivers during the 1700s to 1800s were different than they were in 1912. The rivers of the 1700s to 1800s were also different than the rivers in the 1500s. Those major changes occurred due to floods.

On the Salt River, the time period is less important. The Salt River in 1867 through 1939 remained in a very consistent braided condition.[4] Before 1867, we had very few observations due to the continuing conflict of the

[3]Gookin 2014a, chapter 6 pg 2.
[4]See Appendix A.

Apaches versus the Pimas, Maricopas, United States Army and others. After 1939, the Salt River was totally compromised by non-Indian development.[5]

What caused the changes that did occur on the Salt River were the major floods. The first major recorded flood on the Salt River was in February 1890. The Salt River rose 17 feet[6]

There were two more moderate floods on the Salt River between 1890 and 1891. The next major flood on the Salt River was in February 1891 – a 150,000 cfs[7] flood flowed down the Verde River and into the Salt River. As a result "… the channels of both the Salt and Gila Rivers were changed in many places."[8] There were moderate floods on the Salt River in 1895 through 1898.[9]

In January 1905 through December 1906, there was another period of multiple and major floods on the Salt River. For several months, the snow pack had been building until a rapid snowmelt[10] occurred causing the flow below the Salt River/Gila River confluence to reach 115,000 cfs.[11] In November 1905 and August 1906, there were more floods on the Salt River. In November

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[5]In 1939, Bartlett Dam had closed creating a totally regulated system.
[6]Webb, Leake, and Turner, pg 315
[7]Pope, Rigas, and Smith, pg 741.
[8]Russell, pg 62 based on talking stick records.
[9]Durrenberger and Ingram, pg 8-9.
[10]Durrenberger and Ingram, pg 9-16.
[11]Graf, pg 1089.

1906, a large snow pack developed followed by a large warm rain on December 1-4.[12] The runoff may[13] have been 200,000 cfs.

The 1915-16 flood on the Salt River is significant because the flood would have also reworked the river channels. Since we are interested in the natural conditions as of Statehood, we need to consider channel data that occurs between 1906 and 1915. The natural channel of the Salt River as of 1912 was created by the tremendous erosive and depositional power of the 1905/6 floods. The river channels would have remained in that configuration until the 1915/6 events. After 1916, we do not know if the natural channel was reflective of the conditions as of 1912 or not.

Of particular importance to the question of navigability is river braiding. While it is possible to navigate a braided river, it takes far more river flow than any of the experts or records suggest for the Gila or the Salt Rivers. The reason is explained by Osterkamp:

> [D]ownstream changes in discharge for these [braided] streams are accommodated totally by adjustments in channel width, not by changes in mean channel depth or water velocity... In other words, increases in discharge for braided streams do not result in increased channel depth, and because all flow (at normal discharge rates) remains in proximity to the wetted perimeter,

---

[12] Durrenberger and Ingram, pg 11.

[13] The Graf table shows 200,000 cfs in a spot that would be consistent with 1906. However, it appears to be mislabeled to be 1895. The amount is consistent with other flows in the Gila system specifically 190,000 cfs at Kelvin (USGS website) and the Verde River below Tangle Creek 65,000 cfs (Pope, Rigas, and Smith pg 743).

> velocities also remain nearly constant in the downstream direction.[14]

In simpler English, as more water comes in, the river leaves the lowest flow channel and enters a second low flow channel, and the river spreads and spreads. This river spreading continues until the overall channel that is hundreds or thousands of feet wide is totally covered. Only after that point can the depth of the river begin to significantly increase. This spreading characteristic of braided rivers is one of the major reasons the Hydraulic Geometry technique is not useful for the computation of stream depths. The Hydraulic Geometry technique assumes all flow is concentrated into one channel that holds all non-flood events.

There was considerable confusion in the Gila River navigability hearings over the terms, low flow channel, compound channel and braided channel. A braided channel has multiple channels. Fuller refers to a quotation I used in my Gila report from the US Army Corps of Engineers:

> …the most common channel type in dry regions, compound channels are characterized by a single, low-flow meandering channel inserted into a wider braided channel network.[15]

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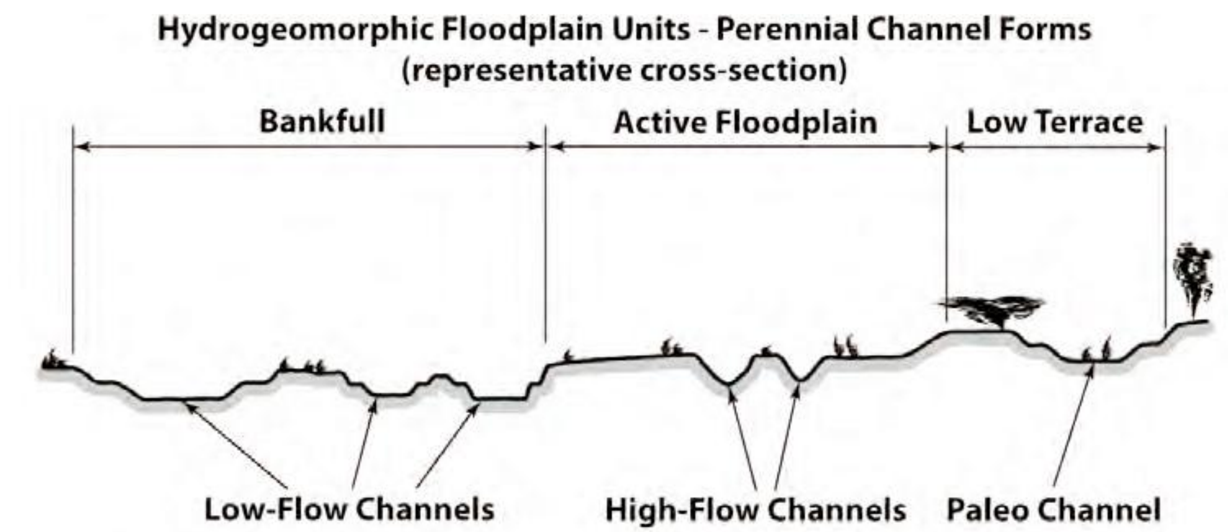
[14]Osterkamp 1980, pg 193.

[15]Fuller 2015b, slide 21. Fuller made a minor mistake in his "Source" by citing to Waters & Ravesloot in my report. He got two footnotes in my Gila report mixed up. The quotation was from the US Army Corps of Engineers.

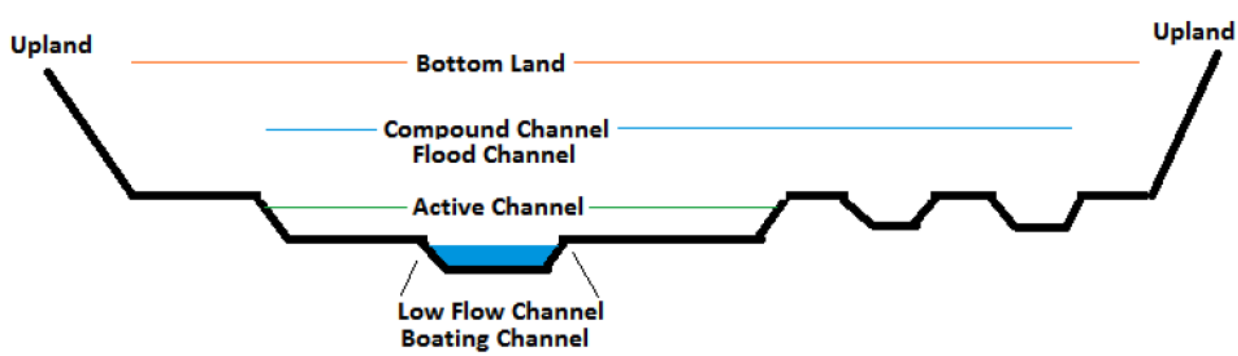
Fuller erroneously believes the Corps by using his term "compound channel" to mean that the braids only receive water during floods.

As an engineer, I was taught that a compound channel is a channel with 2 or more "critical depths". As a hydrologist, I was taught that a compound channel is a channel that has different characteristics at different flow rates. For example, in the cross-section I derived from the Olberg Plane table topographic survey (made right after Statehood), the Salt River is a single meandering low flow channel (the first channel to carry water) for the first three inches of depth. As the river rises to 4 inches, a new channel begins to flow and the river is braided. As the river continues to rise the two channels unite and the water begins to spread laterally until it hits the embankments. At that point, the river is a straight channel. When the embankments are overtopped, you probably have reached flood stage on the river.[16] Figure V-1 compares Fuller's cross-section to the cross-section presented in the same Corps report as the quotation. The Corps cross-section is described by the Corps as a very common river configuration for perennial rivers in the Southwest (see

[16]The term flood stage is a political/factual term that means that the water surface has risen high enough that the water begins to damage human developments.



Army Corps of Engineers



Fuller

Figure V-1

Figure V-1). The Corps presents a picture (Figure V-2) that shows what they think a compound channel looks like.

The Corps cross-section and photo show what their definition is. The critical aspect, which the Corps cross-section and photo makes clear, is that as more water flows in the channel, the river primarily widens rather than deepens. It would take a lot of water to get the mean depth to three feet as defined in the Utah Decision.

Further, when a river has two active channels, it does not follow that one will always be consistently the deepest. While the river elevations of the two channels must match immediately before the split and after the split what happens in the two (or more) channels in-between can vary dramatically.

In accordance with the directions from the Supreme Court, and the Appellate Court, I have broken the river configuration into three periods; Predevelopment, Statehood, and Current.

A. PREDEVELOPMENT

The Arizona Appellate Court indicated that records before the impact of the non-Indians on the Salt River may be indicative of the condition at the time of Statehood. The Pimas individually, and later the Pimas and the Maricopas jointly, controlled the Salt River Valley for hundreds of years. In the 1700s, the influx of the Apaches into the area forced the Pimas and Maricopas to

Figure 5. Compound channel with a low-flow feature in the foreground, Mojave River, CA.

Army Corps of Engineers

Figure V-2

consolidate into larger groups generally along the Gila River. The Salt River area did not become Apache territory but primarily became a "no man's land" between the warring parties. As such, the Salt River area was generally uninhabited, except near its confluence with the Gila River. By 1867, the Salt River was mostly abandoned, had acquired and/or maintained its then natural state - that is braided. In this region, navigation of a braided stream requires far more water than the Salt River could ordinarily provide.

The entire length of the Lower Salt River was surveyed in the 1860s by the Government Land Office from the current day location (approximately) of Granite Reef Dam to the junction with the Gila River. This survey occurred while the first non-Indian canal on the Salt River was in the process of being constructed. The survey plats of this survey are contained in Appendix A. Approximately 80% of the Lower Salt River was braided before the Anglo-Americans developed the area. Usually there were two channels, although on occasion there could be three or more channels. This is the best evidence available of the Salt River's condition before Anglo-American occupation.

B. STATEHOOD

The second period is the Salt River condition as of 1912. There are three sources of information concerning this second period. These are the Quadrangle maps by the USGS, the post 1860s surveys by the GLO, and the

Olberg Survey. Appendix A shows excerpts from these maps with excerpts from the Fairchild aerial surveys of the mid 1930s.[17] On the Lower Salt River, the Fairchild photos were taken in 1937. Although flows had been dramatically reduced, the Lower Salt River was still a live river in 1937 due to the unregulated inflow of the Verde River. This provides us with a good opportunity to see what very low flow looked like in the Lower Salt River.

C. CURRENT

Finally, there is the modern condition. The upstream area of the Salt River is heavily dammed. The Lower Salt has been channelized, mined for sand and gravel, bridged, and had a lake installed. There are numerous other changes that make it totally different than it was at the time of Statehood. There are two areas along the Salt River today where boating can occur (except when there is a major flood down the River). The first area is the Tempe Town Lake which is created by artificial inflatable dams and imported water from the Central Arizona Project. The second area where boating can occur along the Salt River is near the Salt's confluence with the Gila. The 91st Ave treatment plant releases a slowly varying flow that has created a single channel river that has considerable development and is becoming the Tres

[17]The Fairchild Aerial Survey was the first significant aerial mapping in Arizona. Aerial images obtained from the Maricopa County Flood Control District website, gis.maricopa.gov/MapApp/GIO/AerialHistorical/index.html

Rios Wetlands Project. Currently, the Tres Rios area is heavily infested with a non-native tree called salt cedar or *Tamarisk*. Salt cedar is very aggressive, and, given a good groundwater supply, grows fast and thick. If the navigability decision is based on what was the “natural” condition as of 1912, then what actually existed on the Lower Salt River in 1912, was the “natural” condition.

VI. COMPUTED DEPTH OF FLOW

As discussed in chapters II and III, the Lower Salt River was not navigated despite a historic need to do so. This appears to meet the test required by the Utah Decision for the Lower Salt River to be declared non-navigable. The Arizona Appellate Court laid out its understanding of what makes the susceptibility aspect to become relevant to the issue of navigability:

> ... {B}ut, where conditions of exploration and settlement explain the infrequency or limited nature of such use, the susceptibility to use as a highway of commerce may still be satisfactorily proved.[1]

This chapter assumes that the exploration and settlement discussed in Chapter III of this report and from other evidence causes ANSAC to conclude that the conditions and settlement were such that theoretical susceptibility is relevant. Based on that assumption, this chapter answers the question of why the Lower Salt River was not susceptible to navigation and examines four specific elements of that navigation question.

To compute the depth of water in the Lower Salt River, I need information concerning four variables.

- Flow (Q)

[1]Arizona Appellate Decision, pg 30.

- Longitudinal slope of the channel (S)
- Channel shape
  - a. Cross-sectional area (A)
  - b. Wetted perimeter (P)
- Roughness factor (n)

The flows (designated Q) are discussed in part A Flow. Longitudinal slope and the channel shape factors of cross-sectional area and wetted perimeter are discussed in part B Survey. The roughness factor is discussed in part C Soils. These are the variables necessary to solve the Manning's Equation for depth. Part D Depth discusses the depth of flow needed to determine whether the water was sufficiently deep that it could have, hypothetically (ignoring any obstacles), provided a "highway of commerce" on the Salt River.

A. FLOW

The Arizona Appellate Court indicates that the flow value must be under virgin or undeveloped conditions. This section discusses those flows.

1. Above the Salt/Gila Confluence

The river flow above the Salt/Gila confluence was discussed in some detail in my report on the Gila River. In that analysis, I determined the flows just above the Salt/Gila confluence on the Gila River and just below the

Salt/Gila confluence. The Salt River flow just above the Salt/Gila confluence is, by the engineering law of the conservation of mass,[2] equal to the flow determined by subtracting the Gila River flow above the confluence from the Gila River flow below the confluence. The resulting value represents the surface flows leaving segment 6b of the Lower Salt River.

The Salt River flow immediately above the confluence is higher than the upstream flows of the Salt River along the Gila River Indian Reservation (Reservation).[3] To be conservative, I am using the flow immediately above the Salt-Gila confluence for the entirety of the Salt River along the Reservation.

I conclude the virgin flows in the Salt River along the Reservation to be:

Mean	1760 cfs
Median	581 cfs

[2]The engineering law of the conservation of mass says that mass is neither created nor destroyed. In hydrology, this concept is also called a water budget. There are more technical exceptions to this whole concept but none apply here.

[3]The Gila Reservation Indian Reservation boundary is the middle of the Salt River. The location of the middle of the Salt River and hence the Reservation's boundary is being negotiated. Depending on where this boundary ends up, and where the Salt River channels were when the various flows occurred, the entire flow, none of the flow, or anything in between might have occurred on the Reservation. I am using the phraseology along the Reservation to mean the entire Salt River in Township 1 North Range 1 East G&SRB&M.

Low	86 cfs[4]

2. Below the Salt/Verde Confluence.

In my report on the Gila River, I found it necessary to compute the virgin flow of the Salt River at Granite Reef Dam. The virgin flow of the Salt River at Granite Reef Dam is virtually the same as the Salt/Verde confluence. I concluded the virgin flows of the Salt River at Granite Reef Dam to be:

Mean	1965.3 cfs
Median	791.0 cfs
Low	296.0 cfs[5]

3. The Old Mill Ave Bridge

Segment 6a was the subject of a groundwater study by the USGS that initially used data from early historic sources and then from a groundwater computer model.[6] Based on the early historic data, the water lost by the flowing river in segment 6a was 52.5 cfs (38,000 acre-feet per year).[7] This loss rate would vary based on flows, sedimentation, vegetation, temperature and numerous other factors. As the Salt River neared the

[4]Based on subtracting the flows from above the Salt-Gila Confluence (Gookin Hydrology, P.L.C. 2014b, Chapter II pg 12-13) from Below Confluence (Gookin Hydrology, P.L.C. 2014b, Chapter II pg 13).
[5]Gookin Hydrology, P.L.C. 2014b, Appendix A pg. 1.
[6]Thomsen and Porcello, generally.
[7]Thomsen and Porcello, pg 18.

bedrock barrier underlying the current day Old Mill Ave Bridge, the groundwater from the basin was thought to have returned 34.5 cfs (25,000 acre-feet per year) to surface flow[8] Since there was a very large groundwater basin receiving and discharging water, the return to surface flow would be virtually constant. As is discussed next, these early historic values along the Lower Salt River were found to be significantly different than pre-development values.

One issue during the hearing on the Gila River that seemed to create considerable confusion was the concept that before significant groundwater pumping, the use of water for irrigation normally increases the base flow of the river from which it comes. When farmers irrigate, some of the water diverted is consumed by evaporation or by the plants (called transpiration). However, some of the water seeps down into the groundwater and raises the groundwater. In early times, before the large storage dams or groundwater pumps, the amount of water consumed by the irrigation process as evaporation and transpiration was considerably lower than today's crops. However, the diversions were often as high or higher.

Today, a farmer can usually schedule a water delivery or turn on a groundwater pump whenever it is deemed best for the crop. A farmer of the

[8]Thomsen and Porcello, pg 13.

late 1800s and the early 1900s did not have that ability and would generally divert water whenever they could, before and during an irrigation season, in order to ensure that water would remain available in the soil for the plants. Major portions of those diversions would percolate down into the groundwater. This additional groundwater would cause the groundwater table to rise. In the early 1900s, groundwater levels had risen to the point that Tempe was waterlogging or as it is more commonly called, becoming a swamp. As the groundwater level rises, the amount of discharge from the groundwater at points of outflow (i.e. baseflow) increases.

After the USGS developed their groundwater model, they discovered that the early historic flows that they had thought were representative of the pre-development condition[9] were "...corrupted by irrigation return flow resulting from canal leakage and irrigation techniques."[10] This corruption of the data would lead to about a 60 percent variance in the amount of groundwater returning to the river.[11] The simulated river losses due to groundwater in segment 6a were 27.2 cfs (19,700 acre-feet per year).[12] This rate of loss would vary from time period to time period. The groundwater contribution to base flow at the outflow of segment 6a was,

[9]Thomsen and Porcello, pg 13.
[10]Thomsen and Porcello, pg 27.
[11]Thomsen and Porcello, pg 28.
[12]Thomsen and Porcello, pg 1.

according to the USGS model,13.5 cfs (9,800 acre-feet per year).[13] The difference between the early development and the pre development was due to the increase in the water tables, and hence the baseflow, by irrigation.

B. SURVEY

The same plane table survey that I used for the Middle Gila River in my Gila River report covered the westerly portion of segment 6b of the Lower Salt River. I derived the cross-section along with the information for the cross-sectional area, the wetted perimeter, and the slope from that plane table survey. The relevant portion of the survey is in Appendix A.

C. SOILS

The primary factor that affects the Manning's "n" in the low flow channels is the soil type. Vegetation, which is a huge factor on the floodplain is not present or at most minimally present in the channel. The only source of information on the soils at the site of the cross-section of the Lower Salt River in segment 6b was the soils survey by Thomas Means published in 1900. Means' description of the soils in the Salt River was that:

> [t]he material is almost entirely gravel and sand mixed in a heterogeneous mass, ... [o]f a similar class are the low islands in the stream channels.[14]

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[13]Thomsen and Porcello, pg 1.
[14]Means, pg 295.

Examination of the field notes from the Harrington 1919 survey of T1N R1E provided no information as to what the soils in the bottom of the Salt River were. The flood plains on the Lower Salt River were often described and the descriptions were consistent with Means' soil survey.

The variable for roughness of the channel (n) reflects numerous factors. These are generally soil, vegetation, and obstacles. There are several ways to pick Manning's "n". It is critical to remember that what we are looking for in this analysis is the flow within the channels for what is termed ordinary flow. This limits this analysis to no more than the daily average flow.[15] An ordinary flow channel usually has little to no vegetation. In fact, one of the primary determinants of the limits of the "ordinary high-water mark" is the area swept clean of vegetation. If the river channel had significant vegetation in the low flow channel(s), the vegetation would interfere with navigation. Obstacles are addressed separately in chapter VII.

This leaves us to discuss the Manning's "n" for a gravel and sand mixed channel bed. To eliminate the controversy, I have run computations for the minimum and the maximum "n" values of gravel and sand flow

[15] I am not denying that navigation can take place in the flows above the average flow. After subtracting the period of flood flows and recognizing the fact that the natural mean average flow is only exceeded about 20-25% of the time, there is such a small window left that it, by itself, does not suffice to meet the "ordinary" test.

Manning's Rougness "n" Values Figure VI-1						
River	Location	Beginning Page	"n"	"n" w/o Vegetation	Soils	Comments
Agua Fria	Below US 74	91	0.028	0.028	Coarse Sand and Gravel	Ephemeral
Agua Fria	Jomax	97	0.028	0.028	Coarse Sand and Gravel	Ephemeral
Cave Creek	Below Carefree Hwy	77	0.040	0.035	Cobbles and Boulders	Ephemeral
Waterman	Below Rainbow Valley	111	0.030	0.025	Sand	Ephemeral
Waterman	Below Eagle Rd	119	0.033	0.027	Sand	Ephemeral
Centennial	Below Railroad	83	0.025	0.025	Sand and Gravel	Ephemeral
Agua Fria	Below Buckeye Rd	105	0.030	0.030	Sand and Gravel	Ephemeral
Hassayampa	at CAP canal	53	0.027	0.022	Silt and Sand	Ephemeral
New River	Above New River Rd	65	0.040	0.040	Cobbles and Boulders	Flowing
New River	Above I17	71	0.030	0.030	Boulders	Flowing
Gila	Above Bullard Ave	15	0.030	0.027 0.025	Sand and Gravel	Flowing
Hassayampa	Below Highway 80	59	0.028	0.025	Sand and Gravel	Flowing
Hassayampa	Near Wikenburg	47	0.025	0.025	Silt and Sand	Flowing
Salt	Below Granite Reef	32	0.055	0.040		Flowing
Gila	Above Gillespie Dam	23	0.025, 0.025, 0.029, 0.030	0.025 0.027		Flowing
Salt	Below 24th ST	39	Not Applicable due to Artifical Condition			

Source: Thomsen and Hjalmarson pg #s in table

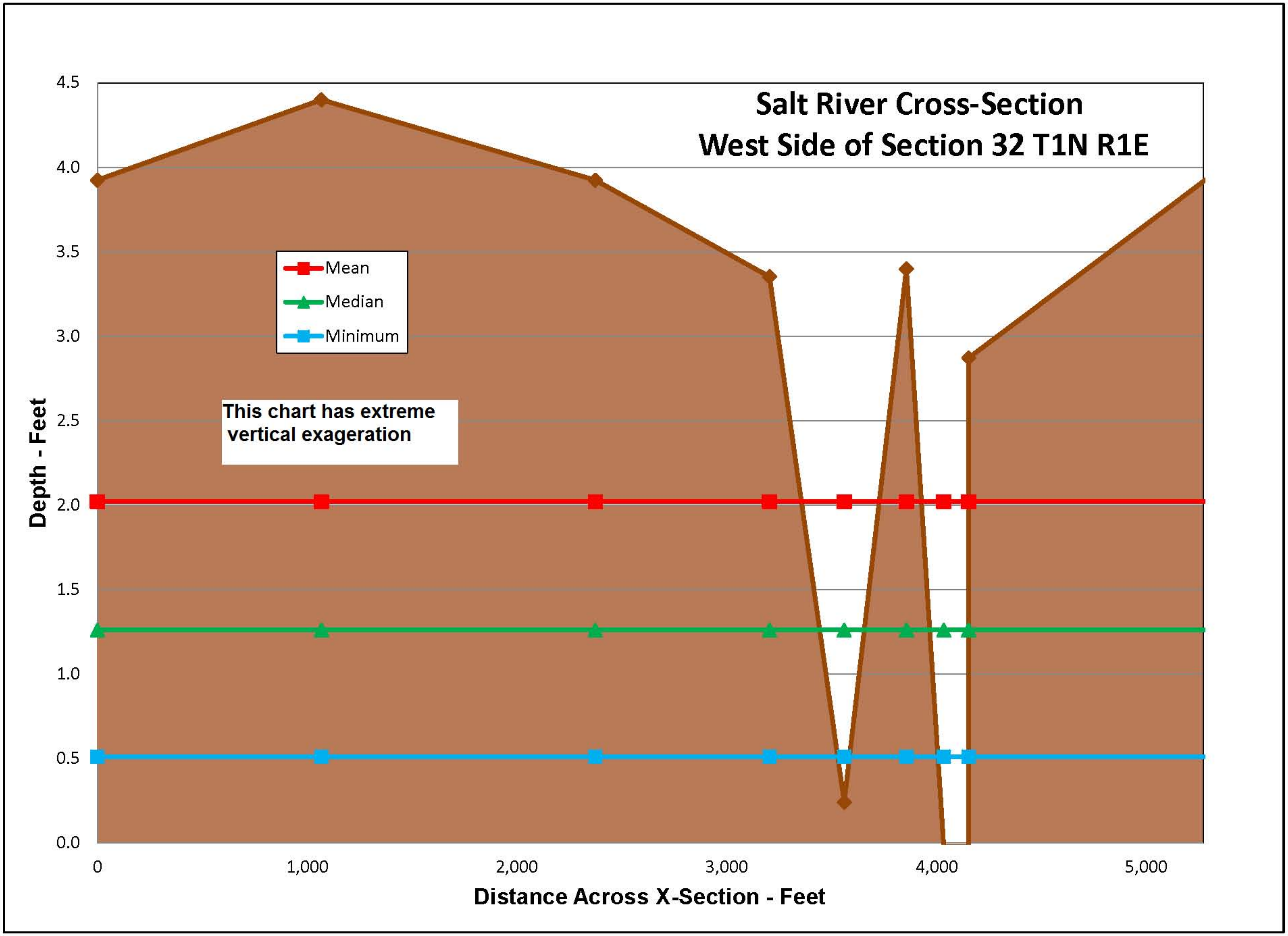
Green means most applicable

Yellow means somewhat applicable

channels using values from Hjalmarson's Maricopa County Flood Control Book[16] of 0.025 and 0.030 (see Figure VI-1). I believe that .030 is a bit low and think .035 if more indicative of gravel and sand channels. Fuller in his analysis[17] states "a composite Mannings'[*sic*] roughness coefficient of 0.045 was selected to represent gravelly sand beds, with possible dune and ripple bed forms, and channel bank and floodplain vegetation."[18] I do not agree that dune and ripple bed forms or floodplain vegetation would be relevant to the ordinary flow channel(s). There are no dune and ripple bed forms in a gravel and sand riverbed except at very high flows. The gravel and sand channel is what was observed at the time by Soil Scientist Means. The use of an artificially high Manning's "n" caused the depths to be overstated by Fuller. The results of all four values of "n" discussed are shown in Figure VI-2.

Using Manning's Equation, I computed the water elevation that would have occurred at various flows on the Lower Salt River.[19] This cross-section is presented as Figure VI-3 based on the values using Manning's "n" of .035. Figure VI-2 shows the resulting maximum and mean depths, widths, and velocities for all four Manning's "n" along the Lower Salt River segment

[16]Thomsen and Hjalmarson, pg 16-17, 60-61, 84-85.
[17]CH2MHill, pg 7-22.
[18]CH2MHill, pg 7-22.
[19]I solved the equation using the section factor technique.


Salt River Cross-Section
West Side of Section 32 T1N R1E
Mean
Median
Minimum
This chart has extreme vertical exageration
Depth - Feet
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1,000
2,000
3,000
4,000
5,000
Distance Across X-Section - Feet

Results of Manning's Eq'n					
Figure VI - 3					
	Mean Depth - Feet				
	Flow - cfs	n=.025	n=.030	n=.035	n=.045
Mean Flow	1,760	1.04	1.12	1.18	1.30
Median Flow	581	0.69	0.74	0.78	0.86
Minimum Flow	86	0.34	0.36	0.38	0.42
	Maximum Depth - Feet				
	Flow - cfs	n=.025	n=.030	n=..035	n=.-045
Mean Flow	1,760	1.87	2.02	2.15	2.39
Median Flow	581	1.16	1.26	1.35	1.50
Minimum Flow	86	0.46	0.51	0.55	0.62
	Average Velocity - fps				
	Flow - cfs	n=.025	n=.030	n=.035	n=.045
Mean Flow	1,760	2.69	2.35	2.09	1.73
Median Flow	581	2.04	1.78	1.54	1.31
Minimum Flow	86	1.27	1.11	0.98	0.81
	Width - Feet				
	Flow - cfs	n=.025	n=.030	n=.035	n=.045
Mean Flow	1,760	628	672	712	783
Median Flow	581	414	443	470	516
Minimum Flow	86	202	216	229	252

6b. All the computations indicate that a boat that only needs 6 inches could, based only on depth, float the Salt River. A boat that requires 3 feet could only float the Salt River during extra-ordinary flows.

D. DEPTH

The question arises as to what is required for a commercial boat to travel on a river. This was discussed in considerable detail in my Gila River report where I concluded, based primarily on the Utah Decision, that a river should have a mean average depth of three feet or more to meet the test of navigability.

The pro-navigability parties have been claiming that 6 inches or less constitute navigable waters. Fuller, in 1998, explained that there is considerable disagreement.

> Charts are available which indicate minimum width and depth for various kinds of boats, but there is little agreement on the actual figures.[20]

Not only is the navigable depth dependent on the type of boat, it is also dependent on what you carry in it. As Fuller pointed out, "[w]ith two paddlers and some goods, a canoe can sink 6" deeper than with one paddler and a few supplies."[21] Fuller indicates that a canoe can carry 500

[20]Stantech, pg 36.
[21]Stantech, pg 37.

lbs of cargo.[22] If that value is true and one person and supplies (estimated at 200lbs) adds 6 inches then 500 lbs would add 15 inches to the 12 inches the two people require for a total of 27 inches. Fuller states that:

> [d]raw is a good indication of required depth, but not equivalent to it, as the needs of the paddler must be considered as well as the ability to avoid rocks on the bottom.[23]

The U.S. Army Corps of Engineers indicates that draw be limited to 75% of channel depth.[24] This means that Fuller's required depth for a highway of commerce using a modern recreational canoe is three feet.[25]

Fuller presents depths for 3 flow rates (277, 1230, and 2,957 cfs) in his 2015 PowerPoint on the Lower Salt River.[26] For those flow rates, he indicates the depths 0.8, 5.3, and >6 foot depths respectively. The depths for those flows according to Fuller's rating curve[27] are 1.7, 4.2, and >6 feet.

Fuller’s PowerPoint presents maximum depths. The Utah Decision uses mean depth which can be calculated for the data on Fuller’s PowerPoint slide[28] for the first two values.

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[22] Fuller 2015a, slide 71.
[23] Stantech, pg 37.
[24] U.S. Army Corps of Engineers 1980, pg 4-2.
[25] 12 inches + 15 inches = 27 inches/0.75 =36 inches= 3 feet. This load would probably sink the canoe.
[26] Fuller 2015b, slide 238.
[27] CH2MHill, pg 7-24, see also Fuller 2015b, slide 235.
[28] Mean Depth = Flow / (Width*Velocity)

Flow	PPT Table Max Depth	PPT Rating Curve Max Depth	Computed Mean Depth
277	0.8	1.8	0.8
1230	5.3	4.2	2.0
2957	>6	>6	??

In a 1996 report, Fuller prepared several cross-sections, including the one presented in the 2015 PowerPoint, for the Salt River and presented the "Average Hydraulic Characteristics"[29]. These average hydraulic characteristics show the flow, maximum depth, and mean depth[30]

Flow	Maximum Depth	Mean Depth
20	0.3	< 0.1
300	1.4	1.1
1400	3.2	2.1

The values shown immediately above represent the average of the cross-sections. Although the flows in the two tables are not the same, you would expect that the PowerPoint cross-section's maximum depth at 1230 cfs (shown as either 5.3 or 4.2 feet) should be less than the average of the cross-sections' maximum depths at 1400 cfs. Yet the average is only 3.2 feet. In 1996, Fuller concluded from his rating curve analysis that

[29]CH2MHill pg 7-26.
[30]Mean Depth is calculated by me.

"[m]aximum depths generally range between one and five feet."[31] This means that the PowerPoint slide and the rating curve chosen for display by Fuller in his PowerPoint is for a better than average cross-section. Using the value of 1230 cfs and checking all the rating curves in Fuller's Appendix D[32], it is obvious that Fuller is presenting his best (deepest) case cross-section as being representative of the entire river. Four of the six cross-sections in Appendix D come in at a maximum depth that is less than three feet. Fuller should be presenting the worst (shallowest) case cross-section.

I examined the rating curves shown by Fuller in his Appendix D.[33] The rating curves have one fundamental problem. In each case, the cross-section shows that Fuller assumed that only one channel is being used.[34] That is probably true for the very very low flows. The maps used by Fuller for this study do show one active channel. Those maps were for 1902. By 1902, all but the very high flows were being diverted. All that was left was a residual trickle. Assuming one channel during median and mean flows is often incorrect. The second channel in most cases would be flowing during median and mean flows. Cross-section 1 (which is located near to my cross-section) and cross-section 5, in particular, show that the two low flow

[31]CH2MHill, pg 7-22, 7-25.
[32]CH2MHill. Appendix D
[33]CH2MHill.
[34]CH2MHill, Appendix D cross-sections.

channels have equal or nearly equal depth bottoms.[35] I know that in the cross-section 1, the Salt River channels join and divide again repeatedly. This would cause the flows to enter both channels. By assuming 1 channel, the flow depth computed by Fuller becomes significantly overstated.

The flow in the Lower Salt River was well below the three foot mean depth needed for navigation. The Utah Decision used mean depth as its criteria. The Lower Salt River segment 6b is clearly not navigable.

[35] CH2MHill, pg 7-26. Figure 17.

VII. OTHER BARRIERS TO NAVIGATION

The use of Manning's Equation as described in chapter VI did not consider obstacles. Simply computing a water depth does not prove the susceptibility of a river to navigation. As Mr. Fuller has explained:

> Obstacles include **boulders**, overhanging branches, **beaver dams,** sand bars or man-made obstacles such as dams or barbed wire fences. Some of these obstacles are more of a problem at some times of year than others....Boulders that are fully submerged by plenty of water can be avoided, while boulders emerging from the water can lead to crashes.[emphasis added][1]

Obstacles can, and often do, exist in the natural state. Four types of obstacles existed; they were floods, marshes, beaver dams, and rapids. Each is discussed below.

A. FLOODS

One of the aspects of floods in the Southwest is that they are very rapid, very violent, come without warning, and carry a tremendous amount of debris with them. In short, floods are dangerous to watercraft, cars, and people. As the USGS observed concerning the Gila and Salt River in their 1889-1890 Annual Report:

> These floods are of the most destructive and violent character; the rate at which the water rises and increased in amount is astonishingly rapid, … . For instance, in an ordinary flood, the Salt

[1]Stantech, p.37.

> River, the principal tributary of the Gila, has risen in about three hours from 500 second-feet to 30,000 second-feet, falling again almost as rapidly, so that they average for the day or for two or three days would not be more than 10,000 or perhaps 5,000 second-feet. From this it will be recognized that the onsite of such a flood is terrific. *Coming without warning, it catches up logs and bowlders [sic] in the bed, undermines the banks, and tearing out trees and cutting sand-bars is loaded with this mass of sand, gravel, and driftwood – most formidable weapons for destruction... .* [italics added]*.*[2]

The USGS in the 1890-91 annual report stated:

> These streams fluctuate greatly, being at times subject to sudden floods, … when they often sweep up bridges, dams, and canal head works, ...[3]

The USGS went on to state "The floods of the Upper Gila and its tributaries [the Salt River was one of the tributaries listed] are usually short and violent,...".[4]

In the Sixteenth Annual Report in 1894-95, the USGS discussed the Gila, Salt and Verde Rivers and said:

> …but these floods occur at such irregular intervals and come with such violence...[5]

The Special Master in the Utah Decision, in his analysis of the navigability of the rivers, considered the issue of "variations in flow and rapidity

[2]Fuller 2003b, pg IV-42.
[3]Fuller 2003b, pg IV-42.
[4]Fuller 2003b, pg IV-42.
[5]Fuller 2003b, pg IV-46.

of variations."[6] The Utah Special Master concluded that flow variations in the rivers he was considering were not sufficient to preclude navigability. However, the floods that the Utah Special Master considered[7] had slower rises and slower falls than the Gila or Salt Rivers due in part to the large areas that they drain.

The Utah Special Master concluded, based primarily on the fact that people had successfully navigated the rivers that the change in the velocities and stage of the river did not effectively deter navigation and that floods were not an obstacle to successfully using most of the rivers as a highway of commerce. This cannot be said of the Salt River. The changes on the Salt River are more dramatic and have a greater potential for destruction of boats. The people in the Salt River Valley did not use the Salt River as a highway of commerce.

B. MARSHES

As I documented in my 2003 statement, the west end of the Reservation, including the Salt River along the boundary in T1N R1E was marsh land.[8] To the extent that marsh land invaded the channels, the marshes would be difficult to impossible to traverse by boat.

[6] Warren pg 169.
[7] Warren, pg 170.
[8] Gookin Engineers 2003, pg 5.

C. BEAVER

There were earlier impacts along the Salt River due to non-farming related activities. One major activity was beaver trapping. If beaver trapping had not occurred, it would have been much harder to navigate the river. The first recorded trappers, the Pattie party, came in 1825 and numerous other beaver trapping parties occurred after that.

Beaver dams would provide a significant obstacle to commerce up and down the Salt River. While traversing each individual dam would not constitute a major barrier, hundreds of them cumulatively would make commercial trade impracticable. The U.S. Supreme Court made the point that "Even if portage were to take travelers only one day, … it demonstrates the need to bypass the river segment, all because that part of the river is non-navigable."[9] My logic of considering hundreds of small trips as making the river non-navigable is well explained by the Special Master in the Utah Decision, in which he was evaluating the problem of sand bars. The Special Master states:

> The test must be, in my opinion, the extent to which those difficulties prevent persons from using the River by boats to attain the end or purpose which they seek, or, in other words, how far the bars prove an impediment to the practicable use of the Rivers in the commerce for which they are used or capable of being used.[10]

[9]Montana Decision pg 18.
[10]Warren, pg 91-92.

I believe that hundreds of portages would “… prove an impediment to the practicable use of the Rivers.”

We know that the trappers on the Salt River found considerable numbers of beaver and trapped them out of existence. There is one question; did the beavers build dams?

There is no evidence that the beaver trappers used canoes on the Salt River. Evidence did exist for canoes on the "Beaver River" (the San Pedro River) and for the Colorado River. This is significant because it shows the chronicler did consider building water transport worth recording but did not record water transport on the Salt River.

As indicated, all parties agree there were beaver. Further, we know there were beaver dams on the Salt and Verde Rivers. Goode P. Davis copied many paragraphs from an 1867 document by Ornithologist Coues that was published in the American Naturalist.[11] One portion of the copying reported that:

> "[the beaver] is found abundantly on all the streams of the Territory.... Particularly upon the Rio Salado [Salt River] and San Francisco [Verde River] as it is very abundant; and its dams occur, in some places, every few hundred yards"[12] [brackets in original].

[11]Davis Jr., G. P. 1982, pg 167.
[12]Davis Jr., G. P. 1982, pg 172.

This is not surprising for three very good reasons to believe that the beaver did build dams. As is documented in chapter VI, the low flows of the Salt River are less than 3 feet deep. Numerous sources document that the beaver want/need to have a **minimum** of 3 feet of water year-round.[13] If the beaver don't have the required water depth, beavers create the necessary depth by building dams. Fuller denies the existence of beaver dams stating that beavers don't build dams on major rivers. I checked the USGS records for what they defined as major rivers. The USGS used three different criteria: river length, drainage area, and average flow.[14] The Salt River flunked all three criteria for being a major river. The Gila River qualified as being a major river, based on drainage area, but not on the other two criteria.

The second reason to believe the beaver built dams in the area is the marshes that existed in the Salt/Gila confluence areas.[15]When beavers build a dam, it will, over time, fill with silt. The beaver will abandon the site and move to a new site. The silted pond becomes a marsh. Although

[13]Ohmart and Anderson, pg 181. See also Andersen and Shafroth pg 334; and Shepherd and Golden.

[14]Kammerer.

[15]Brawley-Chesworth and Conroy, pg 2.

marshes can occur for other reasons, it is an indicator that beaver dams may have been present in the area.[16]

The third reason to believe the beaver did build dams in the Salt/Gila confluence area is that the beaver are still building them in this area. The Gila River Indian Reservation northwestern boundary is, according to the Executive Orders that created this portion of the Reservation, to the middle of the Salt River. The North half[17] of the Salt River is being developed by a consortium of non-Indian governmental entities. The City of Phoenix[18] has a sewage treatment plant at 91st Avenue that discharges into the Salt River near the Reservation boundary. For many reasons, the water has been used to create a marsh like area called the Tres Rios Wetlands Project in the northern half of the river. Although beaver were not introduced to this area, the beaver found the area anyway.[19] The beaver started building dams. At first the operators of Tres Rios were pleased, then problems arose and now the project is perplexed on how to limit them. Tres Rios has

[16] Brawley-Chesworth and Conroy, pg 2.

[17] I use the term "half" loosely. Given the highly changing nature of rivers, such a description requires the application of a complicated set of factual and legal principles to decide the exact boundary. This issue is the subject of negotiations that may result in a Congressional Solution defining the location of the boundary by an explicit metes and bounds description.

[18] In conjunction with certain other Valley cities.

[19] Brawley-Chesworth and Conroy, pg 1.

attempted to limit the beaver presence by non-lethal means.[20] State law prevents them from trapping and relocating the beaver. Therefore, Tres Rios, with the support of other interested agencies, began looking for other alternatives.

The entire experience on Tres Rios taught us some things and reinforced others.

We already knew that humans historically tended to kill beaver. Humans still do. It is currently illegal to do so but Tres Rios found that at one point in time the beaver disturbances abated to a degree. Based on Tres Rios interviews with locals who saw people shooting the beaver,[21] Tres Rios concluded that illegal hunting could be the significant factor in the abatement of beaver.[22]

We already knew that beaver do not use ephemeral or Intermittent streams. This explains why, for example, the reaches below where the Aqua Fria joins the Gila River do not have beaver dams

While it was known that the beaver, in Arizona, liked cottonwoods and willows, we did not realize the extent of that preference. The area of the Salt/Gila confluence is heavily vegetated with Salt Cedar (aka

[20]Taylor, Bergman, and Nolte, pg 44.
[21]Brawley-Chesworth and Conroy, pg 3.
[22]Nolte et. al., pg 78.

Tamarisk). There are numerous differing explanations as to how they got to this region, but all agree they are a non-native plant (in particular a phreatophyte, a plant that needs its roots in the water). In the Tres Rios Project, many of the *Tamarisk* were removed and replaced with native vegetation. One of the big problems that the beavers caused in the Tres Rios area was the destruction of the cottonwood and willows.[23] One means of trying to control the beaver was to try coating the native vegetation with various compounds to cause the beaver to ignore their native favorites and use the *Tamarisk*. The beaver wouldn't do it. Apparently, the tannin and salt in the *Tamarisk* are extremely repulsive to beaver.[24] The Tres Rios Project had limited success in getting beaver to like Tamarisk if the Project coated the *Tamarisk* with sugar (fructose) mixed with polyethylene glycol and coated the native cottonwood and willow trees with an herbivore repellent.[25]

The southern half of the Salt River is undergoing restoration by the Gila River Indian Community (Community) to create a more natural riverine environment. Some of the water is seepage from groundwater and that groundwater is augmented by agricultural drainage water that exits from a

[23]Nolte et. al., pg 75.
[24]Taylor et. al., pg 45.
[25]Taylor et. al., Abstract.

ditch that runs along the diagonal portion of the Reservation boundary and empties into the Lower Salt River. The Community started development at the discharge of the ditch and have been working downstream from there. Mr. Charles Enos of the Community's Department of Environmental Quality, indicated in a recent presentation at a seminar[26] that when the Department first examined the Community's Salt River area near the change of the millennia, they found that the beaver had built 12 dams in the first 1000 feet of channel (one every 83 feet). The Community also learned from the Tres Rios project that they needed to put physical barriers around the trunks of the native species (cottonwood and willow) to prevent the beaver from getting to them.

D. RAPIDS

Fuller indicates that rapids are a challenge not an obstacle. Fuller has three items of proof. First, Fuller runs rapids in his modern Royalex canoe. This was discussed in Chapter IV. Second, Fuller indicates that a canoe can navigate up to and including Class V rapids.[27] Fuller, in 1998 stated, "[g]enerally speaking Class II is the upper limit for open canoes"[28]

[26] WRRC Annual Conference. Tribal Riparian Restoration in Arizona.
[27] Fuller 2015a, slide 82.
[28] Stantech, pg 36.1

Thirdly, Fuller claims three rivers in the United States with major rapids have been determined to be navigable. In each of those cases, Fuller shows portions of the rivers that have significant rapids and uses that as a basis for showing that the rapids did not impact navigability. These three rivers are the Colorado River, the John Day River, and the Salmon River.

The Colorado River is a navigable river for a portion of its length. Fuller correctly quotes the decision that shows the Colorado River is navigable in portions of Arizona. Fuller states "[t]he ***navigable*** Colorado River has some of the largest rapids in North America." [emphasis in original][29] Fuller goes on to point out that “[r]apids are minor parts of the rivers' lengths."[30] As proof, Fuller references the famous Powell trips down the Grand Canyon. Fuller also points out that the Colorado River, which is navigable, has some of the only class V rapids in Arizona.[31] What Fuller missed was that the referenced decision[32] indicates that the Colorado River is only navigable up to Black Canyon. The Court stated "[w]e knew judicially, from the evidence of history, that a large part of the Colorado

[29]Fuller 2014c, slide 82.
[30]Fuller 2014c, slide 82.
[31]Fuller 2014c, slide 95.
[32]Fuller 2015b, slide 272.

River south of Black Canyon was formerly navigable."[33] The Black Canyon encompasses the Hoover Dam area. The navigable portion of the Colorado River does not extend into the Grand Canyon or into most of the area that Mr. Powell traversed in his two exploratory expeditions. The statement Fuller makes that these reaches are navigable is not that of a court or other legal entity. Fuller also claims that Powell's trips were successful and were repeated in modern times. The story is more complex than indicated by Fuller. Powell did make two trips. On the first trip, Powell lost one of their four boats that started when it "smashed on rocks."[34] "From then on out almost all of the rapids were either portaged or lined[35] through the rapids."[36] This was "...a process that took many hours and tremendous effort."[37] Due to the limited capacity of the remaining three boats, the group "...faced diminishing provisions."[38] This was such a problem that the second time Powell had arrangements made to "...have supplies brought down to the river at various points."[39] Not only was Powell not able to float

[33]U.S. Supreme Court, Arizona v. California, 283 U.S. 423,453 Footnote 3 in the decision states "... [n]avigability extended as far north as the mouth of the Virgin River at Black Canyon." The Virgin River is a tributary to Lake Mead.

[34]The Seattle Times.

[35]Lining is the act of maneuvering an empty boat through particularly difficult rapids by the use of ropes held on the shore.

[36]Arizona River Runners.

[37]Youngs.

[38]Youngs.

[39]Youngs.

commercial goods, he could not carry enough supplies on the boats for either of the trips to be self-sufficient. Successful modern trips occurred on the Colorado River after Glen Canyon Dam and numerous other upstream dams were built that, combined with new materials used in the modern day recreational boats, enabled the activity to be a booming recreational business.

Later, as Fuller indicates, a reenactment of Powell's trip was made[40] by the BBC. The Pacific NW Magazine reported on the original trips and the reenactment. The magazine paints an interesting picture of Powell's trip:

> the one-armed Union Army veteran's [Powell's] big claim to fame was an adventure in which he brought a pocketknife to a gunfight. So to speak. ... Through dumb luck, of his original 10-member expedition only three who deserted and hiked out perished.... Symbolic of Powell's almost numbskulled approach to Western rivers was his command post on a later exploration: a wooden captain's chair... .[41]

The boats used for the reenactment had a couple of advantages. The first is, of course, the dams upstream which eliminate a lot of potential surprises. The second was that the builder of the reenactment boats

[40]Fuller 2014c, slide 35.
[41]The Seattle Times.

"...both boosted the number of frames and made them half again as thick and half again as wide."[42]

The second river in the United States that Fuller claims has major rapids and has been determined to be navigable is the John Day River. The John Day River is located in the State of Oregon. The John Day River is approximately 280 miles long. The Oregon Appellate Court determined that about 17 miles of the John Day River were navigable under the federal standard.[43] The remaining 253 miles were not before the Oregon Appellate Court and did not receive a navigability determination pro or con. It is a major and undocumented assumption that the rapids portions of the River were part of the navigable determination. The Oregon Appellate Court Decision does talk about varying boating activities that had historically occurred and how the boating activities were limited to specific reaches between rapids.

Fuller also points out that the Salmon River "is navigable"[44] and again presents a picture of rapids. I am unaware of where Fuller got the statement that the Salmon River is navigable unless it is just a personal opinion. I looked for the case that determined that the Salmon River was

[42] The Seattle Times.
[43] Haselton 112 P.3d 383, 199 Or. App. 471.
[44] Fuller 2014c. slide 10.

navigable. There is one case making New York's Salmon River navigable for Commerce Clause purposes.[45] In Idaho, where the other Salmon River lies, the "Advocates of the West" filled a petition with the U.S. Army Corps of Engineers asking the Corps to "revisit its determination from the 1930's that Idaho's Salmon River is not navigable".[46] Finally, SRP compiled a report of rivers that have had navigability for title purposes.[47] Neither Salmon River was listed.

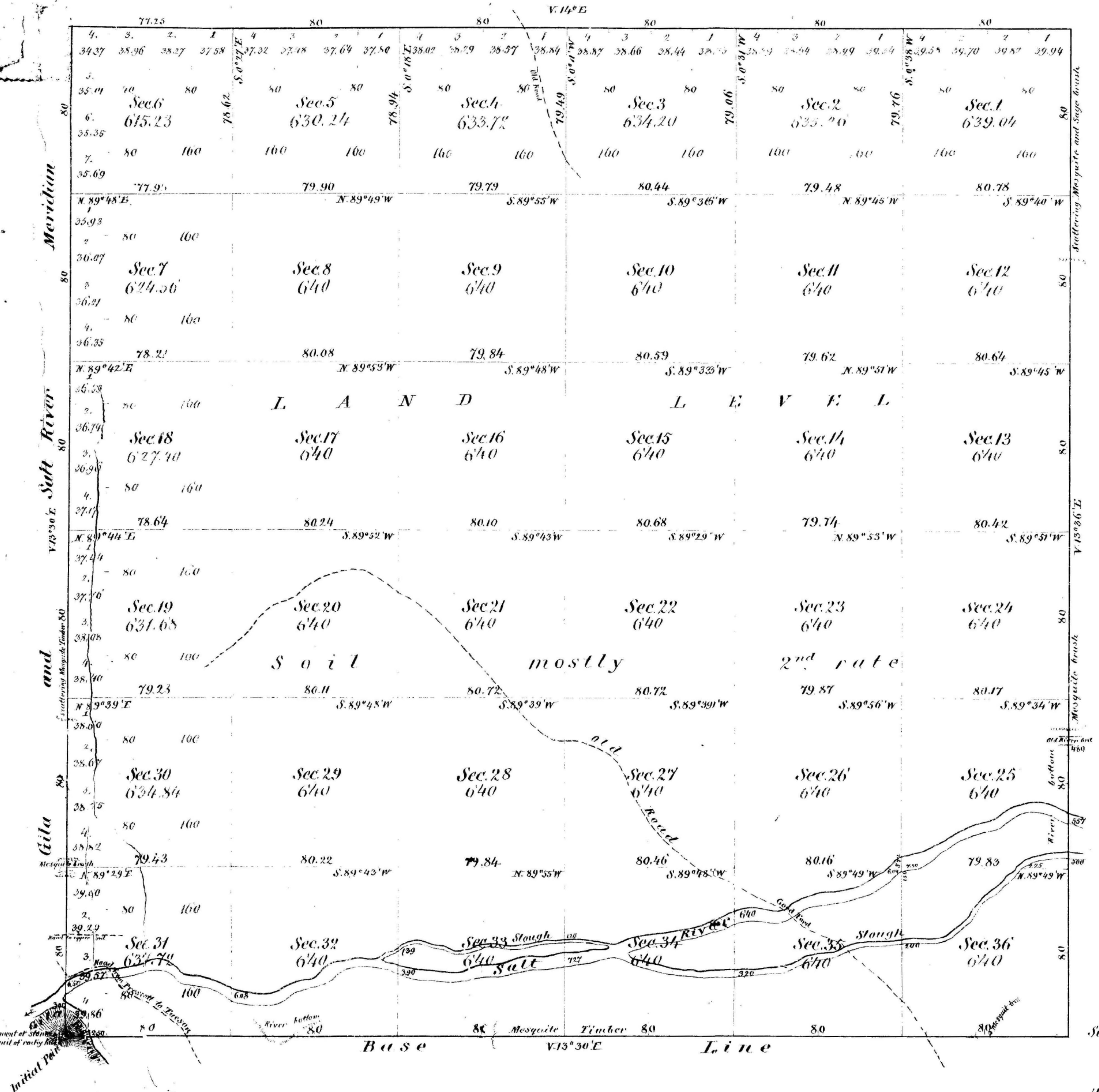
[45]American Whitewater.

[46]Advocates for the West.

[47]Salt River Valley Water User’s Association and Salt River Project Agricultural Improvement and Power District.

Appendix A

Township No. 1 North, Range No. 1 East, Gila and Salt River Meridian



Received at U.S. Land Office Prescott Arizona December 2 1870.

OFFICIALLY FILED 12-2-1870

Section lines run at a Variation of 13° 36' East.

Aggregate Area of Public land 22,944.89 Acres

Surveys	Designated	By Whom Surveyed	Date of Contract	Amount of Surveys	When Surveyed
West and South boundary of Township		Wm. H. Pierce	December 15th 1866	———	1867
East " North	" " "	W. F. Ingalls	February 18th 1868	11 Ms. 77 Chs. 25 Lks.	1868
Section lines		" " "	" " "	59 " 73 " 80 "	March 12th 1868

The above Map of Township No. 1 North, Range No. 1 East of Gila and Salt River Meridian is strictly conformable to the Field notes of the Surveys thereof on file in this Office which have been examined and approved.

Surveyor General's Office,
San Francisco, California,
October 8th 1868.

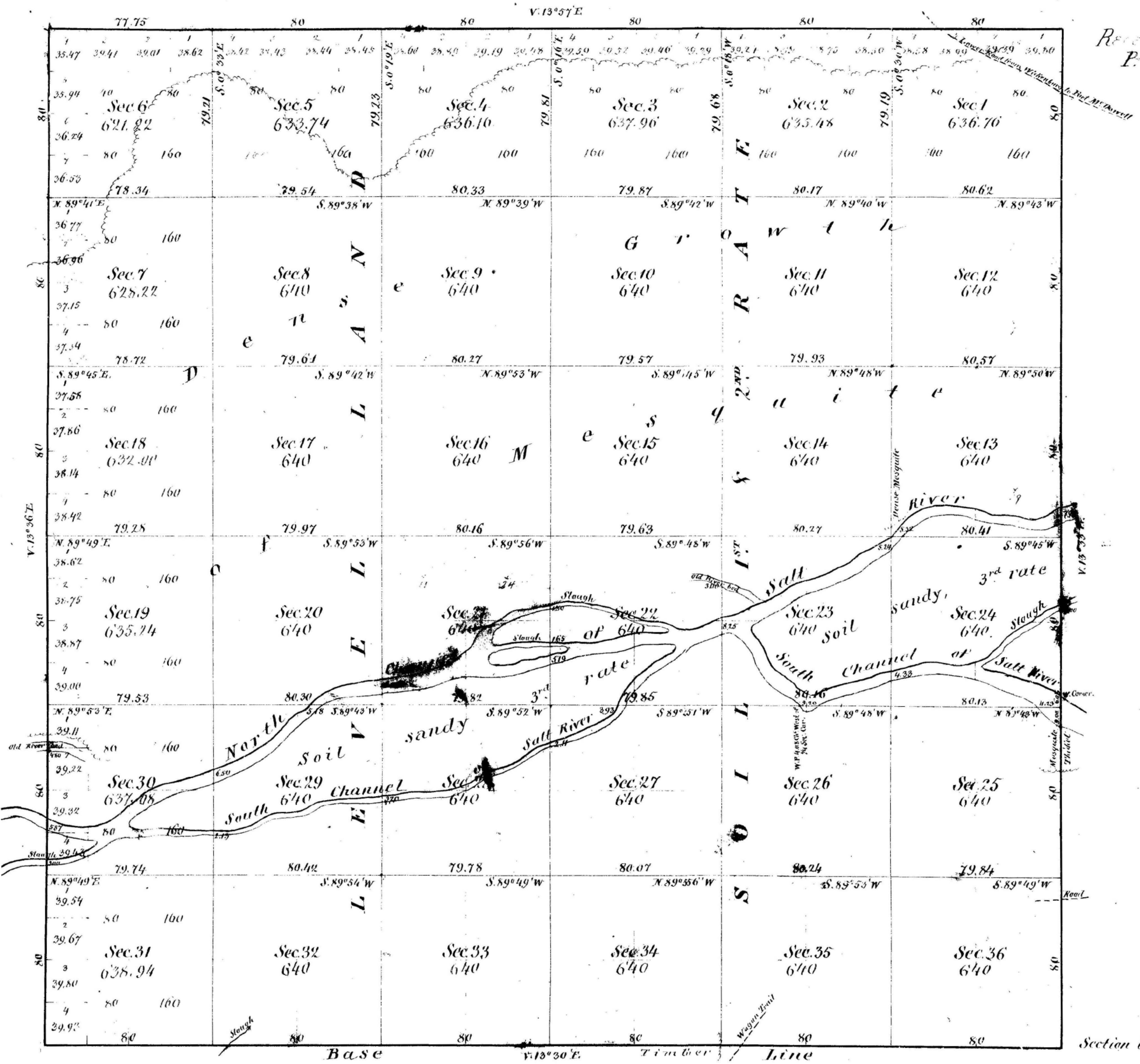
Surv. Gen. Cal. and Arizona.

00005

Township No. 1 North. Range No. 2 East, Gila and Salt River Meridian

Recorded and filed U.S. Land Office [illegible]

OFFICIALLY FILED 12-2-1870



Section lines run at a Variation of 13°33' East.

Aggregate Area of Public land 22,972.80 Acres.

Surveys Designated	By Whom Surveyed	Date of Contract	Amount of Surveys	When Surveyed
South boundary of Township	Wm. H. Pierce	December 15th 1866		1867.
Rest of Township lines	W. F. Ingalls	February 14th 1868	17 Ms. 77 Chs. 75 Lks.	1868
Section lines	" " "	" "	59 . 74 . 26 .	March 24th 1868.

The above Map of Township No. 1 North, Range No. 2 East of Gila and Salt River Meridian is strictly conformable to the field notes of the Surveys thereof on file in this Office, which have been examined and approved.

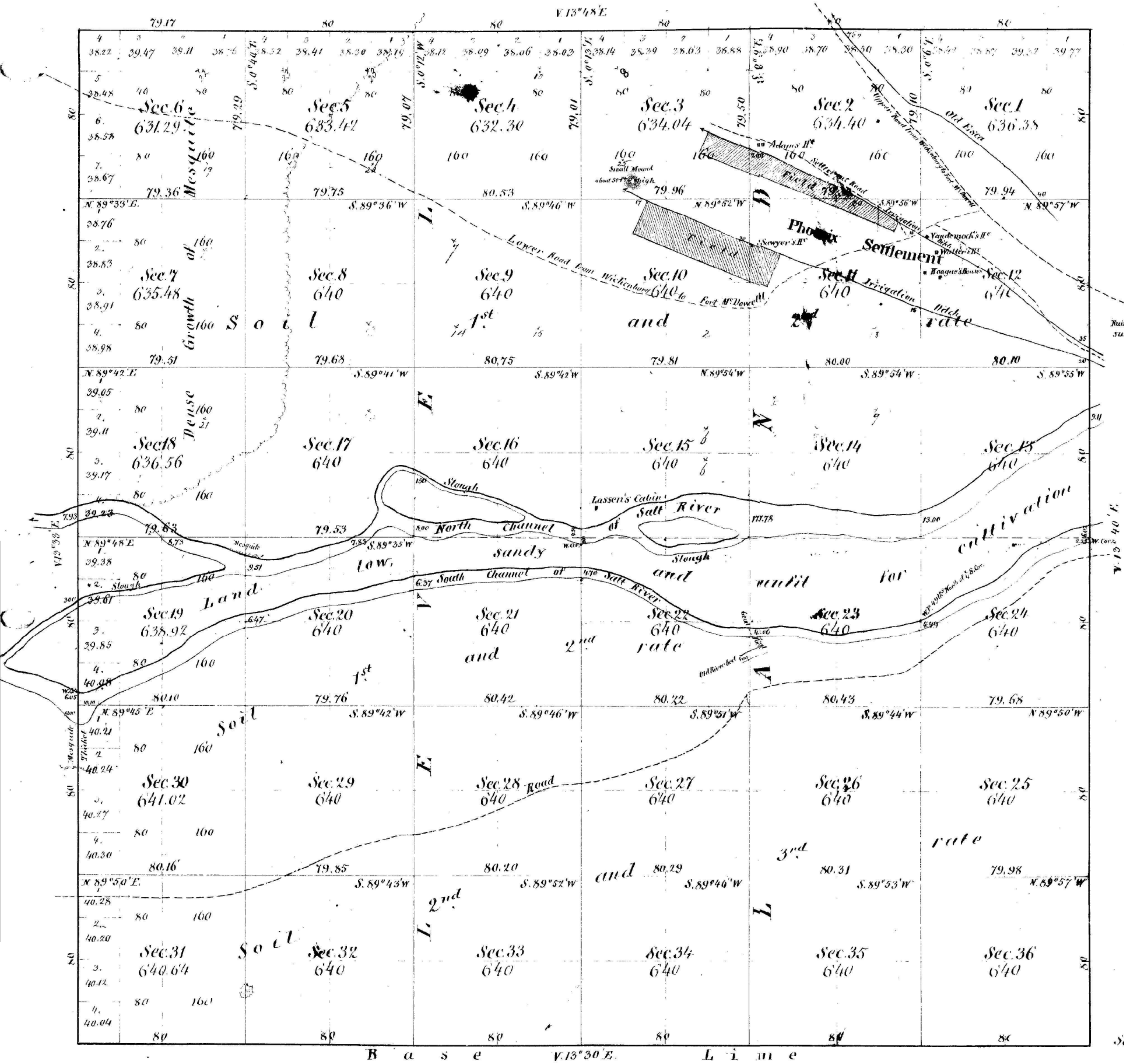
Surveyor General's Office,
San Francisco, California,
October 9th 1868.

Sherman Day

Surv. Genl. Cal. and Arizona

00009

Township No. 1 North, Range No. 3 East, Gila and Salt River Meridian



Aggregate Area of Public land 22,997.89 Acres.

Section lines run at a Variation of 13° 40' East

Surveys Designated	By Whom Surveyed	Date of Contract	Amount of Surveys	When Surveyed
South boundary of Township	Wm. H. Pierce	December 15th 1866		1867
Rest of Township lines	W. F. Ingalls	February 18th 1868	17 Ms. 79 Chs. 71 Lks.	1868
Section lines	" "	" " "	55 " 75 " 82 "	April 4th 1868

The above Map of Township No. 1 North, Range No. 3 East of Gila and Salt River Meridian is strictly conformable to the field notes of the Surveys thereof on file in this Office, which have been examined and approved.

Surveyor General's Office,
San Francisco, California,
October 15th 1868.

Sherman Day
Surv. Gen. Cal. and Arizona

Received and filed in U.S. Land Office Prescott, Arizona December 2d 1870.
Wm. J. Berry
Register.

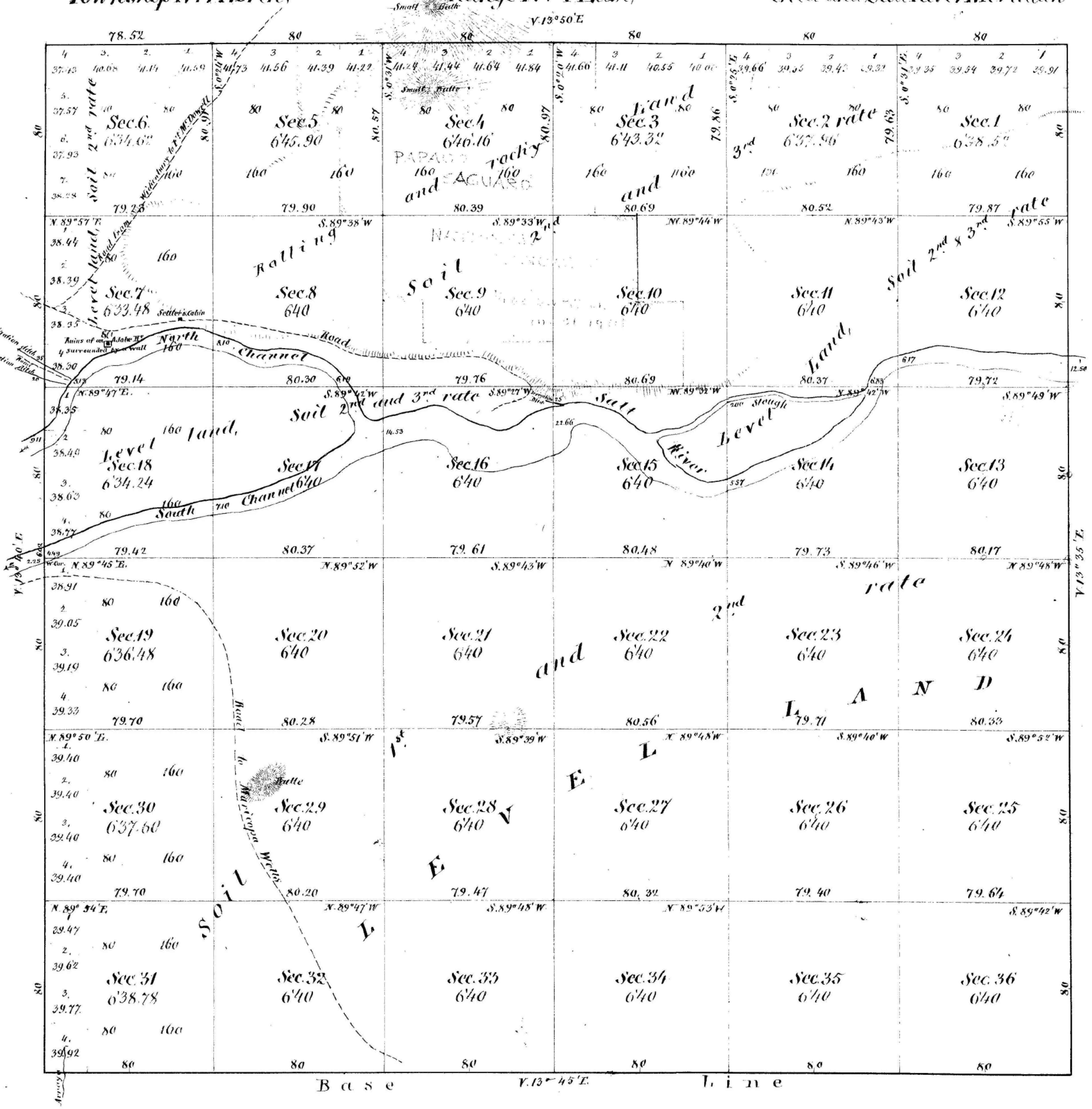
OFFICIALLY FILED 12-2-1870

Township No. 1 North, Range No. 4 East, Gila and Salt River Meridian

Recorded & filed in U S Land Office Prescott Arizona December 2nd 1870

Recorder

OFFICIALLY FILED 12-2-1870



Aggregate Area of Public land 23,027.06 Acres.

Section lines run at a Variation of 13° 35' East.

Surveys Designated	By Whom Surveyed	Date of Contract	Amount of Surveys	When Surveyed
South boundary of Township	Wm. H. Pierce	December 15th 1866		1867.
Rest of Township lines	W. F. Ingalls	February 18th 1868	17 Mls 78 Chs 52 Lks	1868
Section lines	" " "	" " "	60 " 01 " 18 "	April 16th 1868.

The above Map of Township No. 1 North, Range No. 4 East of Gila and Salt River Meridian — is strictly conformable to the field notes of the Surveys thereof on file in this Office, which have been examined and approved.

Surveyor General's Office,
San Francisco, California,
October 24th 1868.

Sherman Day
Surv. Gen. Calª and Arizona

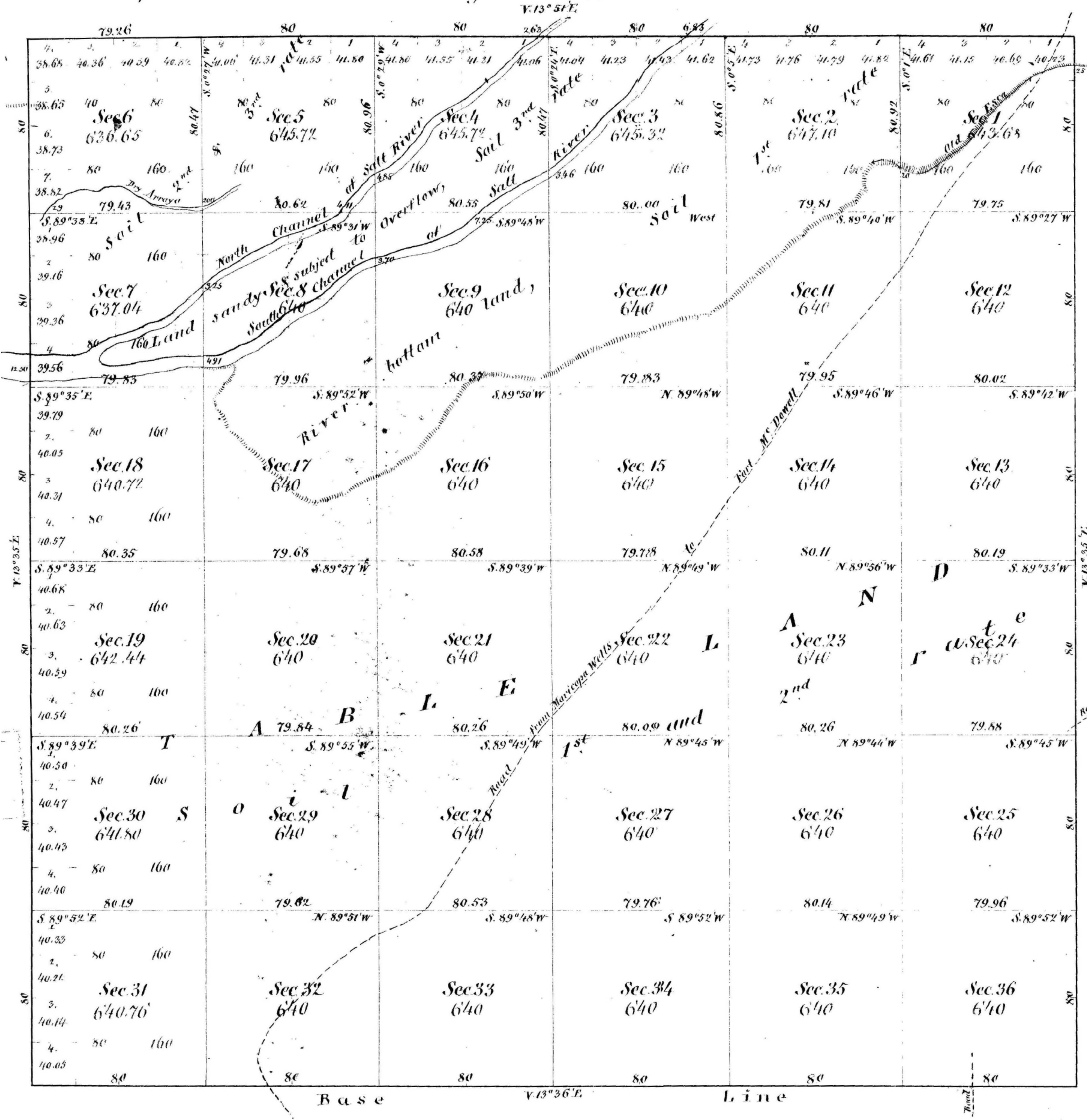
Township No. 1 North, Range No. 5 East, Gila and Salt River Meridian

Recorded and filed in U.S. Land Office Prescott Arizona December 2nd 1870.
[illegible] Register

THE SUSPENSION OF THIS SURVEY PLAT IS HEREBY LIFTED;
AUTHORITY DIRECTOR'S MEMORANDUM DATED OCT. 30, 1979

This survey plat is hereby suspended - Authority: Secretary's Memorandum dated January 17, 1969 and Director's Memorandum dated February 20, 1969.

OFFICIALLY FILED 12-2-1870



Aggregate Area of Public Land 23,066.95 Acres.

Section lines run at a Variation of 13°35' East.

Surveys Designated	By Whom Surveyed	Date of Contract	Amount of Surveys	When Surveyed
South boundary of Township	Wm. H. Pierce	December 15th 1866		1867.
Rest of Township lines	W. F. Ingalls	February 18th 1868	17 M. 79 Ch. 26 Lk.	1868
Section lines	" " "	" " "	60 " 05 " 28 "	April 29th 1868

The above Map of Township No. 1 North, Range No. 5 East of Gila and Salt River Meridian is strictly conformable to the field notes of the Surveys thereof on file in this Office, which have been examined and approved.

Surveyor General's Office,
San Francisco, California,
October 22nd 1868.

E. Sherman [signature]
Surv. Gen. Cal. & Arizona

Township Nº 2 North, Range Nº 5 East, Gila and Salt River Meridian

00091

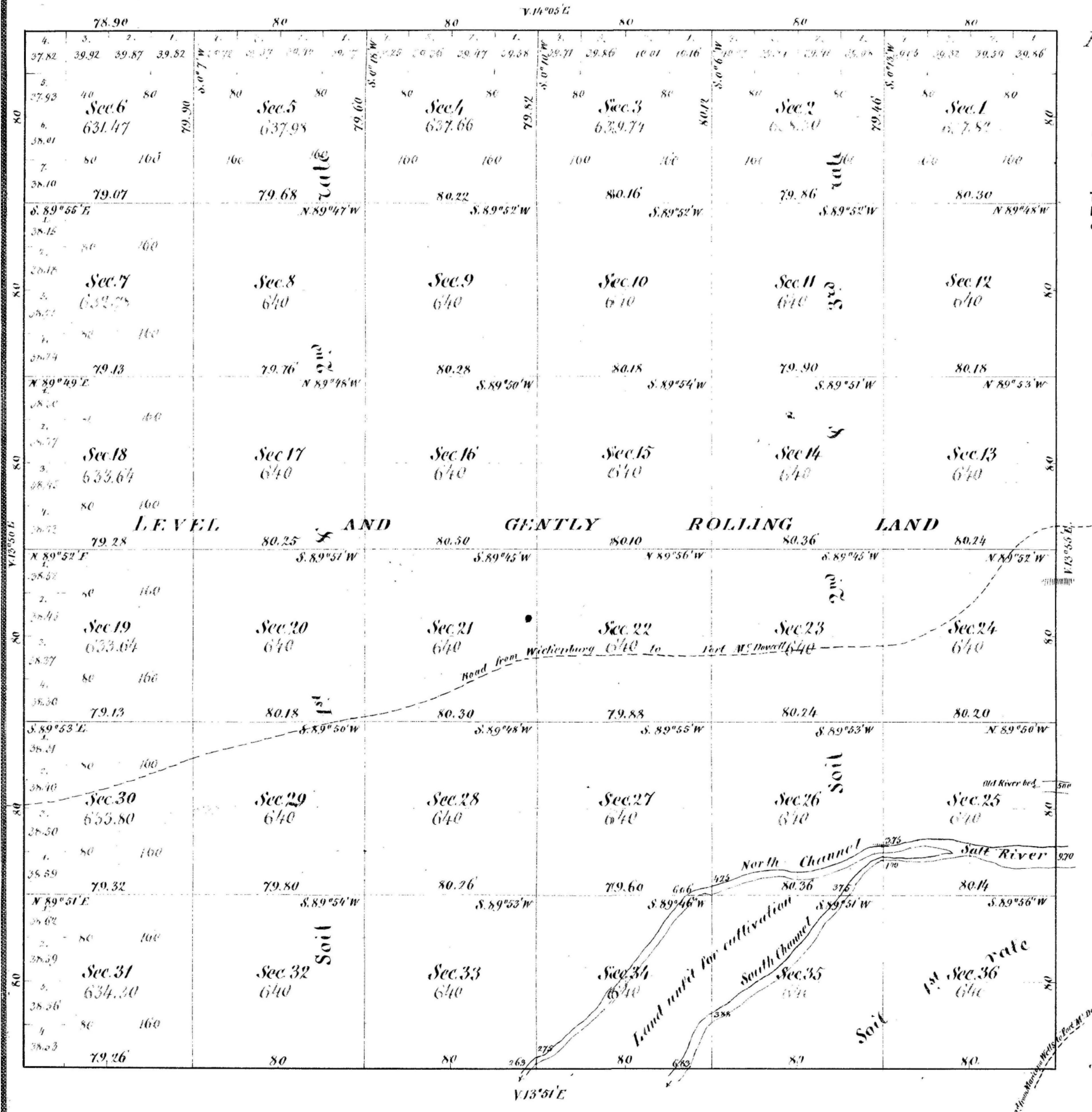
Received and filed in U S Land Office Prescott Arizona December ...

... Register.

THE SUSPENSION OF THIS SURVEY PLAT IS HEREBY LIFTED; AUTHORITY DIRECTOR'S MEMORANDUM DATED OCT. 30, 1979

This survey plat is hereby suspended - Authority: Secretary's Memorandum dated January 17, 1969 and Director's Memorandum dated February 20, 1969.

OFFICIALLY FILED 12-2-1870



Aggregate Area of Public land 22,991.13 Acres

Section lines run at a Variation of 13° 55' East

Surveys Designated	*By Whom Surveyed*	*Date of Contract*	*Amount of Surveys*	*When Surveyed*
South boundary of Township	*W. F. Ingalls*	*February 18th 1868*		*1868*
Rest of Township lines	*G. P. Ingalls*	*February 29th 1868*	*17 M. 78 Chs 90 Lks*	*1868*
Section lines	*" "*	*" " "*	*59 , 77 " 76 "*	*May 25th 1868*

The above Map of Township Nº 2 North, Range Nº 5 East of Gila and Salt River Meridian is strictly conformable to the field notes of the Surveys thereof on file in this office, which have been examined and approved.

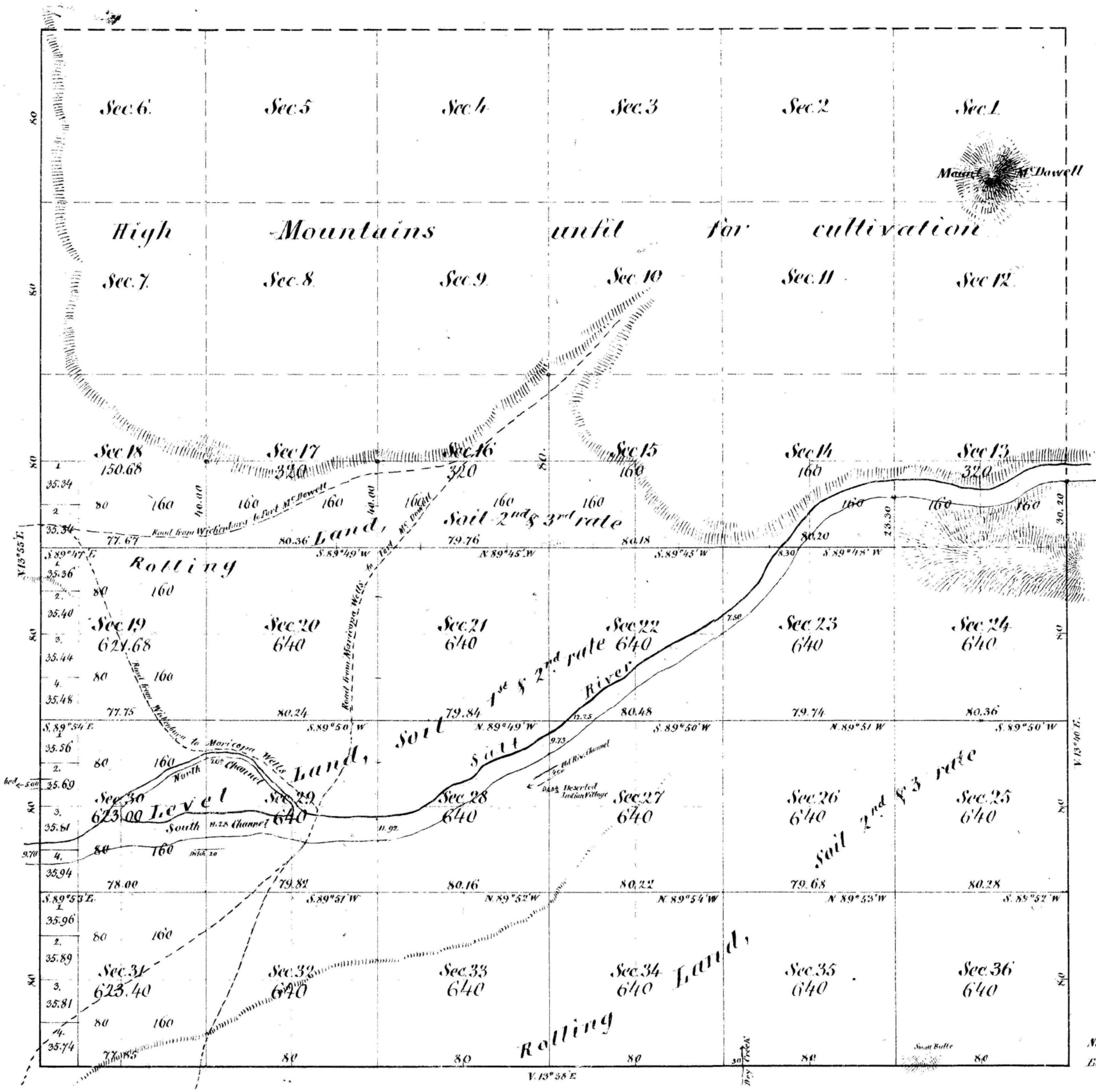
Surveyor General's Office,
San Francisco, California,
December 31st 1868

Sherman Day
Surv. Gen. Cal.

Township No. 2 North, Range No. 6 East, Gila and Salt River Meridian

Received and filed in U.S. Land Office
Prescott Arizona December 2nd 1870
[signature] Register

OFFICIALLY FILED 12-2-1870



North and South Section lines run at a Variation of 13°40' East.
East and West Section lines run at a Variation of 13°38' East.

Aggregate Area of Public land surveyed	13,058.76 Acres
Estimated Area of unsurveyed Mountain land	9,870.00 "
Aggregate	22,928.76 "

Surveys	Designated	By Whom Surveyed	Date of Contract	Amount of Surveys	When Surveyed
Township	lines	G. P. Ingalls	February 29th 1868	15 Ms. 28 Chs. 51 Lks.	1868
Section	lines	" " "	" " "	34 " 18 " 04 "	June 11th 1868.

The above Map of Township No. 2 North, Range No. 6 East of Gila and Salt River Meridian is strictly conformable to the field notes of the Surveys thereof on file in this Office, which have been examined and approved.

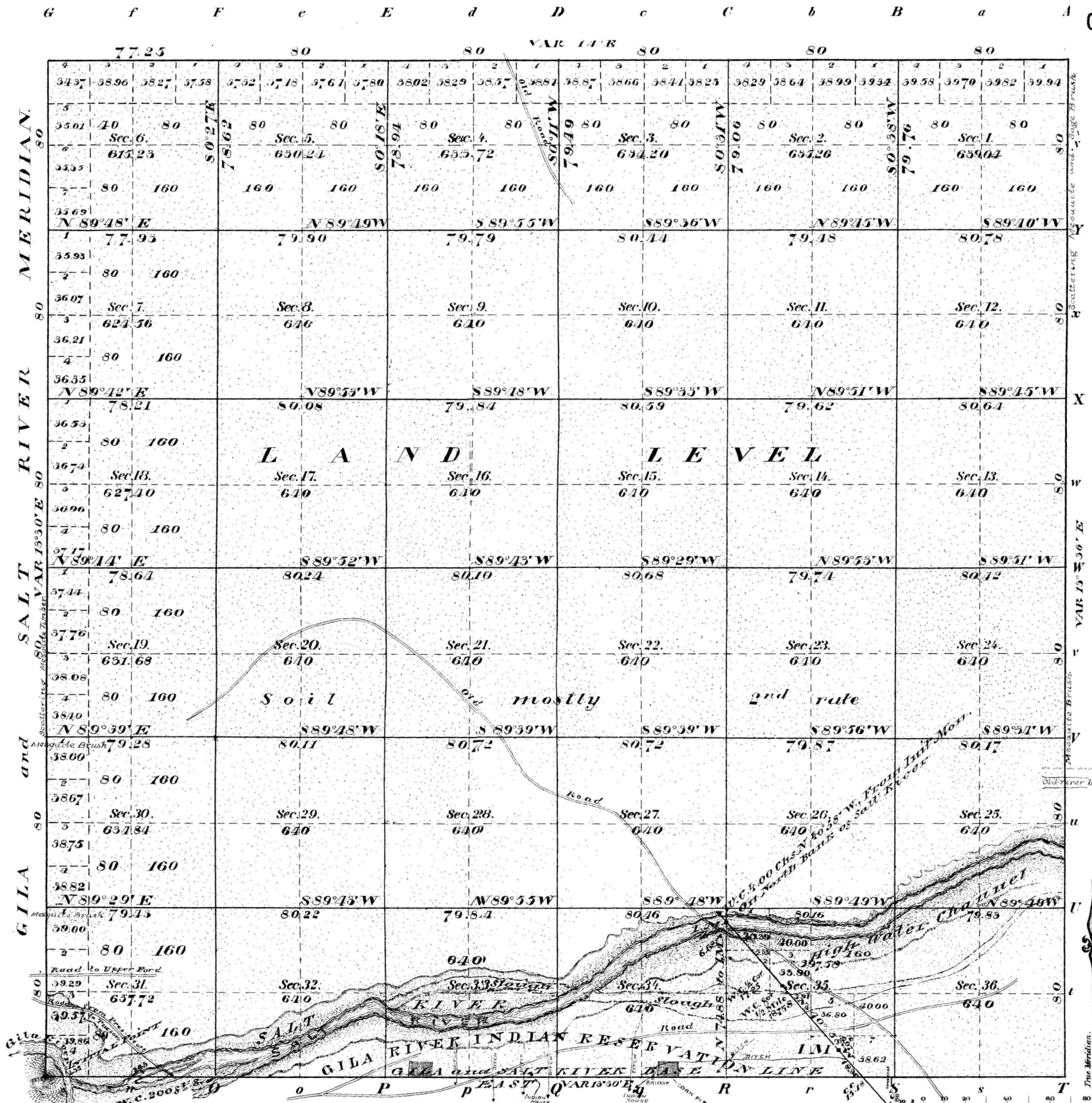
Surveyor General's Office,
San Francisco, California,
December 31st 1868.

[signature]
Surv. Gen. Cal.a and Ariz.

Township No. 1 North Range No. 1 East Gila and Salt River Meridian Ariz.

OFFICIALLY FILED 2-14-1901

00003



Meanders of								
Posts	Courses	Ch.Lk.	Posts	Courses	Ch.Lk.	Posts	Courses	

Total number of Acres 22,701.47

Latitude 33° 22' 40" N
Longitude 112° 11' 13" W
Mean mag. decl. 13°30' E

Surveys Designated	By Whom Surveyed	No.	Date of Contract	Amount of Surveys M.	Ch.s	Lk.s	When Surveyed
W & S Township lines	Wm. H Pierce		Dec. 15, 1866				1867
Subdivisions	W.F. Ingalls		Feb 18, 1868	59	73	80	Mar. 12, 1868
E & N Tp. lines	" " "		" " "	11	77	25	1868
Base Line	H.R. Patrick	51	Apr. 17, 1899	4	15	18	Oct 17 - Nov 29 1899
N.E. B'dry	" " "	"	" " "	1	18	90	" " " "
Connecting Lines	" " "	"	" " "		18	90	" " " "
Aux. Line N.	" " "	"	" " "	1	00	00	" " " "

The above Map of Township No. 1 North of Range No. 1 East Gila & Salt River Meridian, Arizona, is strictly conformable to the field notes of the survey thereof on file in this Office, which have been examined and approved.

Surveyor General's Office.
Tucson, Arizona, October 16, 1900.

George Christ
Sur. Gen.

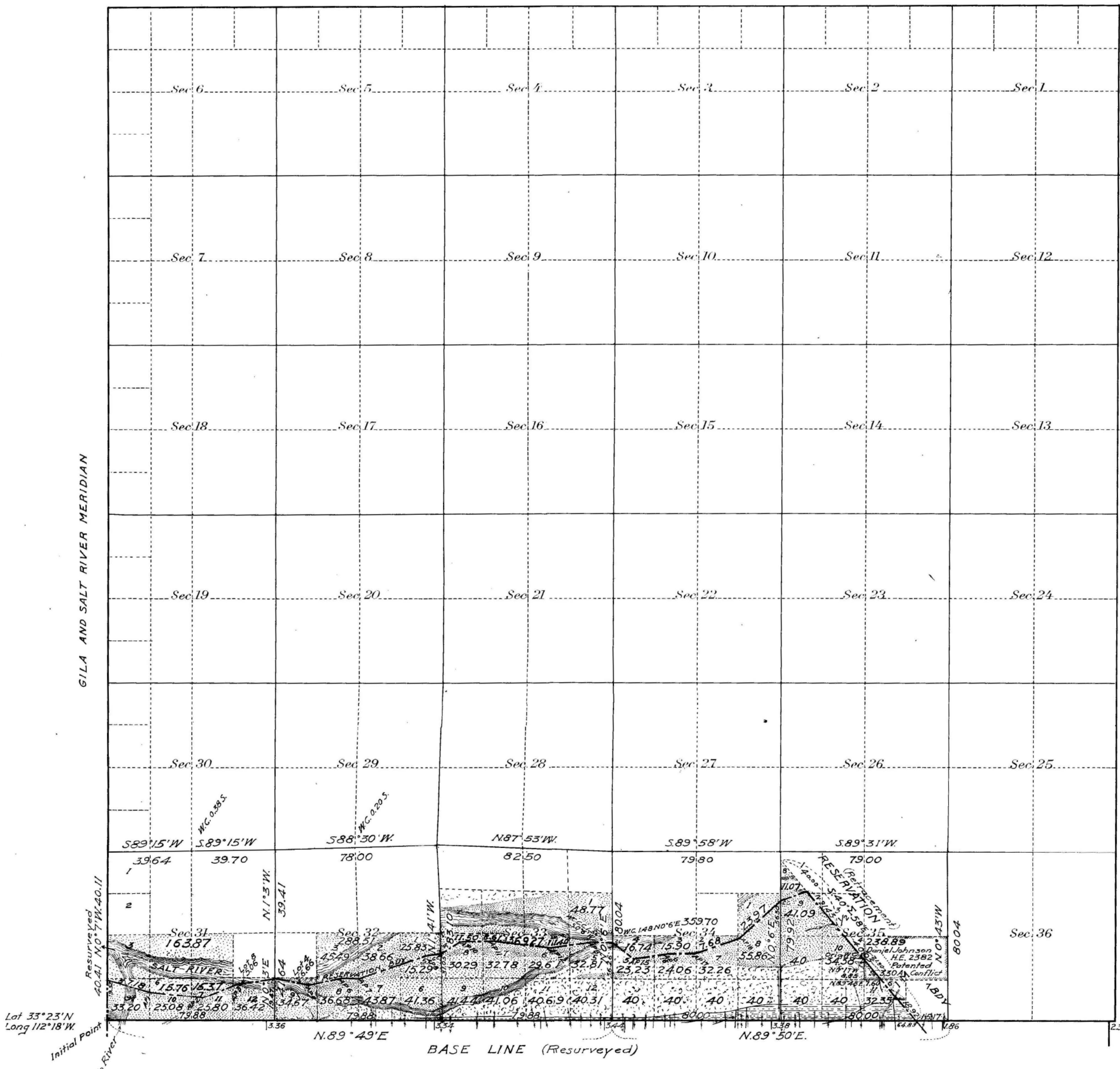
ORIGINAL Accepted Nov. [illegible] 1920.

Township Nº 1 North — Dependent Resurvey of a Portion — Range Nº 1 East, Gila and Salt River Meridian, Arizona.

GILA RIVER INDIAN RESERVATION

00002

OFFICIALLY FILED 11-3-1920



Areas in Acres	
Public Land	315.65
Indian Reservation	1107.89
Indian Allotments	
Mineral Claims	
Water Surface	
Total Area	1423.54

TRUE MERIDIAN

0 10 20 40 80

Scale 40 Chains to an inch

Mean Magnetic Declination

Note; This plat of the resurvey of Secs. 31 to 35 inclusive, delineates a retracement and reestablishment of the lines of the original township survey as shown upon plat approved October 8, 1868, as amended by the survey of the northeast boundary of the reservation in Sec. 35, as shown on plat approved October 16, 1900, in their true original positions. A survey is also represented hereon of the irregular north boundary of the Gila River Indian Reservation in the position as originally described in Executive Order dated June 14, 1879; thus showing what portions of these sections are included within the reservation. The plat of the original survey approved October 8, 1868, as amended by plat approved October 16, 1900, governs the disposal of all lands, to which new areas have not been assigned hereon. The patented H.E.2382 F.C. 1037, of Daniel Johnson for the N½ SE¼ Sec. 35 (described in accordance with original plat approved October 8, 1868) conflicts as to the NE¼ SE¼ Sec. 35 with the reservation, to the extent of 3.30 acres. This area in conflict is marked upon the ground with an iron post at each angle point.

The area of the patented Hd. F.C.1037 exclusive of its conflict with the reservation, is 76.70 acres.

Surveys Designated	By Whom Surveyed	Group No.	Group Date	Amount of Surveys (Mls. chs. lks.)	When Surveyed Begun	When Surveyed Completed
Base Line	G.P. Harrington U.S.S.	}	Oct. 11, 1910	Under direction of A.F. Dunnington	December	5-8, 1910
Reservation Bdy N.E.	"	}		Topographer in chargee	"	6-8, "
G. and S. R. Meridian	" U.S.C.E.	98	Sept. 20, 1919	W. of Sec 31	November	30, 1919
Subdivisions	"	"	"	Secs 31, 32, 33, 34 & 35.	"	16, "
Irregular N. Bdy. Ind. Res.	"	"	"	" "	"	17-24, "
D.M.P.						

The above map of resurvey of Township No. 1 North Range No. 1 East of the Gila and Salt River Meridian Arizona is strictly conformable to the field notes of the resurvey thereof on file in this office, which have been examined and approved.

U.S. Surveyor General's Office.
Phoenix Arizona; Sept. 2, 1920.

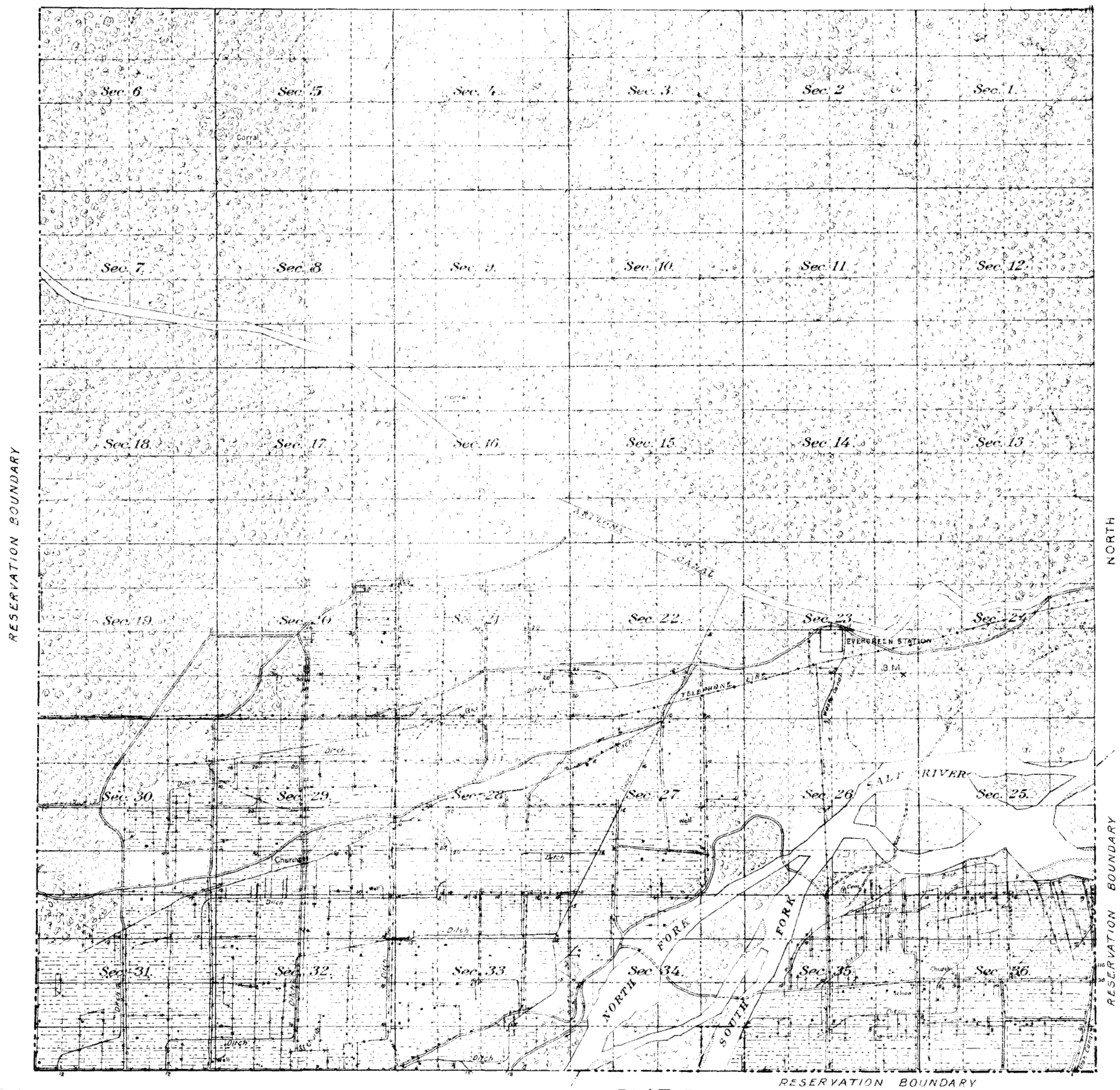
Thomas F. [illegible]
Surveyor General.

Resurvey of Township No. 2 North Range No. 5 East of the Gila and Salt River Meridian, Arizona.

SALT RIVER INDIAN RESERVATION

08090

6-27-1913



True Meridian

Latitude 33° 27′ 55″
Longitude 111° 47′ 09″

PLAT B

See Plat "A" for lot numbers, areas, bearings and lengths of lines

Scale 40 Chains to an Inch.

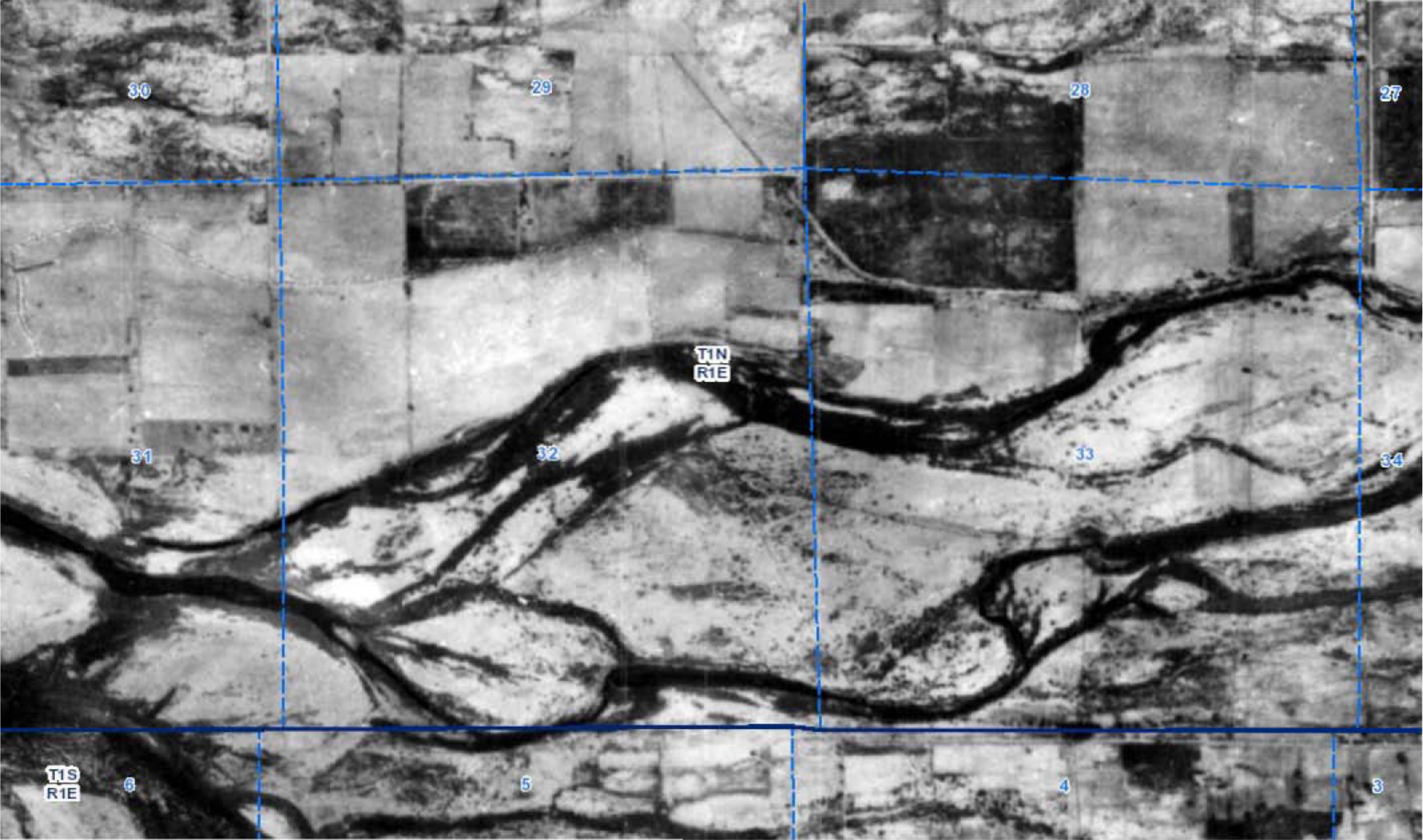
Surveys Designated	*By Whom Surveyed*		*When Surveyed*
Standard lines			
Township "	R.A. Farmer		Dec. 6-13, 1910
Subdivision "	"		Dec. 8, '10 - Jan. 28, '11.
Meander "	"		Dec. 14 '10 - Jan. 28, '11.
Boundary "	"		Dec. 5-8, 1910.

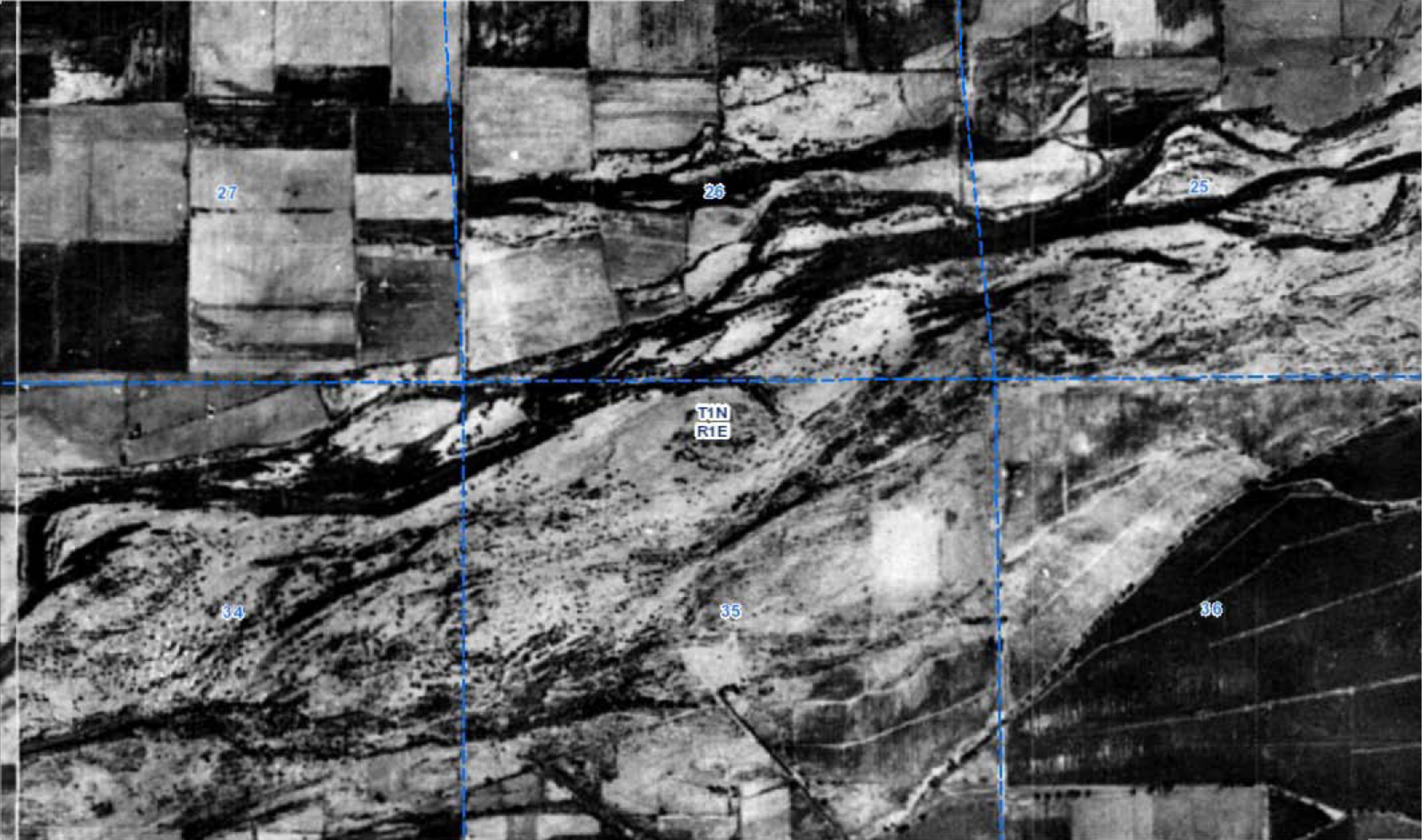
A. F. DUNNINGTON,
Topographer in charge.
Instructions October 11, 1910.

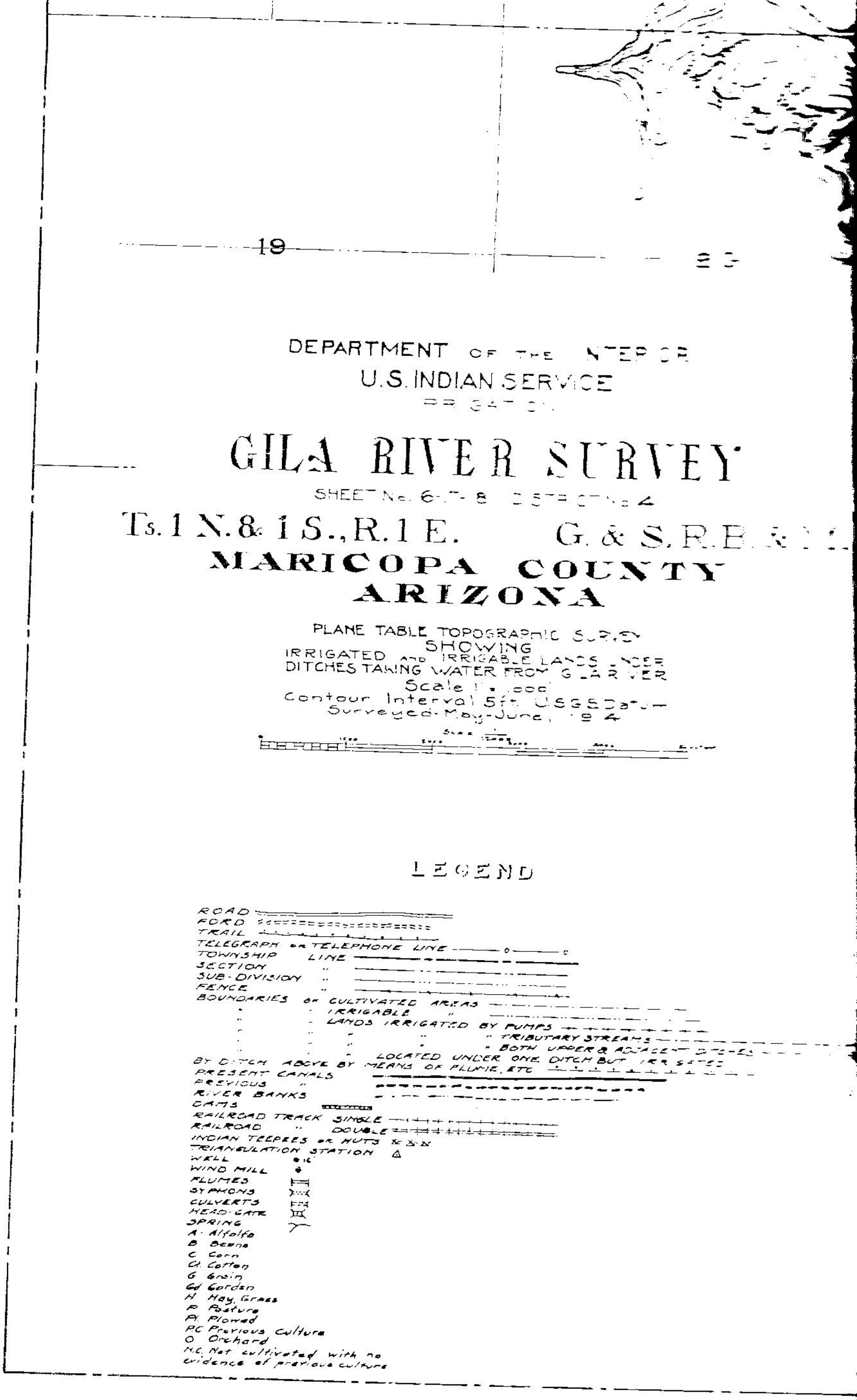
The above Map of Township No. 2 North of Range No. 5 East of the Gila and Salt River Meridian, Arizona, is strictly conformable to the field notes of the resurvey thereof on file in this Office, which have been examined and approved.

U. S. GENERAL LAND OFFICE
Washington, D. C.
March 29, 1913

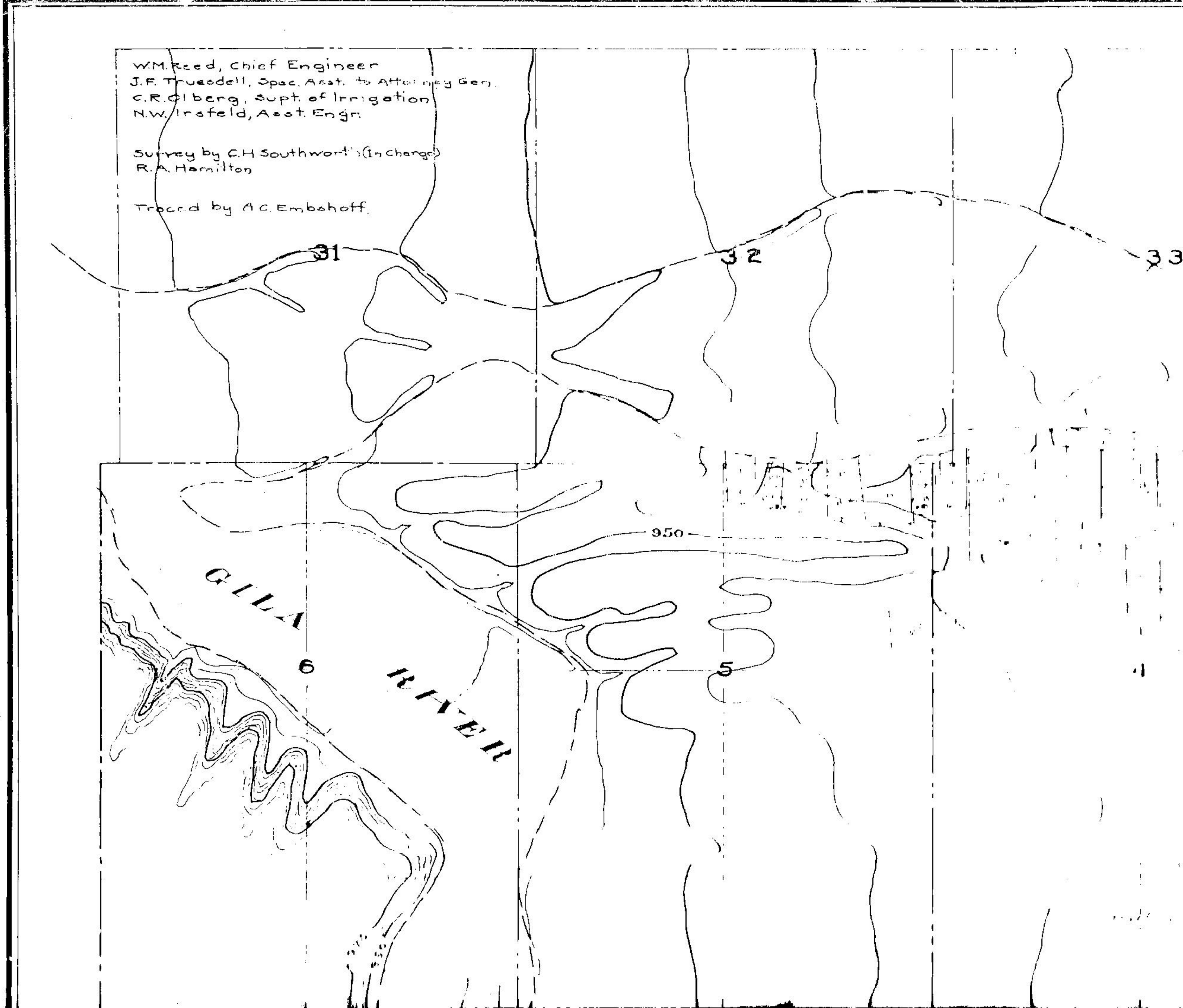
Commissioner.

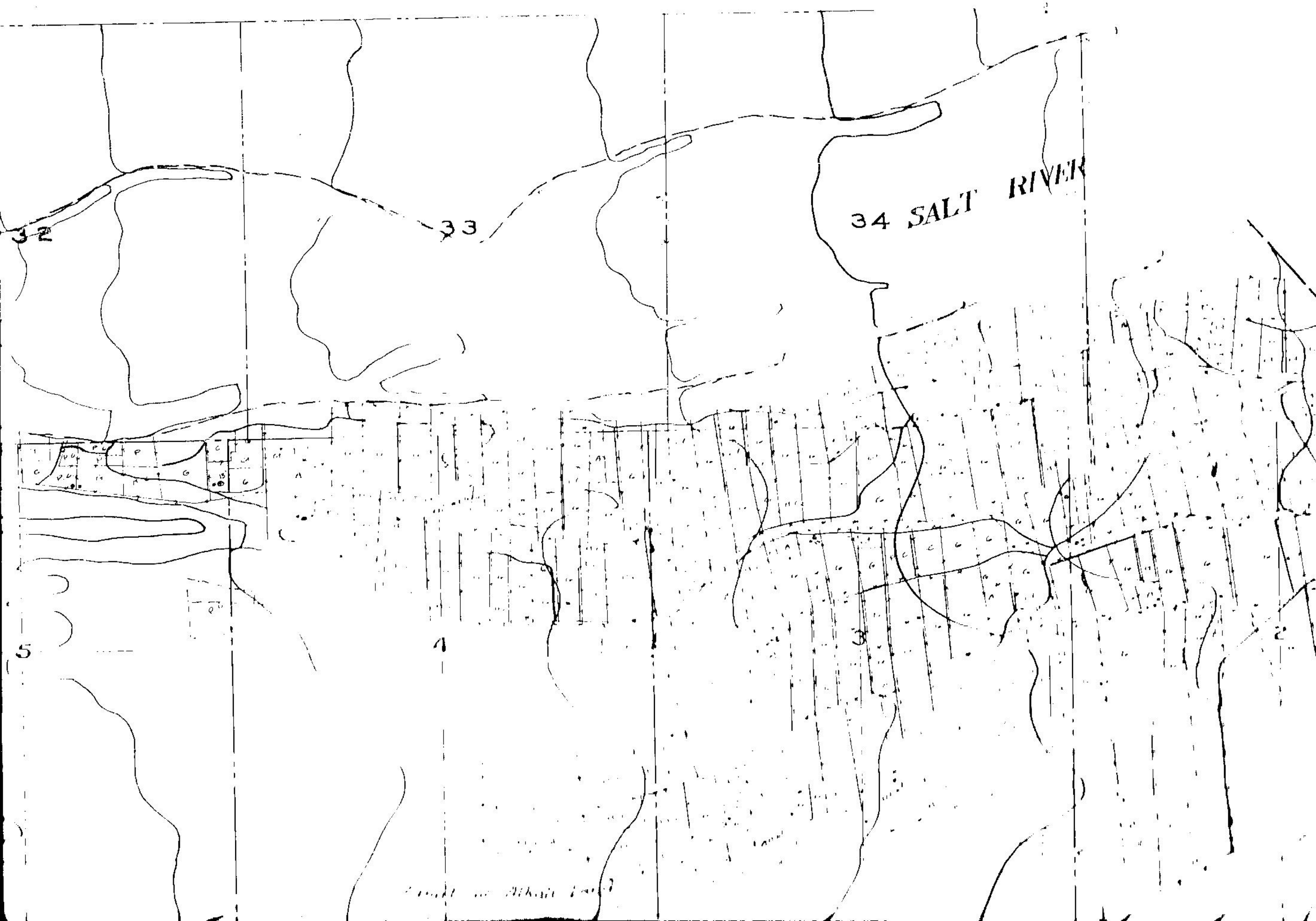

30
29
28
27
T1N
R1E
31
32
33
34
T1S
R1E
6
5
4
3


27
26
25
T1N
R1E
34
35
36



19
DEPARTMENT OF THE
U.S. INDIAN SERVICE
GILA RIVER SURVEY
SHEET No. 6-7-8
Ts. 1 N. & 1 S., R. 1 E.
G. & S. R. B.
MARICOPA COUNTY
ARIZONA
PLANE TABLE TOPOGRAPHIC
SHOWING
IRRIGATED AND IRRIGABLE LANDS
DITCHES TAKING WATER FROM
Scale
Contour Interval 5 ft.
LEGEND
ROAD
FORD
TRAIL
TELEGRAPH OR TELEPHONE LINE
TOWNSHIP LINE
SECTION
SUB-DIVISION
FENCE
BOUNDARIES OF CULTIVATED AREAS
IRRIGABLE
LANDS IRRIGATED BY PUMPS
TRIBUTARY STREAMS
BOTH UPPER &
LOCATED UNDER ONE DITCH BUT
BY DITCH ABOVE BY MEANS OF FLUME, ETC
PRESENT CANALS
PREVIOUS
RIVER BANKS
DAMS
RAILROAD TRACK SINGLE
RAILROAD DOUBLE
INDIAN TEEPEES OR HUTS
TRIANGULATION STATION
WELL
WIND MILL
FLUMES
SYPHONS
CULVERTS
HEAD-GATE
SPRING
A Alfalfa
B Beans
C Corn
Ct. Cotton
G Grain
Gd Garden
H Hay, Grass
P Pasture
Pl. Plowed
PC Previous Culture
O Orchard
N.C. Not cultivated with no evidence of previous culture


W.M. Reed, Chief Engineer
J.F. Truesdell, Spec. Asst. to Attorney Gen.
C.R. Olberg, Supt. of Irrigation
N.W. Irsfeld, Asst. Engr.
Survey by C.H. Southworth (In Charge)
R.A. Hamilton
Traced by A.C. Embshoff.
31
32
33
5
6
950
GILA RIVER


34 SALT RIVER
33
32
5
4
3
2

Appendix B

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Appendix C

T. ALLEN J. GOOKIN, P.E., L.S., P.H., S.W.R.S.

SUMMARY

Mr. Gookin has been involved in river movement studies, demographics, power and energy contracts and studies, various phases of engineering design and surveying, economic analyses and hydrologic fields, such as groundwater, surface water and flood control. Mr. Gookin is co-author of the computerized “Call System” adopted by the United States District Court to administer diversions on the Gila River mainstem. Mr. Gookin has also been a lecturer to the Arizona State Bar on “Subflow” in Arizona.

EDUCATION

West High School - Phoenix, Arizona
Graduated - Magna Cum Laude
Arizona State University - Tempe, Arizona
B.S. in Engineering - With Distinction

SEMINARS AND OTHER STUDIES

2010	HEC-RAS
2009	Editor - AIH/AHS Conference Proceedings
2009	Co-chair and Presenter – AIH/AHS Annual Conference
2007	Presenter – AIH Annual Conference
2006	Resolving Conflicts of Survey Evidence Seminar
2006	Incoming AIH Vice-President for Institutional Development
2006	AIH Conference
2006	Urban Watershed Mgmt. Seminar
2005	Single-Family Plan Rev. Workshop
2004	Presenter – AIH Annual Conference
2004	Arizona Boundary Law Conference
2004	Pipe Design, Installation, Inspection Seminar
2003	ADS Training Seminar
2003	Land Survey Seminar - COS
2003	Instructor on Subflow Arizona Water Law Conference
1997	Understanding & Protecting Your Water Rights in Arizona Seminar
1994	Cybernet
1987	HEC-1
1985	Engineering Management
1983	Hydrology & Hydraulics
1979	Survey Boundary Control
1977	Modeling of Rivers
1977	Civil Engineering Review Course
1976	Hydraulics and Hydrology Seminar
1976	Fundamentals of Engineering Rev.
1975	Surveyor's Review Course

REGISTRATIONS

CA	27892	Civil Engineer
AZ	12255	Civil Engineer
AZ	15864	Land Surveyor
NV	8169	Civil Engineer
NV	1242	State Water Right Surveyor
A.I.H.	949	Hydrologist

PROFESSIONAL HONORS

NSPE Young Engineer of the Year, Papago Chapter, 1979
Order of the Engineer
Tau Beta Pi Honorary Engineering Fraternity
Who's Who in the West
Who’s Who in America
Who's Who in the World
Who's Who in Finance and Industry
Who's Who of Emerging Leaders in America
Who's Who in Science and Technology
Who's Who in American Colleges & Univ.
Outstanding Engineering Project - ASPE

PROFESSIONAL AFFILIATIONS

Member of:
AZ Board of Technical Registration
Engineering Enforcement Committee,
Land Surveying Enforcement Committee,
Past President - Papago Chapter NSPE
American Society of Civil Engineers
Arizona Department of Water Resources
Subflow Delineation Committee
American Institute of Hydrology (AIH)
National Vice President, 2007-8
National Treasurer, 2009 - present
Arizona Hydrological Society (AHS)

PUBLISHED ARTICLES

“Annual Virgin Flows of Central Arizona” (2009)
“Stockpond Seepage in Southern Arizona” (2007)
“Subflow The Child of the Stream” (2007)
“Pumping and Globe Equity No. 59 – The Turner Study” (2006)
“Groundwater Recharge from the Gila River in Safford, Arizona” (2005)

RELEVANT EXPERIENCE - DAM OPERATION

- **SALT RIVER SYSTEM** - Reviewed yields of various operation criteria for utilization in Indian Water Rights Hearings.

- **SALT RIVER FLOODING** - Computed means by which peak flood flows could have been reduced using snow survey data.

- **HOOVER 1983 FLOODING** - Represented Needles in litigation concerning flood releases from Hoover Dam.

- **CAP OPERATIONS** - Computed Colorado River Dam operations under proposed AWC operating criteria.

- **ALAMO DAM** - Provided testimony concerning downstream impacts of water releases on riparian habitats.

- **IDAHO** - Computed and routed maximum probable flood for dam safety analysis.

- **GE #59** – Prepared numerous Reservoir Operation Studies of Coolidge Dam to:
    1. Maximize water yield under provisions of the Gila Decree and
    2. Determine penstock capacities of Coolidge Dam at various “heads”.

- **INDIAN CLAIMS COMMISSION** – Determining sustainable yields of Buttes and Orme Dams under 1883 watershed conditions.

- **GRIC SETTLEMENT** – Prepare reservoir operations under “equal sharing” concepts. Also computed spill probabilities due to reserved storage.

- **HATCH** – Computed and testified to the amount of water that could be developed for municipal use in Tucsyan.

- **ARIZONA (BABBITT) SETTLEMENT** – Worked with representatives of the Arizona Water Commission and the Bureau of Reclamation to identify and prepare preliminary cost estimates of numerous water development scenarios.

- **BUREAU OF INDIAN AFFAIRS** - Prepared computer models to determine the impact and total usable supplies given various states of regulation on both the Salt and Gila Rivers, taking into account the interaction between the surface and groundwater regime.

- **CENTRAL ARIZONA PROJECT** - Prepared computer models to analyze yield situation under various scenarios of reservoir operation.

RELEVANT EXPERIENCE –
SURFACE HYDROLOGY

- **LINCOLN RANCH** - Testified regarding water rights values and water exchanges as they relate to Lincoln Ranch on the Bill Williams River.

- **PAYSON** - Prepared study analyzing the ability of Payson to divert from the East Verde River.

- **NORTHERN PUEBLOS TRIBUTARY WATER RIGHTS ASSOCIATION** - Testified on the ability of an irrigation system to divert water and provide an integrated surface groundwater irrigation supply. Also analyzed and laid out an irrigation system and computed cost feasibility thereof.

- **PRESCOTT** - Analyzed flows of Verde River to compute various diversion schemes that would minimize the impact of riparian habitat downstream from the diversion. Responsible for report which analyzed potential for conservation through rate structures. Also worked on analyses of water requirements and savings.

- **GILA RIVER INDIAN COMMUNITY** -Computed the impact of depletions upstream from the Gila River Indian Reservation upon flows of the Gila River.

- **MAHONEY** - Reviewed evidence concerning water measurements.

- **SALT RIVER INDIAN COMMUNITY** - Determined the virgin surface water flow available from the Salt River and the surface virgin water flow available to the Central Arizona area as a whole.
- **SUPERIOR COMPANIES** - Prepared determinations of normal high flows at ungaged locations. Plotted mean high water channel boundaries.
- **TEMPE** - Prepared analysis showing adequacies of existing supplies and supplementation recommendations.

- **ARIZONA (BABBITT) SETTLEMENT** – Worked with representatives of the Arizona Water Commission and the Bureau of Reclamation to identify and prepare preliminary cost estimates of numerous water development scenarios.

- **ARIZONA WATER RIGHTS SETTLEMENT VALIDATION** – Prepared and presented depositional testimony quantifying available water right claims under PIA, Prior Appropriation and existing Court Decrees.

RELEVANT EXPERIENCE – SURFACE HYDROLOGY

- **FIVE CENTRAL ARIZONA INDIAN TRIBES** - Studied the use of irrigation water of the five Central Tribes.

- **IRRIGATION DISTRICTS** - Computed agricultural, municipal and industrial water requirements as well as design of a tentative canal layout for the Queen Creek, San Tan, Harquahala, McMicken and Chandler Heights Citrus Irrigation Districts.

- **GLOBE EQUITY** – Study operation of Gila Decree (Globe Equity #59) and its impact on the Gila River Indian Community. Prepared numerous river operation studies for various settlement options.

- **SAN PEDRO HSR** - Reviewed, provided comments and detailed analysis on the HSR Report. Examined the Jenkins Surface/Groundwater Inter- action Formula.

- **TOHONO O'ODHAM NATION** - Designed gaging stations for surface stream measurements. Examined surface flows for San Simon Wash.

- **UPPER SALT RIVER HSR** - Reviewed and commented on Hydrographic Survey Report.

- **CALL SYSTEM** – Primary creator and co-author of the Globe Equity No. 59 Call System. The Call System is a computerized water rights administrative procedure and tool. The Call System is currently being used by the Gila Water Commissioner to “run the river.”

- **SUBFLOW** – Testified before the Superior Court on the legal/physical characteristics of the Younger Alluvium and Subflow.

- **SUBFLOW II** – Testified before the Special Master on the interpretation of the Arizona Supreme Court Gila IV decision and application of that decision in delineating the Subflow zone.

- **CUFA** – Assisted in negotiations of the Consumptive Use Forbearance Agreement between the Arizona Parties and the State of New Mexico. Prepared analyses of divertible water from the upper Gila subject to restrictions of Arizona v. California, the Colorado River Basin Development Act and Globe Equity No. 59.

RELEVANT EXPERIENCE – HYDRAULICS

- **JOINT PROJECT** - Writing and utilizing computer programs for computation of natural and artificial streams for backwater, inflow and drawdown occurrences, as well as sizing pipelines and flood control channels.

- **SAN CARLOS IRRIGATION DISTRICT** - Designed interconnection between Hohokam main lateral and Pima lateral.

- **PRESCOTT** - Use of computer programs for computing natural and artificial streams for backwater inflow and drawdown occurrences.

- **SCOTTSDALE** - Utilization of computer programs to compute natural and artificial backwater inflow, as well as sizing and flood control channels.

- **WOOLLEY** - Responsible for calculating backwater and drawdown occurrences.

- **COOLIDGE DAM** - Computed penstock capacity curves.

- **DESERT MOUNTAIN** - Computed water hammer times and loads. Designed valving to prevent hammers in the high pressure main.

- **ADAMAN WATER COMPANY** - Supervised design of cast-in-place concrete pipeline to interconnect Beardsley Irrigation System to Adaman Water Company.

- **JAREN** - Prepared Master Plan of pipeline distribution system for Rawhide Water Co. Designed computer program for Pipe Network Solutions.

- **JOHN NORTON SUBDIVISIONS** - Assisted in design of waterlines and sewers for subdivision. The water systems involved loopback to the City system and pipelines, wells and a pressure system.

- **GRIFFIN** - Provided design of well and water production facilities.

- **DYSART** - Provided design of water line fire loops for Dysart High School and cafeteria expansion. Design and inspection of sewer line hookups and off-site lines with lift station to treatment plant. Computed Hardy Cross water system analysis and built necessary connections. Provided design alternatives to water hookups with El Mirage for treatment of nitrates.

- **BRW** - Consultant for the design and sizing of water production and transportation facilities.

- **NADABURG** – Designed water system for service to school including well, storage tank and pumps.

RELEVANT EXPERIENCE –
RIVER MOVEMENT STUDIES

- **THOMAS THODE** - Prepared testimony concerning avulsions and accretions near the Yuma Island and the confluence of the Gila and Colorado Rivers.

- **GILA RIVER INDIAN COMMUNITY** - Analyzed the historic meanderings of the Salt and Gila Rivers near their junction and their impact on the Gila River Indian Reservation boundary.

- **NATIONAL INDIAN YOUTH COUNCIL** - Testified to a sub-committee of the U. S. House of Representatives concerning river movements of the Arkansas River.

- **WOOLLEY** - Studied the cause of the migration of the flows from one channel to another on the Salt River during flooding.

- **PALO VERDE VALLEY FARMLAND ASSOCIATION** - Aided in research and testimony preparation in study concerned with accretion and avulsion for various lawsuits.

- **SALT RIVER INDIAN RESERVATION** - Aided in research, analyzed data, and participated in the preparation of a report concerning the thalwag of the Salt River and its movements.

- **PETERSON VS. USA** - Researched, reported and prepared testimony regarding river movements near Bullhead City.

- **SIMONS VS. RIO COLORADO DEVELOPMENT CO.** - Performed on-site inspection, research and prepared report concerning the influence of levees on river channels near Needles.

- **ARIZONA STATE NAVIGABILITY COMMISSION** – Presented testimony concerning changes in the Salt and Gila River channel characteristics.

RELEVANT EXPERIENCE –
GROUNDWATER

- **NORTHERN PUEBLOS TRIBUTARY WATER RIGHTS ASSOCATION** - Supervised a portion of the highly technical and complex testing program used in preparing a 3 dimensional leaky artesian computer model.

- **SAFFORD VALLEY** - Analyzed interaction between the Gila River and the groundwater of the Safford Valley.

- **J. ED SMITH WELL** - Co-authored report that was submitted in evidence before the U. S. District Court about the impact of the well upon river flows.

- **PRESCOTT** - Supervised the well test on an exploration hole and wrote a comprehensive report concerning the results of the pump test and aquifer characteristics.

- **NADABURG** – Prepared specifications and field inspections for a well drilled as a part of a water system for the Nadaburg School.

- **FIVE CENTRAL ARIZONA INDIAN TRIBES** - Researched the impact of a well system for use by the Bureau of Indian Affairs.

- **BELLAMAH COMM. DEV.** - Studied groundwater reserves in the East Carefree basin. Determined physical and legal constraints on development potential.

- **GRIFFIN COMPANY** - Designed well and water system for truck stop west of Tolleson.

- **GILA RIVER INDIAN RESERVATION** - Conducted research of groundwater availability and location of wells. Co-authored report concerning the need for non-Project wells. Assisted in the construction of an emergency drought relief system as well as participating in negotiations, preparations of specifications, design of well screens and field /inspections.

- **GE #59 AND HISTORY OF PUMPING** – Provided testimony concerning pumping history and evidence of coverage of pumping by Globe Equity #59 impacts. Received the following accolade from U. S. District Court Judge Coughenour "…let me help them understand how enormously helpful I have found Mr. Gookin's testimony to be and how proud we should be to have somebody of his caliber helping you with this case."

- **ARIZONA GAME AND FISH** - Prepared a hydrologic analysis of the groundwater resource potential and reliability of Pinetop Springs and local wells.

- **MARICOPA ALLIANCE** - Studied the impact of landfills on groundwater in the western Phoenix area.

RELEVANT EXPERIENCE – GROUNDWATER

- **PAYSON** - Supervised pump test and evaluated reliability of and recharge to a fractured rock groundwater system.

- **FLETCHER FARMS** - Demonstrated an assured water supply on the west side of Phoenix.

- **CHANDLER HEIGHTS CITRUS IRRIGATION DISTRICT** - Responsible for all phases of the preparation of specifications and receipt of bids for the construction of a multi-purpose well.

- **SAFFORD** - Prepared analysis of the interrelationship between surface and groundwater in Safford Valley. Aided and reviewed computer modeling using MODFLOW.

- **SAN PEDRO HSR** - Prepared detailed analysis of the validity of failing to meet assumptions under the Jenkins Formula.

- **TOHONO O'ODHAM** - Computed groundwater recharge from all sources.

- **SUBFLOW** – Testified before the Court on the legal/physical characteristics of the Younger Alluvium and Subflow.

- **SUBFLOW II** – Testified before the Special Master on the interpretation of the Arizona Supreme Court Gila IV Decision and application of that decision in delineating the subflow zone.

- **W&EST, INC**. – Provide historic water use information and historic consumptive use data for use in a groundwater model for Central Arizona Basin area.

- **PAYSON WELL (GAIL TOVEY)** - Assist Gayle Tovey in performing pump test on her property in Payson.

- **ARIZONA (BABBITT) SETTLEMENT** – Worked with representatives of the Arizona Water Commission and the Bureau of Reclamation to identify and prepare preliminary cost estimates of numerous water development scenarios.

RELEVANT EXPERIENCE –
SURVEYING AND LEGAL DESCRIPTIONS

I have prepared numerous surveys for houses, commercial developments and schools that are not listed. The following represents the more complex studies performed.

- **DESERT SUN SUBDIVISION** - Assisted in the layout of Desert Sun Subdivision.

- **PALO VERDE VALLEY** - Responsible for examination and comparison on boundary surveys between Arizona and California along the Colorado River.

- **HANCOCK** - Prepared subdivision plat near Bullhead City, Arizona.

- **JOHN NORTON – SUBDIVISIONS** - Assisted in design of waterlines and sewers for subdivision. The water systems involved loopback to the City system and pipelines, wells and a pressure system.

- **FONTES – STARR** – Provided consultation to resolve survey difficulties.

- **VALTECH** - Provided ALTA Survey of Los Arcos Mall in Scottsdale, Arizona.

- **BLUE RIDGE UNIFIED SCHOOL DISTRICT #32** - Responsible for topographic site survey of property lines and existing physical conditions of the site, monument markers, bench marks, legal description, sidewalks, curbs and gutters, utility locations, topographic map and boundary survey drawing, playground area, as-built plans, traffic control signal, maintenance and transportation facility, parking lot.

- **DYSART** - Provided as-built survey of Dysart High School.

- **STATE OF ARIZONA PARKING** - Construction staking for parking lot and storm drainage line.

- **SAN CARLOS IRRIGATION & DRAINAGE DISTRICT** - Provided surveys for intertie of Central Arizona Project Aqueduct into Florence - Casa Grande Canal.

- **SQUATTER SURVEY** – Review survey history and survey site to locate property corners, section corners, encroachments, and to establish location of existing features on site.

- **WATER RIGHT TRANSFER** – Evaluate over 100 applications for the sever and transfer of water rights. Provide affidavits on inadequacy of legal descriptions Testified in U. S. District Court as to the inadequacies of 10 test case applications. Also provided testimony of the history, development and accuracy of the Gila Water Commissioner’s Decree map.

RELEVANT EXPERIENCE -
EXPERT WITNESS

- **LINCOLN RANCH** - Provided testimony regarding water rights values and water exchanges as they relate to Lincoln Ranch on the Bill Williams River.

- **NORTHERN PUEBLOS TRIB. WATER RIGHTS ASSOC.** - In charge of preparation of canal delivery systems. Presented testimony on P.I.A.

- **NEEDLES** - Prepared and presented expert testimony concerning power contracting with the Department of Energy.

- **HATCH** – Provide testimony concerning the amount of water being generated from an ungaged watershed during pre and post development conditions. Also testified concerning potential water contamination from a neighboring airport.

- **IDAHO** – Computed and routed maximum probable flood for dam safety analysis. Provide depositional testimony.

- **PRESCOTT** - Provided expert testimony concerning the magnitude of flooding on Willow Creek.

- **WINDOW ROCK** - Provided testimony concerning the value of a substandard sewer system.

- **GILA DECREE** - Provided testimony on numerous occasions concerning provisions of the Gila River Decree and its impacts on the allocation of water between different users.

- **FORT MOHAVE** - Provided testimony regarding hydropower contracting from Colorado River Storage Project.

- **ALAMO DAM** - Provided testimony concerning downstream impacts of water releases on riparian habitats.

- **WOOLLEY vs. SALT RIVER PROJECT** – Provided depositional testimony concerning the cause of the floods of 1978, 1979, 1980 and 1983 in the Salt River and their impact on the river channel. Evaluated damages in water elevations and determined scour in the channel during the flood events.

- **JOHN FRANK** – Provide testimony concerning the impact of breeches in levies along the Colorado River on neighboring lands.

- **THODE** - Presented testimony concerning historic river movements in the area where the Gila River joins with the Colorado River.

RELEVANT EXPERIENCE -
EXPERT WITNESS

- **PETERSON VS. USA** - Researched, reported and prepared testimony regarding historic river movements near Bullhead City.

- **BOULDER CREEK** - Provide expert witness testimony for Boulder Creek Ranch, Inc. Provide deposition testimony on the value of surface water rights for water from the Agua Fria River and Boulder Creek. Perform water right valuation including the acreage at the headwaters of Lake Pleasant and the leased acreage appurtenant to and surrounding it. Subject property was used as part of a cattle ranching operation with fee lands leased from private parties, grazing lands leased from the State of Arizona, and grazing privileges leased from the BLM.

- **NATIONAL INDIAN YOUTH COUNCIL** - Presented testimony to a subcommittee of the U. S. House of Representatives of historic river movements of the Arkansas River.

- **COYOTE WASH**-Expert assistance regarding Plourd v. IID et al. break. Computed storm frequencies. Determined cause of channel failure and course of flood waters exiting channel breach. Reviewed Coyote Wash depositions. Provided deposition and expert witness testimony in El Centro, California.

- **SUBFLOW** – Testified before the Arizona Superior Court on the legal/physical characteristics of the Younger Alluvium and Subflow.

- **SUBFLOW II** – Testified before the Special Master on the interpretation of the Arizona Supreme Court Gila IV decision and application of that decision in delineating the subflow zone.

- **ARIZONA BILTMORE** – Provided review of studies by the Corps of Engineers concerning ACDC in Reaches 1, 2, 3 and 4. Provided detailed analyses of flows out of Cudia City Wash. Testified to the City of Phoenix.

- **AAMODT** - Evaluated quality of water for growth of crops in conjunction with various soils in the area and provided expert testimony.

- **SALT RIVER SYSTEM** - Reviewed yields of various operation criteria for utilization in Indian Water Rights Hearings.

- **SALT RIVER FLOODING** - Computed means by which peak flood flows could have been reduced using snow survey data.

- **HOOVER 1983 FLOODING** - Represented Needles in litigation concerning flood releases from Hoover Dam.

RELEVANT EXPERIENCE – EXPERT WITNESS

- **CAP OPERATIONS** - Computed Colorado River Dam operations under proposed AWC operating criteria.

- **IDAHO** - Computed and routed maximum probable flood for dam safety analysis.

- **INDIAN CLAIMS COMMISSION** – Determining sustainable yields of Buttes and Orme Dams under 1883 watershed conditions.

- **GRIC SETTLEMENT COURT RATIFICATION** - Provided a PIA Justification for Court approval of the Arizona Water Rights Settlement. Presented depositional testimony.

- **DE MINIMIS** – Provided report and testimony on hydrologic impacts of "de minimis" domestic, stock- watering, and stockpond uses.

- **GOLD CANYO**N – Provided expert testimony on failure of flood control system and regulatory impacts of sewage spills.

- **SALTON SEA** – Expert testimony concerning the impact of tropical storms Doreen and Kathleen and irrigation practices of the irrigation district on the Salton Sea elevations.

- **GE #59 AND HISTORY OF PUMPING** – Provided testimony concerning pumping history and impacts. Received the following accolade from U. S. District Court Judge Coughenour "…let me help them understand how enormously helpful I have found Mr. Gookin's testimony to be and how proud we should be to have somebody of his caliber helping you with this case."

- **ALAMO DAM –** Provided expert testimony concerning impacts of water releases on downstream riparian habitats.

- **GE #59 –** Prepared testimony on numerous Decree provisions in comparison of historic operations. Provided design of the Call System computer program adopted by the United States District Court and currently being used by the Gila Water Commissioner to allocate river flows under Globe Equity #59.
  - Worked with the Gila River Indian Community on arranging fish pool exchanges in 1990, 1997, and 1999.
  - Worked with the Gila River Technical Committee to resolve issues concerning fish pool accounting and wells.
  - Prepared numerous Reservoir Operation Studies of Coolidge Dam to:
    Maximize water yield under provisions of the Gila Decree and
    Determine penstock capacities of Coolidge Dam at various "heads".

RELEVANT EXPERIENCE – EXPERT WITNESS

- **HATCH –** Computed and testified to the amount of water that could be developed for municipal use in Tucsyan. Provided expert testimony concerning water contamination potential from a neighboring airport.

- **ARIZONA WATER RIGHTS SETTLEMENT VALIDATION** – Prepared and presented depositional testimony quantifying available water right claims under PIA, Prior Appropriation and existing Court Decrees.

- **WATER RIGHT TRANSFER** – Evaluate over 100 applications for the sever and transfer of water rights. Provide affidavits on inadequacy of legal descriptions Testified in U. S. District Court as to the inadequacies of 10 test case applications. Also provided testimony of the history, development and accuracy of the Gila Water Commissioner's Decree map.

- **DUGAN** – Determine cause of home flooding and provide expert testimony relating to the cause and remedy.

RELEVANT EXPERIENCE –
HYDROLOGIC HISTORY

- **HYDROLOGIC HISTORY OF THE GILA RIVER INDIAN RESERVATION** – Author of a report determining irrigation development from 1876 to 1924 and hydrologic impacts of non-Indian irrigation on the Gila and Salt River system and tributaries. Prepare analysis of virgin state conditions in Arizona.

- **CIRCULARITY** – Provided historic research on San Carlos Apache buyout provisions of Globe Equity #59.

- **POOLING REPORT** – Prepare historic analysis of origination and changes in the Pooling provisions of the San Carlos Indian Irrigation Project.

- **236-C** – Prepared analysis of virgin flows and the progression of irrigation depletion of the Gila River.

- **NATIONAL INDIAN YOUTH COUNCIL** – Presented testimony to a subcommittee of the U. S. House of Representatives of historic river movements of the Arkansas River.

- **PALO VERDE VALLEY FARMLAND ASSOCIATION** - Aided in research and testimony preparation in study concerned with historic accretion and avulsion of the Colorado River for various lawsuits.

- **HATCH** – Provided testimony concerning the amount of water being generated from an ungaged watershed during pre and post development conditions.

- **GE #59 AND HISTORY OF PUMPING** – Provided testimony concerning pumping history and impacts. Received the following accolade from U. S. District Court Judge Coughenour "…let me help them understand how enormously helpful I have found Mr. Gookin's testimony to be and how proud we should be to have somebody of his caliber helping you with this case."

- **THODE** – Presented testimony concerning historic river movements in the area where the Gila River joins with the Colorado River.

- **PETERSON VS. USA** - Researched, reported and prepared testimony regarding historic river movements near Bullhead City.
-
- **GILA RIVER INDIAN COMMUNITY** – Analyzed the historic meanderings of the Salt and Gila Rivers near their junction and their impact on the Gila River Indian Reservation boundary.

- **INDIAN CLAIMS COMMISSION** – Determining sustainable yields of Buttes and Orme Dams under 1883 watershed conditions.
-
- **W&EST, INC.** – Provide historic water use information and historic consumptive use data for use in a groundwater model for central Arizona basin area.

- **FISH POOL** – Study history of San Carlos Reservoir operations and their impact on fish kills.

PERSONAL NARRATIVE

OF

EXPLORATIONS AND INCIDENTS

IN

TEXAS, NEW MEXICO, CALIFORNIA, SONORA, AND CHIHUAHUA,

CONNECTED WITH

THE UNITED STATES AND MEXICAN BOUNDARY COMMISSION,

DURING THE YEARS 1850, '51, '52, AND '53.

BY

JOHN RUSSELL BARTLETT,

UNITED STATES COMMISSIONER DURING THAT PERIOD.

IN TWO VOLUMES, WITH MAP AND ILLUSTRATIONS.

VOL. II.

NEW YORK:

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through a thick underbrush of willows, we at length reached the bank of the river, when I found the statements of the Indians too true. There were many fine large cotton-wood trees, beneath which we stopped, and which afforded us a good shade from the scorching rays of the sun; but there was not a blade of grass to be seen, and, what was worse, *the Gila was dry!* We crossed and recrossed its bed without wetting the soles of our shoes; although by digging a couple of feet, we found water for ourselves and our animals.

We now turned the animals loose to browse upon the twigs of the willows and cotton-woods, as there was no other food for them; and I sent Mr. Leroux up the stream, in search of the two great desiderata for the party, grass and water, and shade if it was to be found. In three or four hours, after making a diligent search through the bottom, he returned and reported that the river was dry as far as he had followed it, and that he had met with no grass. In fact, he was told by the Indians, that we should find no grass until we passed the Pimo villages, from twelve to fifteen miles beyond. It was so hot and dry where we were, that we did not pitch our tents, having concluded to retrace our steps in the morning to our first camp at the water-holes.

The dryness of the river was produced by the water having been turned off by the Indians to irrigate their lands, for which the whole stream seemed barely sufficient. It is probable, however, that, with more economical management, it might be made to go much further.

A party of the Coco-Maricopas remained with us

NORTHLAND
RESEARCH, INC.

THE MIDDLE GILA BASIN

An Archaeological and Historical Overview

Claudia F. Berry
William S. Marmaduke

1982

Central Arizona Project * Indian Distribution Division
Department of the Interior * Bureau of Reclamation

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16. ABSTRACT

The Central Arizona Project (CAP), Indian Distribution Division (IDD) is designed to deliver allocated CAP water to Indian users. The Middle Gila Basin Overview summarizes and evaluates the known cultural resources in an area 3,570 square miles (9,139 sq km) large, centered on the Gila River. A critical review of past research suggests that many of the concepts and theories used to describe and explain the past in the study area are suspect, that physical and biotic zonation in the study area predict archaeological site distributions in only the most general fashion; and that much of the study area remains poorly examined, or completely unexplored. CAP-IDD systems features are likely to encounter cultural remains of considerable research potential in all parts of the Middle Gila Basin.

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final showdown, Scott attempted to block the Yuma crossing with a Texas and Pacific work crew laboring feverishly to grade the footings for a Texas and Pacific bridge. After a few inquiries, Huntington filed an official complaint with federal authorities: Scott had failed, in his haste, to acquire a federal permit to cross the Fort Yuma Reservation. In response, the commander at Fort Yuma forced the Texas and Pacific crew to cease operations. Immediately, Huntington, also without permit, put his own crew to work at the bridge site grading footings and erecting their bridge at night, while the Fort Yuma garrison slept. Soon, Huntington had his bridge, and was pushing his line east into Arizona. Incensed, Scott roared in outrage. President Hayes peremptorily summoned an unchastened Collis Huntington to his office and informed him that he could be arrested for his boldness. Huntington it is reported, batted not an eye, but instead regaled Hayes with his account of the night bridging at Yuma. In the end, Hayes did nothing, and Huntington and Southern Pacific did not even slow their construction pace while lower Federal authorities fumed. President Hayes treated Scott and Huntington as if they were fractious poker partners, good for company, but not really hurt by each others antics. Scott knew he had been beaten: as a result of the Yuma incident, Texas and Pacific threw in the towel. The remainder of construction was uneventful. Southern Pacific tracks reached Tucson in A.D. 1880, passing close to the Pima Villages, taking again traditional route of travel through the Gila Basin first trod by Spanish explorers.

The railroad brought, aside from improved transportation into and out of Arizona, large numbers of Chinese immigrants, many of whom worked as laborers on railroad construction crews, as was common in the West in the latter half of the 19th century. Those who stayed after the railroad was completed settled in Tucson. Their material culture recovered in recent excavations suggests an ethnic subculture strongly bound with traditionalism (Olsen 1978). Its ceramic inventory, from A.D. 1850 to 1960, contains substantial quantities of vessels imported from major period Chinese kiln sites: Canton, Swatow, Macao, and Hong Kong. Living in a basically alien and occasionally hostile social environment, the Tucson Chinese were probably traditionalists of necessity, the adherence to older conventions reinforcing their own sense of worth, and preserving their identity.

The arrival of the railroad truly opened southern Arizona. Intensive farming and ranching, and substantial new city and town development date to the completion of the railroad.

It provided a way to ship out agricultural and mining products, and to bring in imported foodstuffs and finished products which formerly had been subject to hideously expensive and always uncertain overland freighting from Mexico, California, and Texas (Hamilton 1884; McGuire 1979). With the railroad, Arizona was no longer so remote: between A.D. 1880 and 1900, and 1900 and 1920, the population of the Southwest doubled, and doubled again (Meinig 1971:52, 83). Southern Arizona ceased to be a backwater, and became part of a major transcontinental system of production and distribution extending from Los Angeles to El Paso, and then on to New Orleans and the eastern seaboard (Meinig 1971).

American Mining-The Mercurial Basis for a Territory

The Gadsden Purchase brought immediate benefits not only to continental transportation and communications, but also to the fledgling western mining industry, which was then beginning to exhaust the initial potential of California's mother lode country. American miners knew of Arizona and its mineral possibilities from Spanish and Mexican sources, but until A.D. 1853, prospecting by Americans was illegal in the part of Arizona where gold and silver had been earlier discovered, the lands south of the Gila. With the purchase, knowledgeable prospectors, and not a few moonlighting Army officers, began to explore the area in detail. There was no immediate boom, largely because the same obstacles that prevented wholesale Spanish exploitation also blocked American mining ventures. Water, quicksilver, and fuel were lacking for on-site smelting of sulfide ore; transportation was rudimentary in the remote purchase area. Until after the Civil War, successful mining ventures would consist solely of local chloride ore reduction, the lone exception being the Spanish-discovered New Cornelia lode at Ajo, whose gold-silver-copper ores were rich enough to merit overland wagon freighting to San Diego, there to be loaded aboard ship for a long voyage to British smelters in England.

Silver mining, however, in the mountains surrounding Tucson was not entirely negligible. Several of the mines made their owners and investors moderately wealthy for a while, and their silver production, coupled with the A.D. 1863 gold strikes near Prescott, induced Abraham Lincoln to support Congressional

[redacted]

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Recreation and Instream Flow. Volume 1 Flow Requirements, Analysis of Benefits, Legal and Institutional Constraints

Jason M Cortell and Associates, Inc, Waltham, Mass

Prepared for

Bureau of Outdoor Recreation, Washington, D C

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Very few provisions for the controlled releases of water from dams and other such water resources projects to increase instream flow specifically for water-based recreation exist in the United States. The few projects that provide such releases are discussed and analyzed. These projects are more common in the humid East; in the drier West such releases are mainly for contaminant dilution and support of fish and wildlife.

Such questions are dealt with as: how much flow is required for recreation, how justified are such flows compared to other needs, and what legal and institutional obstacles exist.

The conclusions of the document are: while instream flows for recreational purposes cannot be guaranteed in a specific case, a recreational planner can measure the amount of water required, its value, and the obstructions to be encountered.

An annotated bibliography is included.

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Recreation and Instream Flow

Vol. 1

Flow Requirements
Analysis of Benefits
Legal and Institutional
Constraints

Submitted to

U.S. Department of the Interior
Bureau of Outdoor Recreation

Prepared by

Jason M. Cortell and Associates Inc.
Waltham Massachusetts

BOR D6429
JULY 1977

1a

PREFACE

This study is Volume I of two volumes published under the provisions of BOR Contract 5-14-07-7. Its purpose is to develop criteria for quantifying water requirements for instream recreation use; to develop methodologies and guidelines for evaluating impacts and for determining monetary and non-monetary benefits for increments of flow relating to recreation; and to determine the legal and institutional constraints on the use of instream rates for recreation. Additional analytical material is contained in the appendices.

Volume II, Recreation and Instream Flow: River Evaluation Manual, is a handbook for recreation and water resource planners.

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SECTION 1

INTRODUCTION

The demand for water based recreation has grown substantially in the past several decades. Like many other forms of recreation, use has, in fact, grown faster than population. This has to do with the increase since the turn of the century in the amount of leisure time and disposable income available to individuals. Additionally, many water related activities, such as white water canoeing, have undergone phenomenal growth. This growth has affected both lake and stream based activities. There are, however, inherent differences betweeen the two types of activities which must be recognized.

Lake activities may be viewed as activity oriented. That is to say, the activity may be successfully and pleasureably carried out on virtually any relatively large body of water. More to the point, lake environments can, and have been, provided by human works (dams). Thus, it is not a supply limited resource in any immediate sense.

Stream based activities, on the other hand, are resource oriented. The availability of the activity and its quality may depend on the particular stream in which it occurs. Additionally, free flowing water has seldom been created by human works; indeed the dam that creates a new lake almost always inundates a stretch of free flowing stream.

1.1 INSTREAM FLOW PROVISIONS OF VARIOUS WATER PROJECTS

Many water resource projects in the country do have provisions for controlled releases for purposes other than that of their design purpose. Such releases, however, are generally for dilution and minimal ecological support; releases specifically for recreation are not common. A few who have provided for recreation are discussed below. Of those projects queried, minimum releases for the accommodation of fish habitat was the most frequent recreation provision - particularly in the western part of the country. Also in the West, future water supply is a major concern, often taking precedence over auxiliary releases.

1.1.1 Sugar Creek, Indiana

The Sugar Creek plan involved creation of two reservoirs on the stream (Koenings, 1967). There were to be state parks at each, providing new recreational benefits in the dam pools. Additionally, water was to be released into the stream on weekends and holidays during the summer recreation season in sufficient quantities to guarantee satisfactory canoeing flows below one of the reservoirs. Natural flows on the stream are highest during late winter and early spring and tend to drop off during the recreation season from April to October. In an average year the river is not canoeable for much of the prime recreation season. The flow augmentation would have increased canoeing use from an estimated 2,500 to 15,000 recreation days per year. Using the values per recreation day assigned by the study, the canoeing benefit would have been considerably smaller than the benefits at the reservoirs but still appreciable. Ultimately, the project was not approved, and Sugar Creek was kept in its natural state by designation as one of Indiana's natural streams.

1.1.2 Two TVA Projects

The Tennessee Valley Authority has built in provisions for releases to permit instream recreation below the dams in two projects: the Duck River in Tennessee and Bear Creek in Alabama.

<u>Duck River</u>

The Duck River in its natural condition suffered from low flows above the site of the new Normandy dam. The discharge required for canoeing and floating was available only about a third of the time during the prime recreation months of May through September. Two new reservoirs will inundate 71 miles of the stream. While this will eliminate canoeing and floating on this stretch, general recreation activities such as fishing, hiking, and other water related or water enhanced activities will still be possible. These amounted to about half of the estimated 17,000 visits to the river each year. Added to these, of course, will be the large number of reservoir oriented activities in the dam pools. Balancing the loss of the instream opportunities behind the dams will be the creation of improved conditions below the second dam. TVA will provide assured minimum releases from the lower reservoir which will be sufficient to provide a reliable flow for canoeing and floating over a reach of 27 miles which includes a stretch of scenic beauty. Access points have been acquired to service this portion. The estimated use is 20,000 recreation days, which greatly exceeds the use of the entire river prior to construction. The dam was closed in January of 1976 and use has already started, although it is expected to take up to 5 years for the annual visitation rate of 20,000 to be reached. An ancillary benefit that has been realized is the improvement of an existing trout fishery below the dam. The assured flow, consisting of cold water drawn from the bottom of the dam, has improved habitat.

Bear Creek

The Bear Creek project calls for provision of a 24-mile riverway through an area of unusual scenic beauty which is currently little used because of inadequate flows during peak recreation seasons. The required 100 cfs to support canoeing and floating is available only 10 to 20% of the time from May to October. The plans for the dam operation call for regulated releases of up to 140 cfs to meet the needs of the recreational season. These will be scheduled, permitting people to plan on use of the river. Scenic easements to assure protection of the natural beauty of the gorge along the riverway are planned, but have not yet been acquired. The benefits assigned to boating on the riverway (valued at a modest $6.00 per visit) amount to $198,000 or about 31% of the total recreational benefits assigned to the two reservoirs.

The approach represented by the Sugar Creek, Duck River, and Bear Creek proposals represents an interesting example of the possibility of improvement of instream recreation by creating impoundments. By sacrifice of part of a marginal resource, that which remains may be greatly upgraded. The benefits so generated are built into the project justification.

1.1.3 Snake River Basin, Idaho

Recommendations by the State of Idaho for the Snake River Basin include instream flow programs on tributary streams of the Snake River. Recreation on the Snake itself may be affected in the future because of the expected lower flows. The same situation may lead to increased use of stored water which would be reflected by greater seasonal fluctuations in some reservoirs.

The Idaho study recommended legislation for instream flow appropriation with the following provisions:

1. That the name of the stream and legal description of the point on, or reach of the stream where the instream flow is proposed to be appropriated, be determined;

2. That the proposed flow be stated in cubic feet per second (cfs);

3. That the purposes for which the instream flow appropriation is proposed be stated;

4. That the period of time or season of the year during which said appropriation be stated;

5. That the proposed legislation will not interfere with any vested water right, permit, or water right

application with priority of right date earlier than the date of the receipt in the office of the Director, Department of Water Resources, of a complete application of instream flow filed under the provisions of the act;

6. That such projects be in the public, as opposed to private, interest;

7. That such legislation will show the extent to which flows are necessary for the preservation of fish and wildlife habitat, aquatic life, recreation, aesthetic beauty, navigation, transportation, power generation, or water quality of the stream;

8. That it shall be stated the extent to which flows are capable of being maintained as evidenced by records of stream flows and water levels, and the existing or future establishment of necessary gaging stations and bench marks.

In addition, it was recommended that instream flows be established for each river segment in the system; and any future development, improvement, diversion, or impoundment in, above, or below the classified river segment should be regulated so as to protect the stream flows and free flowing condition of the river segment. All water normally used for recreational boating should be classified as to degree of difficulty and danger.

1.1.4 Rickreall Creek, Oregon

Rickreall Creek has a low flow that typically restricts recreation to early season fishing. Proposed regulations call for augmented flows for irrigation and supplements for fish habitat. Since the water of return irrigation flows is often of of poor quality, reduction of pollution is a principle concern, particularly since there is a demand to provide swimming areas for small communities which are unable to afford public swimming pools. Another important need is to provide protection for the resources that will be needed in the future when greater demand will be expected.

Optimum flow for Rickreall Creek would be 100 cfs, based on the following criteria:

1. Maintain stream flow so that no more than 1/3 of the riverbed will be exposed in cross-section,

2. Preserve white water with sufficient flow to produce the most photogenic conditions in the rapids,

3. Maintain sufficient depth for drift boating or floating on inflatable rafts.

1.1.5 Lower American River, California

Long range planners in the West and Far West are finding it necessary to take a serious look at the effects of reduced flows. A recent study of flow from the Nimbus Dam (near Sacramento) is designed to aid planning for a one hundred year span - 1973 to 2073. The main point under investigation is the estimated loss of usage due to anticipated lowering of flows. Observations of the full suite of activities were made at flows of 500, 750, 1000, and 1500 cfs below the dam. A flow of 1500 cfs was determined to be the minimum non-limiting flow. The method then was to determine what would be lost at lesser flows, using the value Average Amount Below (AAB).

1.1.6 Other Rivers, Other Projects

Table 1 is a collection with brief commentary of various river projects throughout the United States. See also Appendix A.

1.2 APPLICATION OF THE PRESENT STUDY

Instream recreation depends upon a supply limited and shrinking resource. To compound this difficulty, there is intense competition for the waters in a free flowing stream. The need now arises to treat instream water and instream recreation as a renewable resource and to enter into the competition for what water remains.

This need can be met by three sets of information. First, it is required that the conditions in a stream which will support instream recreation be clearly described and related to flow in such a fashion that definite recommendations for discharge can be made for a particular stream. Second, an economic framework is required which will accurately reflect the value of such instream flow in a competitive "water market". Finally, the legal and institutional helps and hindrances to the provision or acquisition of such waters must be understood clearly.

The following sections of this document address these three types of information.

TABLE 1

WATER RESOURCE PROJECTS

RIVER	PROJECT	COMMENT
Deerfield, MA	Bear Swamp Pump Storage Plant Rowe, MA	The river passes water between 2 reservoirs. Normal discharge of 50 cfs is increased to 100 cfs during fishing season.
Connecticut River New England	Wilder Bellows Falls Vernon	No recreational discharges. Each project provides 0.2 cfs per square mile of drainage area.
Upper Delaware River, PA - NJ	Reservoir diversions	Unpredictable releases make boating and swimming dangerous especially close to the reservoirs.
Lehigh, PA	Dam	Flow over 750 cfs provides relatively easy whitewater. Less than 750 cfs good for fishing and spawning.
Nantahala, NC	Dam	Amount of discharge not as critical as timing due to conflict between fishermen and canoeists. Special release can be arranged.
Green River, NC	Dam	10-mile canoe stretch below dam. Releases are timed specifically for canoeists (500-600 cfs).

TABLE 1 (continued)

WATER RESOURCE PROJECTS

RIVER	PROJECT	COMMENT
Hiwassee River, TN	Appalachian Dam	Flows determined and regulated as follows: 1200 cfs - easy canoeing, wading-fishing 2400 cfs - good rafting, excessive for wading-fishing 3200 cfs - best rafting, excessive velocity for fishing When generating electricity, water passes through 12-mile tunnel but still permits "good" canoe run. If water is released from spillway, it extends the canoe reach by 12 miles.
Okowee, TN	Dam	Canoeability rated as function of discharge, 400 cfs to 1200 cfs.
Duck River (TVA), TN	Normandy Dam	Releases from lower reservoir will provide reliable flow for canoeing and floating. Cold water drawn from bottom of dam has improved trout fishing.
Bear Creek (TVA), AL	Dam - Bear Creek Reservoir	Optimum flow for canoeing +100 cfs. Plans call for regulated releases up to 140 cfs to provide float stream during May through October. Development includes purchase of scenic easement along both banks. Demand for river recreation is expected to exceed supply by year 2000.

TABLE 1 (continued)

WATER RESOURCE PROJECTS

RIVER	PROJECT	COMMENT
Chattahoochee, GA	Buford Dam	Heavily fished. Low flow (500-600 cfs) to accommodate fishermen. Discharges preceeded by 5 minute warning buzzer. All boating dangerous at full turbine (8000-9000 cfs). "Normal" flow (1800-2100 cfs) sufficient for rafting.
New River, WV	Blue Ridge Project Bluestone Dam	Fishery is major concern. Optimum flows established for recreation activities.
Elk River, WV	Sutton Dam	Optimum flow for aquatic environment and fishability determined to be 250 cfs. Bottom damage assessed at various flows by displacement of colored gravel.
Little Miami River, OH	Caesar Creek & East Fork Reservoirs	Reservoirs will augment flow and substantially improve summer recreation. Optimum flow requirements for canoeing established.
Sugar Creek, IN	Crawfordsville Dam (proposed)	A proposed project that would include provisions for storage and release for canoeing. PROJECT NOT APPROVED.
Gunnison River, CO	Curecanti Project Blue Mesa Dam Morrow Point Dam Crystal Dam	Release criteria developed to support aquatic environment, and picnicking and camping.

TABLE 1 (continued)

WATER RESOURCE PROJECTS

RIVER	PROJECT	COMMENT
Big Thompson River, CO	Lake Estes Dam	Releases in support of fishery. Supports some tubing close to metropolitan area. Enhances fishing and camping.
Blue River, CO	Green Mountain Dam (peaking power)	Release for fishery only.
Green River, WY - UT	Flaming Gorge Dam	Releases vary from 3000 to 500 cfs. Minimum releases during low demand are made for fish and wildlife. Heavy rafting during high flows.
Boise River, ID	Lucky Peak Dam	Regulation of flows in the past has displaced spawning gravel to high elevations and smaller side channels.
Hells Canyon Reach, Snake River, ID	Hells Canyon Dam	Accommodation for fishery, wildlife, and recreation evaluated at different flows.
Rickreall Creek, OR	Irrigation Impoundments	Typical low flow restricts recreation to early season fishing. Augmentation of flow is recommended for irrigation and fish habitat. Optimum flows for recreation identified with particular demand for swimming.
Lower American River, CA	Nimbus Dam	Anticipated lower flows in the future focus need in identifying lowest flow that will not limit water activity.

SECTION 2

THE RELATIONSHIP OF INSTREAM FLOW TO TYPES OF AQUATIC RECREATION

The first step in establishing the flow-to-activity relationship is the setting of the requirements governing recreation activities. These are of two types. First, there are physical criteria which must be met if an activity is to be possible. These can be expressed in terms of width, depth, and velocity. If these conditions are met in a stream, regardless of absolute discharge, then the activity is possible. A second set of criteria helps to determine the desirability of the stream for the activity. These are site and stretch-specific and may or may not be flow related. Examples of this would be the presence of clear, clean water and sandy beaches for swimming or long stretches of water suitable for boating, rather than only a few hundred feet of such water bounded by major rapids or waterfalls.

The second step in this process is to determine the ability of a given stream to meet these requirements as a function of discharge. It is not possible to say in absolute terms that a discharge of so many cfs (cubic feet per second) is suitable for a certain activity. It is possible, however, to say that a discharge of so many cfs is suitable for particular activities in a particular river.

The final step in the process is an analysis of the expected recreation potential on a particular stream as a function of discharge and, ultimately, the recommendation of a flow level, that will support the widest range of recreational uses. This is accomplished by applying the techniques of hydraulic geometry to the stream in question to determine the relationship between stream flow and physical characteristics (width, depth, and velocity). These may then be compared to the physical criteria required by various recreational activities to determine those that may be supported at various stream flows. The stream is then examined for site and stretch characteristics that might either favor or eliminate activities. A determination can thus be made as to the suite of activities compatible with a particular reach of a stream and a definite flow for that suite of activities can be recommended. This recommendation might be in the form of a single flow which maximized a certain suite of activities at all times, or a set of seasonal, monthly, weekly or even daily flows which offer suitable conditions for different suites of activities at different times of the year (e.g. white water canoeing in the spring and swimming, wading, and fishing in the summer).

2.1 FLOW-RELATED REQUIREMENTS FOR RECREATION

For purposes of river evaluation, what is needed is a set of clearly defined physical parameters relating recreational potential to flow. The criteria presented here are intended to meet this need. The data are drawn from a number of sources (primarily Thompson and Fletcher, 1972 and U.S. Dept. of the Interior, Bureau of Land Management, 1972) and modified or extended in some cases. They provide a clear physical description of those conditions in a stream which will support an activity, those which are optimal for the activity, and those which preclude the activity. The main descriptors will be width, depth, and velocity, since these are the main characteristics of a stream which change in response to changing flow. A summary of these is presented in Table 2. Of secondary importance will be those auxiliary conditions which influence the desirability of the activity, such as sand bottoms for swimming; those which might eliminate a physically possible activity, such as a low-flow die-off of fish; and those which might influence the potential market for an activity, such as the presence of a competing, higher quality resource in the immediate area.

2.1.1 Fishing

Fishing depends upon, first, the survival and catchability of desirable species of fish, and second, the ability of fishermen to pursue and capture them. The first requirement has been studied extensively by fisheries departments throughout the nation. Survival conditions are usually specified in terms of a requisite minimum percentage of Average Annual Flow (AAF) to support spawning, hatching, rearing, and passage at appropriate times of the year.

Catchability may also be flow related. The first requirement is that the simple survival criteria of adults of the target species be met. For trout and many other salmonids, these are met if the water is relatively clean, temperatures are less than 60°F to 65°F, and velocities are low enough that the fish can maintain their position in the stream (4 to 8 feet per second). Smallmouth bass will survive in less clean waters and at temperatures into the 90's but may have more limited capacity to deal with high velocity flow. (Stalnaker, 1975)

The willingness of the fish to bite is the other factor which must be considered in catchability. This is perhaps the least understood area in fisheries. The upper bounds for fish catching can be established rather simply. If velocities exceed 5 to 10 feet per second, even strong salmonids are either swept downstream or retreat to sheltered areas (D.L.Tennant, 1975). This may occur for warm water species at about 2 to 4 feet per second. Depth limits the other end of the flow scale. If depths are reduced below six inches, most fish worth catching

TABLE 2

Summary of Instream Flow Requirements for Recreation

ACTIVITY		MINIMUM CONDITION	MAXIMUM CONDITION	OPTIMUM CONDITION	COMMENTS
FISHING	Wading	W = -- D = -- V = --	W = -- D = 4 ft V = 2.5 ft/sec	W = -- D = <4 ft V = <2.5 ft/sec	All conditions should be checked against fish survival flow.
	Boating-Canoeing	W = 25 ft D = 6 in V = --	W = -- D = -- V = 10 ft/sec	W = >25 ft D = 2-5 ft V = <5 ft/sec	
	Boating-Low Power	W = 25 ft D = 1 ft V = --	W = -- D = -- V = 10 ft/sec	W = >25 ft D = 2-5 ft V = <5 ft/sec	
	Bank	W = -- D = -- V = --	W = D = Flood V =	W = based D = on fish V = catchability	
WATER BOATING	Rafts & Drift Boats	W = 50 ft D = 1 ft V = 5 ft/sec (Class I)	W = -- D = -- V = 15 ft/sec (Class V & VI)	W = >100 ft D = 2-5 ft V = 10 ft/sec (Class II,III,IV,V)	In all cases, check against International Classification.
	Canoes & Kayaks	W = 25 ft D = 3-6 in V = 5 ft/sec (Class I)	W = -- D = -- V = 15 ft/sec (Class IV & V)	W = >75 ft D = 2-3 ft V = 10 ft/sec (Class II,III,IV)	
TRANQUIL WATER BOATING	Canoeing	W = 25 ft D = 6 in V = --	W = -- D = -- V = 5 ft/sec	W = >75 ft D = 2-5 ft V = <1.5 ft/sec	
	Rowing	W = 25 ft D = 1 ft V = --	W = -- D = -- V = 5 ft/sec	W = >75 ft D = 2-5 ft V = <1.5 ft/sec	
	Sailing	W = 100 ft D = 2 ft V = --	W = -- D = -- V = 1.5 ft/sec	W = >200 ft D = ∿ 5 ft V = ∿ 0 ft/sec	
	Low Power	W = 25 ft D = 2 ft V = --	W = -- D = -- V = 10 ft/sec	W = >100 ft D = ∿ 5 ft V = <5 ft/sec	
	High Power	W = 100 ft D = 5 ft V = --	W = -- D = -- V = 15 ft/sec	W = >300 ft D = 10 ft V = <5 ft/sec	
WATER CONTACT	Swimming	W = 25 ft D = 3 ft V = --	W = -- D = -- V = 3 ft/sec	W = >100 ft D = 5 ft V = <1.0 ft/sec	Water temp - max 50-100°F Visibility - Opt=Depth Bacteria max 1000mpn
	Wading	W = -- D = -- V = --	W = -- D = 4 ft V = 2.5 ft/sec	W = -- D = 1-4 ft V = 2-5 ft/sec	Max D x V = 10 Opt D x V = 2-5 + above
	Tubing	W = 25 ft D = 1 ft V = 1 ft/sec	W = -- D = -- V = 10 ft/sec	W = >75 ft D = 2-5 ft V = 5 ft/sec	Same as Swimming
	Water-Skiing	W = 200 ft D = 5 ft V = --	W = -- D = -- V = 3.5 ft/sec	W = >500 ft D = 10 ft V = <2.5 ft/sec	Same as Swimming

are restricted in their movements; this may improve gross catchability, but does not provide a high quality sport fishery. Between these extremes of stranding and velocity limitation on movement, there is some optimum set of conditions for angling. These conditions have also been described in terms of Average Annual Flow (AAF) (Fred Johnson, 1976). In small streams, such as trout streams, a flow of from 3 to 5 times AAF often yields good cover conditions and provides food sources not available at lesser flows, thereby improving catchability. In medium-sized streams, flows at or near AAF often seem to provide the greatest fisherman success, while on large streams, water clarity is improved and depths reduced to manageable levels at something less than AAF. Thus, in general, the larger the stream, the smaller the percent AAF required for fisherman success.

These considerations of fish survival and catchability, however, are of secondary importance to the task at hand. Physical limits for fishing as a recreation activity must be set from the perspective of the fisherman. Three forms of recreational fishing occur in rivers and stream: wading, boat fishing, and bank fishing. Flow criteria for these are most directly set by the flows governing the form of pursuit.

2.1.1.1 Wading Fishing

The wading engaged in by fishermen is incidental to the primary aim of capturing fish. Its prime function is to improve the mobility of the fisherman in areas where bank access is poor and to provide casting room where bank vegetation is thick. These considerations specify an essentially longitudinal activity with the intent being to "cover the water". The fisherman will often be equipped with waders, which may set an upper bound on the depth to which he will wade. This would be about 2 1/2 feet for hip boots and 4 feet for chest waders.

In ideal wading conditions, the general criterion is that safe wading is possible as long as the product of the depth of the stream in feet and the velocity in feet per second does not exceed 10 (Hendrickson and Doonan). (The general applicability of this is discussed under Water Contact.) Comparing this velocity-times-depth limit with the rough depth limits for dry wading gives the following criteria.

Minimum Conditions -

> There are none; wading can be engaged in so long as there is water in the stream. Flow is not required. There is a de facto lower limit, however, in the survival flow for the species of interest. Fisheries data indicate that, for coldwater fish, this is about 10% of AAF.

Maximum Conditions -

For a normal-sized, adult fisherman in chest waders, Depth = 4 feet, Velocity = 2.5 feet. At any lesser depth, the product of depth (ft.) and velocity (ft/sec) should be less than 10. Where the bottom is uneven, rocky, or slippery, the maximum conditions are shifted downward.

Optimum Conditions -

These are determined by the catchability of the species being pursued. The ability of the fisherman to pursue the fish by wading is assured by any flow yielding less than maximum depths and velocities.

2.1.1.2 Boat Fishing

Some assumptions are required to set flow criteria for boating in pursuit of fish. It is assumed that fishing occurs from a canoe or similar shallow draft craft and that power boats are small fishing boats, equipped with a motor of 15 horsepower or less. Canoes, when unpowered, can negotiate (with great difficulty) water as shallow as 3 inches and can turn around in little more than their own length. A limit of 6 inches is more realistic if hang-ups are to be avoided. Paddling, as opposed to poling, becomes possible at a depth of 2 feet. Safety for a fishing party is optimized if the occupants can "walk out" after capsizing, implying a depth of less than five feet. There is no maximum depth for canoeing, but there are maximum velocities. Competent, but not expert, paddlers can handle a canoe effectively in waters as fast as 6 feet per second; at this velocity, backpaddling is just sufficient to hold the boat steady in the current. Faster water would make manuevering more difficult, and a firm upper boundary is reached at a velocity of 15 feet per second - even strong paddlers could not make sustained headway against such a velocity. A velocity of 10 feet per second would tax many boaters.

Small power boats offer an advantage in that they can make headway against relatively strong currents without exhausting the fisherman. They, too, however, become unmanueverable and find difficulty in upstream progress in currents of 10 feet per second. Depth limits are less generous than for canoes. With a short-shaft motor, depths of less than 2 feet will often cause propeller fouling on bottom growth. With motors up, negotiating water between 6 inches and 1 foot is possible. Turning within one boat length is feasible, but difficult.

The following criteria govern fishing from small non-powered and low-powered fishing craft.

Minimum Conditions -

Depth = 6 inches for canoes, 1 foot for small power boats. There is no lower limit for velocity. Width can be as narrow as one times the length of the craft being used, or, more realistically 25 feet. (In narrower streams, wading or bank fishing would be preferred to boat fishing).

Maximum Conditions -

Velocity = 10 feet per second. There are no width and depth maxima for boating in pursuit of fish. Velocity maxima should be for short distances only.

Optimum Conditions -

Depth = 2 to 5 feet. Velocity less than 5 feet per second. Width greater than 25 feet.

2.1.1.3 Bank Fishing

Bank fishing, to a high degree, is independent of stream flow from the anglers viewpoint. The activity is possible, although perhaps non-productive, at no flow and can be carried out at any flow that does not over-top or make inaccessible the banks of the stream. Optimal bank fishing flow depends upon the catchability of the fish being sought. In the sense of maximizing the chance of capturing a fish, it is the lowest flow that will sustain the population. This low level of flow minimizes the mobility of the fish. Such a condition, however, cannot be recommended since it would quickly lead to destruction of the fisheries resource.

2.1.2 Non-Tranquil Water Boating

Boating in non-tranquil water (white water, wildwater) is an activity of relatively broad aesthetic appeal, but relatively minor numerical participation. The demands placed on a boater by white water are sufficient to discourage many potential participants. None-the-less, much of the literature on water based recreation concerns this activity and its general popularity is growing rapidly.

There are four common forms of white water craft, each with its own advantages, disadvantages, and criteria for use. Perhaps the most common is the open canoe, usually from 15 to 17 feet in length, which is used by both serious and casual white water boaters. Kayaks are among the most popular craft for the veteran white water boater. On larger rivers, or with larger parties, wooden or aluminum drift boats and rafts are the crafts of choice.

In terms of stream flow criteria, canoes and kayaks may be grouped together. Both are small, maneuverable, and capable of upstream and cross-stream maneuvers. The drift boats and rafts are larger, less maneuverable and almost impossible to move upstream in heavy water. They are, however, very stable in heavy water and can carry unskilled passengers; they are used almost exclusively by commercial river guides.

In either class of craft, a certain minimum condition must be met in a stream to provide even a limited white water experience. The exact conditions of gradient and flow that yield white water vary from stream to stream, but a good rule of thumb is that white water streams have a gradient in excess of 10 feet per mile and a flow in excess of 500 cubic feet per second. These conditions will provide Class I white water on the International River Classification scale. This scale recognizes six grades of white water. These may be subjectively described as:

> Class I - Very Easy. Waves are small and regular, passages are clear. Obstacles are sand bars, bridge piers, and riffles.
>
> Class II - Easy. Rapids of medium difficulty with clear, wide passages.
>
> Class III - Medium. Waves are numerous, high, and irregular. Passages are clear but narrow and require expertise in maneuvering. A spraydeck on open boats is useful.
>
> Class IV - Difficult. Long rapids with powerful waves and many obstacles are present. Passages are difficult to see and powerful, precise maneuvering is required. A spraydeck is essential on open boats.
>
> 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.
>
> Class VI - Extraordinarily Difficult. The difficulties of Class V carried to the extreme of navigability.

For recreational white water boating, only Classes I through IV are of interest. Class I marks the minimum level for a white water experience, Class III is the usual upper bound for open boats, and Class IV is the upper limit for most recreational kayakers. Rafts, drift boats, kayaks, and covered canoes can negotiate Class V waters if they are expertly handled. Class VI waters are stunt waters for expert boaters with maximum safety precautions.

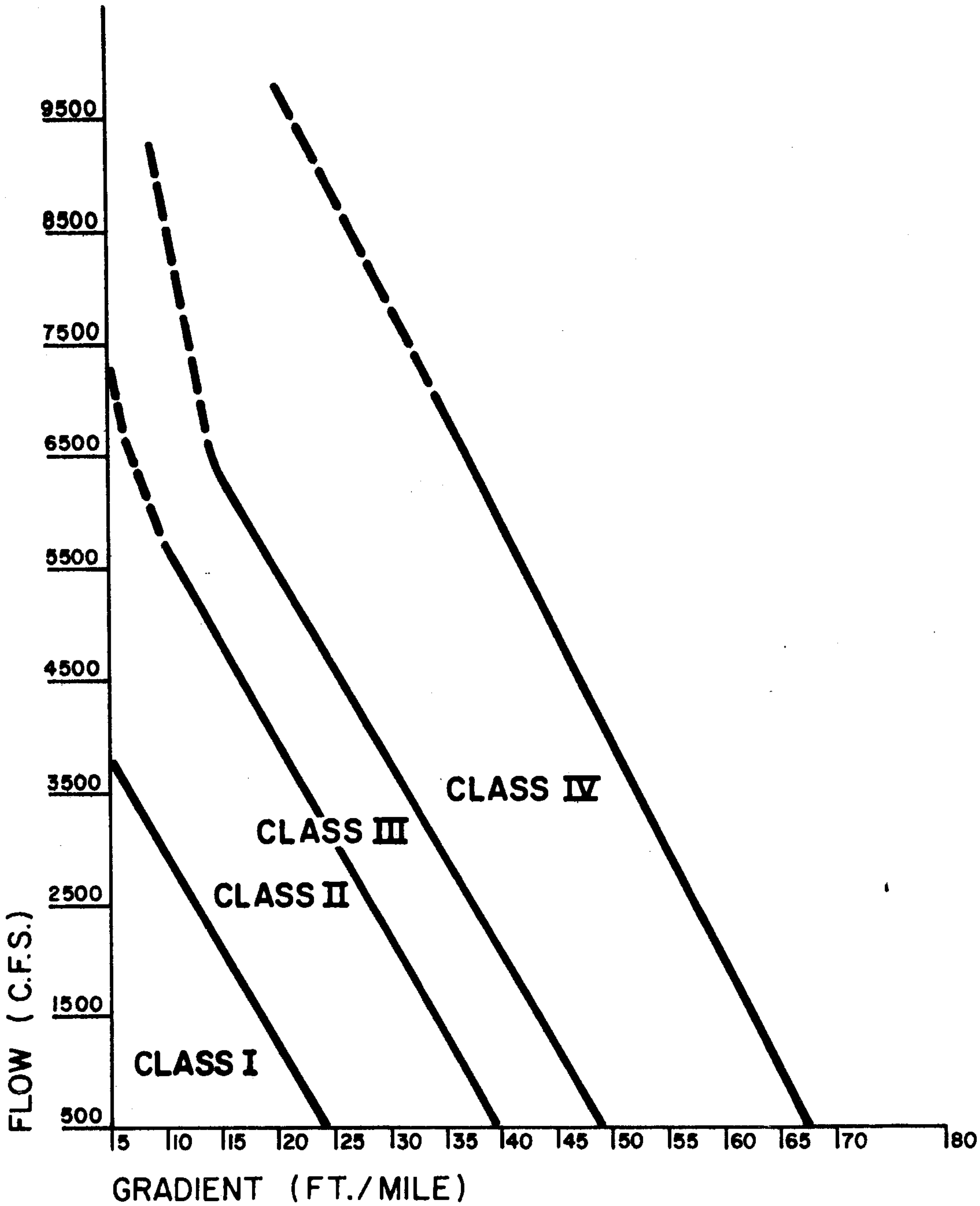
The Class of a stretch of river can be estimated roughly from information on gradient and flow. The following graph applies to stretches of uniform gradient quite well. It does not predict the class of short, steep stretches (See Figure 1).

More precise and less subjective Class determinations can be made if the river can be field inspected. The following chart (Table 3) can be used for this purpose. The stretch of interest is scored in all 11 categories and the scores summed. The total score indicates the International Classification of the stretch.

In addition to providing water of a suitable International Class, a stream must meet other requirements in order to provide a high quality white water experience. These are best described in terms of obstructions and time of travel.

Obstructions must be viewed as detractions from the white water experience. Portaging around a dam is not what is sought by most white water boaters. Thus, careful map, air photo, and field inpsection will be needed to find possible obstructions to boating and to determine if there is sufficient warning of these obstructions to insure against boater injury and suitable portaging areas to allow passage. This must be dealt with on a river-by-river basis, but in general, the more obstructions, the less desirable the water for white water boating.

Time of travel has two influences. First, it may determine the gear and supplies required for a river trip and, second, it may select for or against some forms of boating. The kayaker, for instance, may enjoy running and re-running a short, intense section of a stream with still water above and below. This might not be possible for a group in a drift boat, which is difficult to move upstream and heavy to portage. Thus, short sections of water may be ideal for "practice" and longer runs, of some hours or even days, may be more suitable for float trips or white water expeditions. Garren (1976) has provided some rules of thumb for determining the time of travel for various craft in various river situations. He notes that, if a kayak is assigned a drift time of 1.0, a canoe will require 1.1 times as long to traverse the same distance, a drift boat will require 1.3 times as long, and a rubber raft will require 1.6 times as long. He also presents a generic relationship between river discharge, in cfs, and river velocity in miles per hour. See Figure 2. This, much like the Class derived from the Arighi and Arighi chart, can be greatly refined by the hydrological studies, but the chart is useful for estimating time of travel directly for kayaks. This can be adjusted for other types of craft, if needed, using the multipliers.



ESTIMATING RIVER DIFFICULTY
(Assumes Fairly Even Gradient)

AFTER ARIGHI AND ARIGHI, 1974

Figure

Table 3

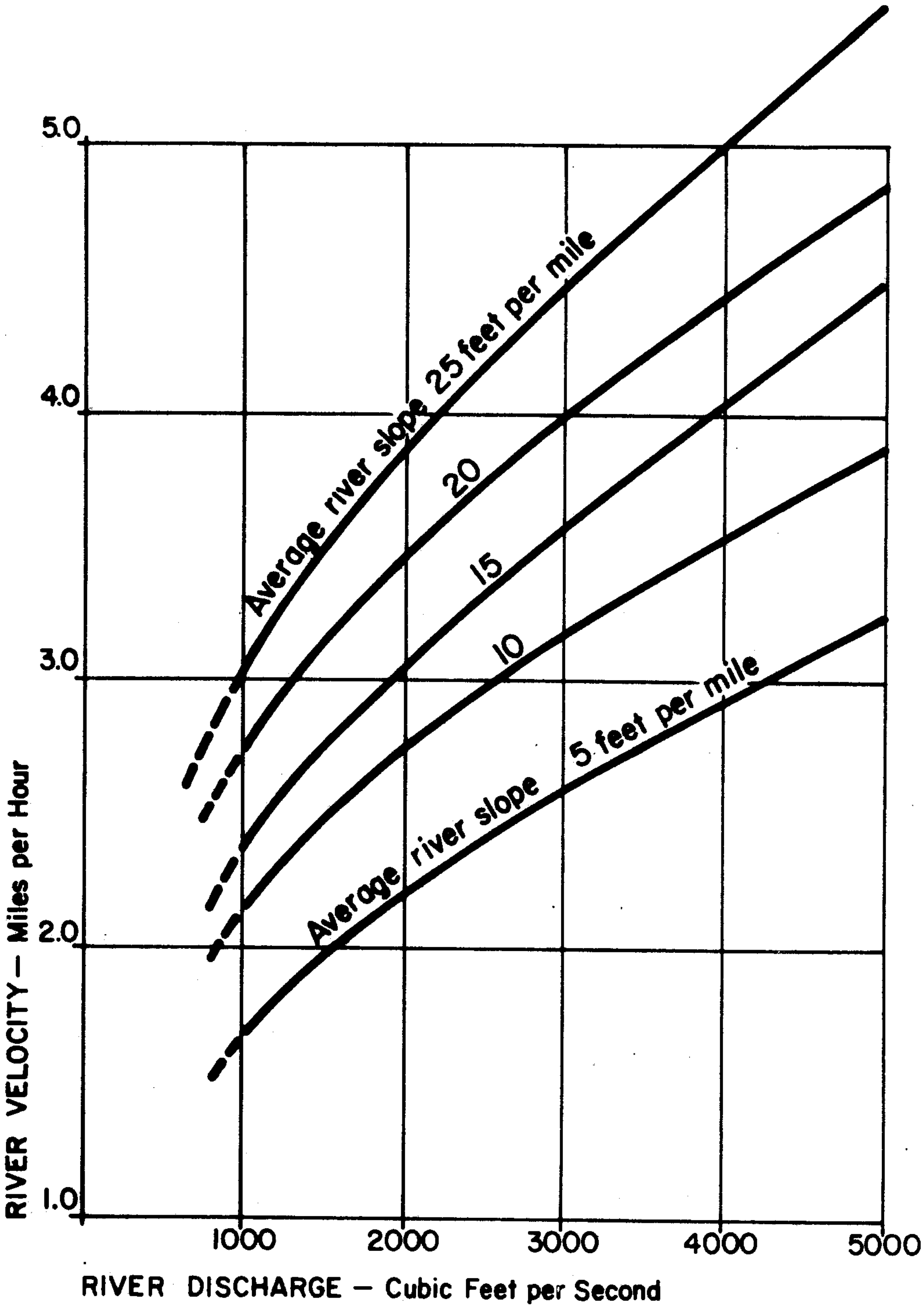
River Rating Scale

Factors Related to Difficulty of Negotiating and Safety

Points	*0*	*1*	*2*	*3*	*4*	*5*	*6*
Bends	few, very gradual	many gradual	few, sharp, blind				
Length, ft.	less than 100	100–700	700–5,000	over 5,000			
Gradient, ft./mi.	less than 5	5–15, even slope	15–40, ledges or steep drops	over 40, steep drops, small falls			
Obstacles (trees, rocks)*	none	few; passage straight and obvious	some; courses easily recognized	maneuvering, courses not obvious	intricate maneuvering; course hard to recognize	course tortuous; frequent scouting needed	very tortuous; always scout from shore
Waves	few inches avoidable	low (up to 1 ft.) regular, avoidable	low to med. (up to 3 ft.) regular, avoidable	med. to large (up to 5 ft.) mostly regular, avoidable	large: irregular, avoidable; or med. to large: unavoidable	large irregular, unavoidable	very large (over 5 ft.) irregular, unavoidable
Turbulence	none	minor eddies	med. eddies	strong eddies, cross currents	very strong eddies, strong cross currents, holes	large-scale eddies and cross currents, some boils	
Resting or rescue spots	almost everywhere			good one below every danger spot			almost none
Water speed, mi./hr. ft./sec.	less than 3 less than 5	3–6 5–9	6–10 9–15	over 10 over 15 or flood			
River width	narrow (75 ft. or less)	wide	narrow	wide			
River depth	shallow (less than 3 ft.)	shallow	deep	deep			
Water temp., °F.	over 65	55–65	45–55	less than 45			
Accessibility	road along river	one hour or less "out"	one hour to one day "out"	more than one day "out"			
Total points Difficulty rating		0–7 I	8–14 II	15–21 III	22–28 IV	29–35 V	36–40 VI
Approximate skill required		practiced beginner	intermediate	experienced	highly skilled · several years with organized groups	team of experts	

*Prepared by Guidebook Committee, American Whitewater Affiliation.

NOT REPRODUCIBLE



ESTIMATED RIVER VELOCITY

(GARREN, 1976 p.13)

Figure 2

Regardless of the approach taken to classification, upper and lower limits on river characteristics can be specified for the two groups of craft type, based on their characteristics.

2.1.2.1 Canoes and Kayaks

Canoes and kayaks are very maneuverable and draw very little water. They can pass over obstacles with as little as 3 inches of water and can be turned in their own length. With small margins for error and to prevent unnecessary bottom dragging, a minimum depth of 6 inches and a minimum width of 25 feet will allow passage. The minimum water velocity to yield Class I white water is about 5 feet per second.

Maxima for these craft are somewhat more difficult to establish. Very wide rivers, especially if they are Class IV or higher, adversely effect safety, but do not physically preclude the activity. Depths, too, cannot alone eliminate the activity, although at very high stage, most of the obstacles that create the white water experience may be so deeply covered as to be unnoticeable. Maximum velocity is in the vicinity of 15 feet per second. Above this speed, even an expert boater or team would be nearly unable to hold position or move upstream.

Optimum flow levels are completely river and boater skill specific. Generally, river conditions yielding Class II and III waters will be optimum for open canoes. The optimum for kayaks and decked canoes, especially for skilled boaters, may include Class IV waters. These optimum conditions will occur on many rivers at a depth of between 2 and 3 feet, with widths on the order of 75 to 100 feet, and velocities of about 10 feet per second.

Thus, the criteria for white water boating are as follows. Note that these are very general and, particularly for the optimum conditions, can only be accurately assessed at streamside or on the water.

Minimum Conditions -

> Width = 25 feet, Depth = 3 to 6 inches, Velocity = 5 feet per second. Conditions should yield Class I (and perhaps some Class II) water in the stream.

Maximum Conditions -

> No firm width and depth maxima can be established. Velocities in excess of 15 feet per second will preclude all but the most skilled and dedicated boaters. Conditions should yield Class IV or V waters over much of the stretch of interest.

Optimum Conditions -

Width = 75 to 100 feet, Depth = 2 to 3 feet, Velocity = 10 feet per second. Conditions should yield Class II and III waters in the stretch of interest (some Class IV might be desirable for kayakers.) The optimum conditions will require field checking, unless flow related classifications for the stream are available from reliable guidebooks or organizations.

2.1.2.2 Rafts and Drift Boats

The primary differences between these craft and canoes and kayaks are their lack of maneuverability and their ability to negotiate very heavy water. In terms of river characteristics, these craft require more space than do the smaller craft. A minimum width of 50 feet and a minimum depth of 1 foot should insure their passage. As before, a minimum velocity of 5 feet per second will often generate mild white water conditions. The implication of these minima is that rafts and drift boats require larger streams and more water to be used successfully.

Maximum and optimum conditions are very similar to those discussed for canoes and kayaks, except that these boats can sustain Class V waters more readily than can the smaller craft. Numerical maxima are as before, but these conditions can yield a higher Class water in the stream without eliminating the activity.

Minimum Conditions -

Width = 50 feet, Depth = 1 foot, Velocity = 5 feet per second. Class I or II waters should prevail.

Maximum Conditions -

No firm width or depth maxima can be established. Velocities greater than 15 feet per second may be limiting. River conditions yielding Class V and VI waters over long stretches will eliminate the activity.

Optimum Conditions -

Width = 100+ feet, Depth = 2 to 5 feet, Velocity = 10 feet per second. Conditions in the stream should yield Class II to IV waters in the stretch of interest. Some Class V will add to the enjoyment of skilled boaters, but may prove dangerous in the event of capsize.

2.1.3 Tranquil Water Boating

Five separate kinds of activity must be considered in tranquil water boating: canoeing, rowing, sailing, low power boating, and high power boating. These activities share many characteristics with non-tranquil water boating, but exhibit much more stringent limits on maximum conditions. The longitudinal suitability and time of travel considerations given above for white water boating apply in much the same fashion to flat-water boating, except that some short flat water reaches will see very heavy use if access is good. Obstructions to flat water boating include not only the dams and falls which obstruct white water activities, but rapids as well. Ideally, a flat water reach would include no dams, falls, or white water stretches. The flow would be uniform and progress could be made both downstream and upstream without severely taxing the participants. Failing of this, major portage areas should be considered as obstructions. A cut-off length of 1/4 mile for portaging may represent the upper end of desirability for users of light craft, such as canoes. Portaging of power boats is generally out of the question and any portage site must be considered as completely obstructing. Should a river reach prove generally suitable for flat water boating, there are specific criteria governing each of the forms of the activity, set by the nature of the craft.

2.1.3.1 Canoeing

Canoes, as discussed above, can negotiate waters as shallow as 3 to 6 inches, although poling will be more appropriate than paddling. Widths as narrow as the length of the boat can be acceptable, although a practical minimum is about 25 feet. The quality of canoeing improves markedly as depths become greater than 2 feet. At two feet, paddling without striking the bottom is possible. Safety considerations make a depth of 5 feet the upper bound of optimal canoeing; at this depth, most people can wade out in the event of capsize. There is no maximum width or depth which precludes canoeing, but velocities in excess of 5 feet per second impede upstream progress and mark the general lower limit of Class I white water conditions. Thus, the criteria are:

Minimum Conditions -

Width = 25 feet, Depth = 3 to 6 inches, Velocity = 0 feet per second.

Maximum Conditions -

There are no depth or width maxima. Velocities over 5 feet per second change the activity from tranquil water boating to low level white water.

Optimum Conditions -

Width greater than 75 feet, Depth = 2 to 5 feet, velocity less than 1.5 feet per second.

2.1.3.2 Rowing

Rowing for pleasure shares many of the same limits as tranquil water canoeing. The major difference is that rowing requires greater depths to be pleasant. Poling a rowboat would detract from the experience. Therefore, minimum depths should be no less than 1 foot.

Minimum Conditions -

Width = 25 feet, Depth = 1 foot, Velocity = 0 feet per second.

Maximum Conditions -

No width or depth maxima can be established. Velocities should be less than 5 feet per second.

Optimum Conditions -

Width greater than 75 feet, Depth = 2 to 5 feet, Velocity less than 1.5 feet per second.

2.1.3.3 Sailing

Sailing even the smallest craft requires a draft of 2 feet to keep a short dagger board off the bottom. A width minimum of 100 feet would just barely allow a small craft (12 to 13 feet) to tack upstream. Maximum conditions, as for other forms of boating, are not applicable except in terms of velocity. If the wind dies, a sail boat must be considered unpowered, since few sail boats carry oars. Thus, 1.5 feet per second can be taken as the upper velocity limit for river sailing activities. Optimum conditions would include a depth of about five feet, the more width the better, and a velocity as near zero as possible.

Minimum Conditions -

Width = 100 feet, Depth = 2 feet, Velocity = 0 feet per second.

Maximum Conditions -

There are no maximum widths or depths for sailing. Velocities should not exceed 1.5 feet per second as a rule.

Optimum Conditions -

Width greater than 200 feet, Depth = 5 feet, Velocity near 0 feet per second.

2.1.3.4 Low-Power Boating

Small power boats (less than 15 feet and less than 50 horsepower) can be operated in streams as narrow as those used by canoes as long as fouling of their propellers can be avoided. Maximum conditions are velocity limited at about 10 feet per second, since many small power boats cannot exceed this speed (about 7 mph). Optimum conditions are found when widths exceed 100 feet, to allow turns under full power, when depths are at or about 5 feet, and when velocities are less than 5 feet per second.

Minimum Conditions -

Width = 25 feet, Depth = 2 feet, Velocity = 0 feet per second.

Maximum Conditions -

There are no maximum widths or depths. Velocity less than 10 feet per second is required.

Optimum Conditions -

Width greater than 100 feet, Depth = 5 feet, Velocity less than 5 feet per second.

2.1.3.5 High-Power Boating

High-power boats (greater than 15 feet in length and greater than fifty horsepower) are far more restricted in their operation on streams than the other classes of tranquil water boats. In fact, this type of boat is most often found on a lake or reservoir, rather than on a stream. It will be found on wide streams or where large lakes are not available. Minimum width for their operation is 100 feet to allow turning even at fairly low speeds. Depth should be greater than 5 feet in the river channel to avoid propeller drag on acceleration. They can also make greater headway than other craft, and can navigate without undue difficulty against 15 foot per second currents. Optimum conditions are widths in excess of 300 feet, to allow full power turns, depths in excess of 10 feet, and velocities less than 5 feet per second.

Minimum Conditions -

Width = 100 feet, Depth = 5 feet, Velocity = 0 feet per second.

Maximum Conditions -

There are no width and depth maxima. Velocity should be less than 15 feet per second.

Optimum Conditions -

Width greater than 300 feet, Depth = 10 feet. Velocity less than 5 feet per second.

These conditions are suitable for the majority of high-powered boats. There are, however, local and regional variant forms of high-power boating which may deserve special consideration, for example: jet-boating on larger western rivers and air-boating on southern rivers and swamps. Generally, the conditions for jet boats are similar to those for propeller-driven high-power boats except that operating depths may be as small as the hull draft of the individual craft (about 18 inches) and jet boats may be powered to make upstream progress in heavy white water conditions. Airboats, used mainly in non-riverine areas, are very maneuverable and can move in virtually no water for short distances. Their extremely shallow draft and flat bottoms make depth limits almost meaningless. As is the case with jet boats, however, they should be considered as a specialty craft and treated accordingly.

2.1.4 Water Contact Recreation

Four activities are considered under this general category: swimming, wading, tubing, and water skiing. All share the characteristic of deliberate contact with or immersion in the water without protective clothing. This places some generic limits on the activities based on temperature and water quality. Temperatures below 50°F or above 100°F will eliminate most water contact activities. Visibility should ideally extend to the bottom of the stream for both swimmer safety and for rescue. Total coliform bacteria counts should be below 1000 MPN (most probable number) per 100 ml of water to meet public health standards (FWPCA, 1968). Other than these general criteria, each water contact activity has its own unique set of physical limits.

2.1.4.1 Swimming

Swimming will be considered here as the advanced form, rather than the splash and wade form, treated as wading below. Advanced swimming requires relatively deep water, relatively still water and a width sufficient for several strokes bank to bank. Ideally, it would also occur at an area with a sand bottom and a beach to maximize the enjoyment of the participants. When lake front beaches are rated, a gentle slope of 100 feet out to a depth of 5 feet is considered ideal, but such conditions will seldom be found in a river. A reasonable minimum width for true swimming is 25 feet. Water depths of 3 feet or greater will allow a clean stroke without striking bottom. An optimum swimming depth is about 5 feet, which allows both advanced swimming and resting or wading out. Velocities of 3 feet per second will tax even a very strong swimmer quickly (Thompson and Fletcher, 1972). One foot per second or less is most desirable.

Minimum Conditions -

Width = 25 feet, Depth = 3 feet, Velocity = 0 feet per second.

Maximum Conditions -

There are no width or depth maxima. Velocities should be less than 3 feet per second.

Optimum Conditions -

Width greater than 100 feet, Depth = 5 feet (10 feet if diving is part of the activity), Velocity less than 1 foot per second.

2.1.4.2 Wading

Whether or not one can wade safely in a river at a given place is related to the depth of the water, the velocity of flow, the nature of the bottom, the purpose of the wading activity, and the physical size and strength of the participant. The depth and velocity are usually directly related to discharge; the nature of the local wadable bottom (slope, roughness, for example) may also be related to discharge. These, in turn, tend to predetermine what activities may safely take place and by what kinds of people.

Wading may be a part of the white water boating activity. The wading involved here is, of course, an unwanted incident of the primary recreational activity. However, the fact that one cannot safely wade out of a bad situation was used earlier to set a boundary on optimum boating conditions.

In terms of numbers of participant days, wading by fishermen is probably the most common wading activity found in riverine recreation. In this case, the wading is incidental to the primary purpose, which is catching fish. Thus, this kind of wading activity is longitudinal in nature.

Finally, wading is often engaged in as a substitute for swimming in rivers. In this case, wading, in the form of a special kind of water contact sport, is the primary activity. It tends to be localized in nature, in contrast to wading for fish, in places chosen because they present special opportunities for water play.

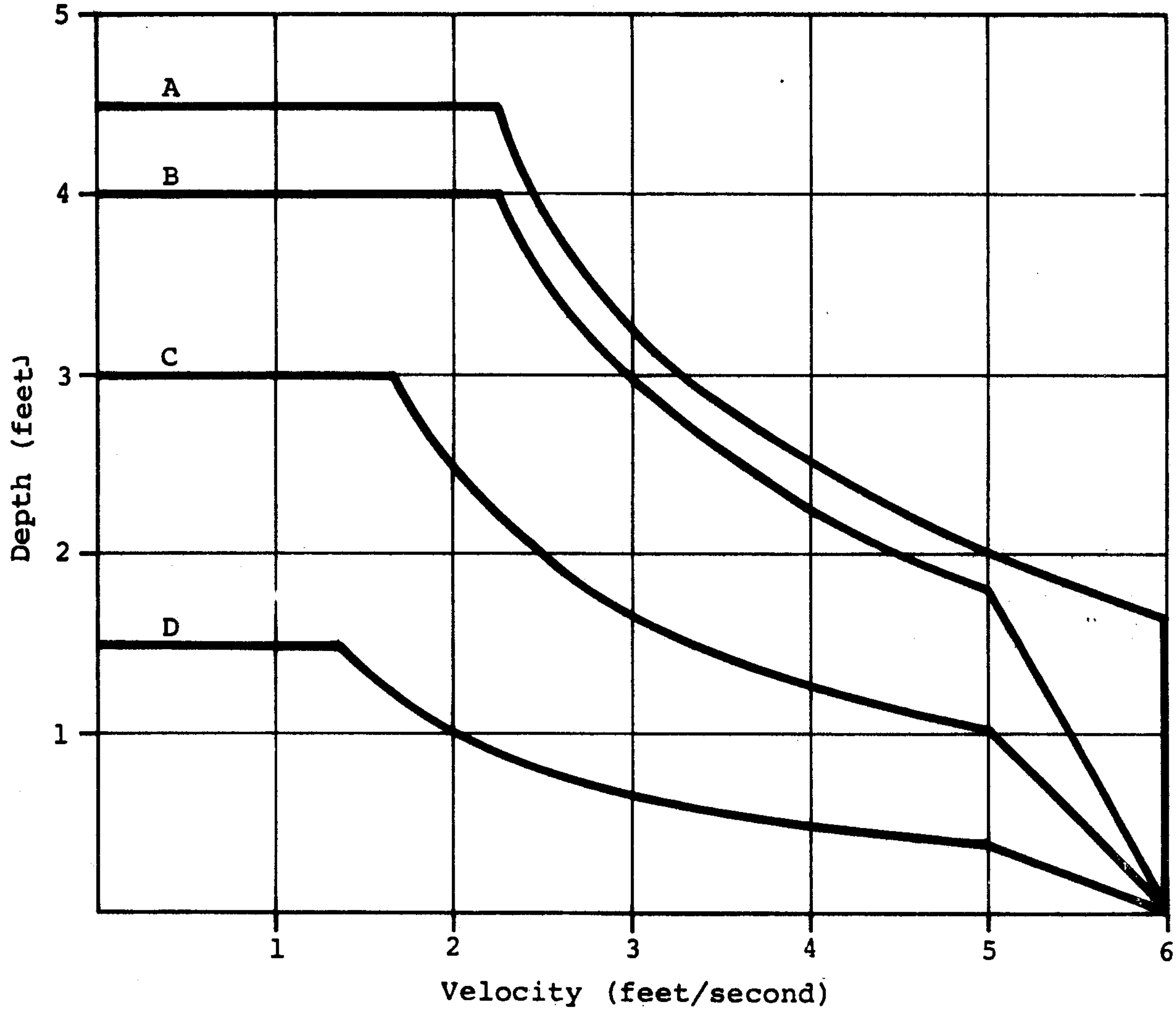
In absolutely calm water, with a smooth, firm bottom of sand or gravel, a person can safely wade up to shoulder height, if not encumbered by heavy clothing or other gear, though few would choose to do this. (Such an area would be ideal for swimming, for which wading is but a surrogate activity.) More to the point, these conditions are not commonly found in rivers, where movement of the water is almost always found. In fact, one can set bounds on wading safety, as a first approximation, by considering depth and velocity.

The rough rule of thumb is that any time the product of depth in feet and velocity of the water in feet per second exceeds 10, conditions are unsafe for wading. This assumes a bottom of gentle slope, with no holes, and covered with fine materials (such as sand or gravel) which provide both bottom smoothness and good footing. Where these physical conditions do not obtain, the depth velocity relationships become more restrictive. In essence, wading safety must depend upon physical conditions which are not conducive to losing one's footing and which will not prevent recovery if one does fall down. Waders may not know how to swim. Or they may not be able to swim because of restrictive clothing, as might be the case of the angler in his chest-high "waders."

Figure 3 presents limit curves for wading by age-body build class. In all cases, good bottom conditions are assumed. The upper curve relates primarily to fishermen. The second curve may apply to either fishing or water contact wading. The lower two curves are most pertinent to the latter activity.

The central portions of curves A, B, C, and D represent depth-velocity products of 10, 9, 5, and 2 respectively. As noted on the legend, they are keyed to large men, normal adults and teens, sub-teens, and pre-schoolers. At the high velocity end of the curves, a cut-off has been provided at velocities in the neighborhood of six feet per second. At such velocities any unexpected change in bottom configuration could lead to danger in the event of a loss of balance, even in rather shallow water. Perhaps more important, in the low velocity area the curves have been flattened out to indicate a suggested maximum safe depth for each class of wader. Even at low velocities, recovery without recourse to swimming becomes difficult when the water depth is greater than about two-thirds to three- quarters of body height.

With the caveats on body size and swimming ability in mind, the following general criteria will serve for wading activity by average sized adults and teens.



A. Tall, heavy adults (> 6')
B. Average adult, teen (≃ 5-6')
C. Sub-teen children (≃ 4-5')
D. Pre-school children (≃ 2-3')

DEPTH-VELOCITY LIMITS FOR WADING SAFETY

After Hendrickson & Doonan
(Modification of Figure 22)

Figure 3

Minimum Conditions -

Width does not affect wading, nor is there any minimum depth in the exact sense. Velocity may be zero.

Maximum Conditions -

Width does not affect the activity. Depth should be less than 4 feet, and the product of depth and velocity less than 10.

Optimum Conditions -

Width is not of importance. Depth = 1 to 4 feet, Velocity times depth less than 5, unless pre-schoolers are involved, then V x D should be 2 or less.

2.1.4.3 Tubing

Tubing, floating down a river on an innertube, is a sport of rapidly growing popularity. It has several forms, from a lazy, swim-suited float down a slow-moving, warm river, to a specialized form of white water boating. Lower limits would be those which met the temperature and chemical requirements of swimming. Upper limits are at or about Class II to III white water. Optimum levels are those which provide some white water sensation, but offer little or no danger to the participants. Thus, wading criteria help to establish optimum levels.

Minimum Conditions -

Width = 25 feet, Depth = 1 foot, Velocity = 1 foot per second.

Maximum Conditions -

There are no maximum widths or depths. Velocity should be less than 10 feet per second.

Optimum Conditions -

Width = 75 feet, Depth = 2 to 5 feet, Velocity = 2 to 5 feet per second.

2.1.4.4 Water Skiing

Water skiing requires the temperature and water quality conditions of swimming combined with the physical requirements of large power boats. There must also be an extra margin of width to allow for turning the boat with the skier attached at sufficient speed to keep the skier at the water surface. As in the case of large power boating, small rivers are poor substitutes for lakes and reservoirs for this activity. The following criteria are from Thompson and Fletcher (1972).

Minimum Conditions -

Width = 200 feet, Depth = 5 feet, Velocity = 0 feet per second.

Maximum Conditions -

There are no width and depth maxima. Velocity must be less than 3.5 feet per second.

Optimum Conditions -

Width greater than 500 feet, Depth = 10 feet, Velocity less than 2.5 feet per second.

2.1.5 Wetland-Related and Water Enhanced Activities

This is by far the largest suite of activities considered under one general heading. Wetland-related activities include water fowl hunting, retriever training, bird watching, wildlife photography, and botanizing (the collecting of plant specimens). Water enhanced activities are all of those that take place out of the water, but which may be made more satisfying by the presence of water. The prime forms would be hiking, camping, picnicking, and sight-seeing along a river. Unlike the other groups considered above, these activities are not clearly related to the instantaneous level of flow, although flow level may be, in some senses, important or even crucial.

Wetland related activities depend, of course, on the presence of wetlands. These may be of two major types: groundwater controlled or surface water controlled. In either case, large changes to the hydrologic regime of a stream could modify or eliminate the wetland. For example, it is possible to capture a stream entirely, either through direct diversion to another body of water or through 100% appropriation of water for irrigation with no return flow. In either event, all wetlands along the stream which depended on the surface water for their supply would be lost. Additionally, such complete diversion would cause changes in water table levels extending some distance from the stream channel. This could destroy or modify nearby ground-water controlled wetlands. A second form of impact might be had with a flood control structure which eliminated spring high flows. Many forms of wetland, such as floodplain forests or wet meadow, depend not on continual water presence, but on annual flooding. Annual flooding also is needed by some wildlife, such as wood ducks, for successful reproduction. Thus, the elimination of spring high flows could compromise both wetlands and transient wildlife.

The only method for dealing with these effects is a radical departure from the criteria approach used for all of the in-the -water activities. Careful map study and limited field reconnaissance will allow the identification of wetland resources along and near the stream of interest. Their elevations should then be checked against both normal and annual high-flow elevations along the stream. Those at or near the normal level of the stream can be assumed to be sensitive to even fairly minor level decreases, as from diversions. Wetlands within the normal highwater elevation of the stream may be either groundwater controlled or depend upon annual inundation. Examination during the dry season can help determine which. Groundwater controlled wetlands will remain saturated nearly to the ground surface in all but drought conditions. Those floodplain wetlands which are dependent on annual inundation will be dry for several inches to a few feet below ground surface by late summer. In this case, flood control projects which eliminate spring high flows as well as controlling rare flood events may cause rapid succession from wetland to upland vegetation. In the case of groundwater controlled wetlands, a substantial reduction in average annual flow (by major diversion) would be required to affect them predictably.

Water enhanced activities are also not amenable to simple criteria setting. The aesthetic attraction of water operates at all flows from a trickle to a torrent. Even dry stream beds may be favored hiking places, both for ease of passage and for the water-carved forms sometimes seen. In general, flowing water must be considered a resource, and its elimination must be considered undesirable. But, from the standpoint of water enhanced activity, even fairly dramatic changes in the regime or absolute flow of a stream might have negligible influence on this particular activity suite.

The aesthetic operation of water in a landscape, however, might be amenable to analysis from photographs. Shafer and Mietz (1970) developed a quantitative landscape preference model based on eight zones within a landscape photograph: sky and clouds, immediate trees and shrubs, intermediate trees and shrubs, distant trees and shrubs, immediate "other features", distant "other features", and water. Their results showed that a preference model worked well, except when water appeared in the photo; in this case, the observer ranking was generally higher than the model-predicted ranking. Their post analysis of the test case results indicated that water features were preferred in the following order:

Waterfall, stream, and lake combined
Multiple waterfalls
Single waterfall and rocky stream
Rocky stream
Lake
Swampy stream

The work of Shafer and Mietz provides some insight into the overall visual preference for water features and the beginnings of a hierarchy of waterscape preference. Additionally, their technique does provide a consistent method of describing a landscape from a photograph which can be of use in developing comparative data, even though firm criteria and numerical flow dependence cannot be clearly demonstrated.

Neither wetland related nor water enhanced activities are in any simple fashion dependent upon flow. Thus, these two groups of activities are not included in the criteria system developed above for the on-the-water activities. The recreation planner, however, must be sensitive to these uses.

2.2 STREAM CLASSIFICATION

Stream classification is the description of stretches of the study reach exhibiting similar channel patterns. The selected system is that of Culbertson, et al., supplemented with a notation of stream gradient and average channel width. The individual classification variables each can be qualitatively related to various recreational pursuits, but, most importantly, the classification system provides a consistent method of describing stream channel form. This will allow comparable stretches of the same stream to be identified and will allow comparison between different streams exhibiting similar channel form.

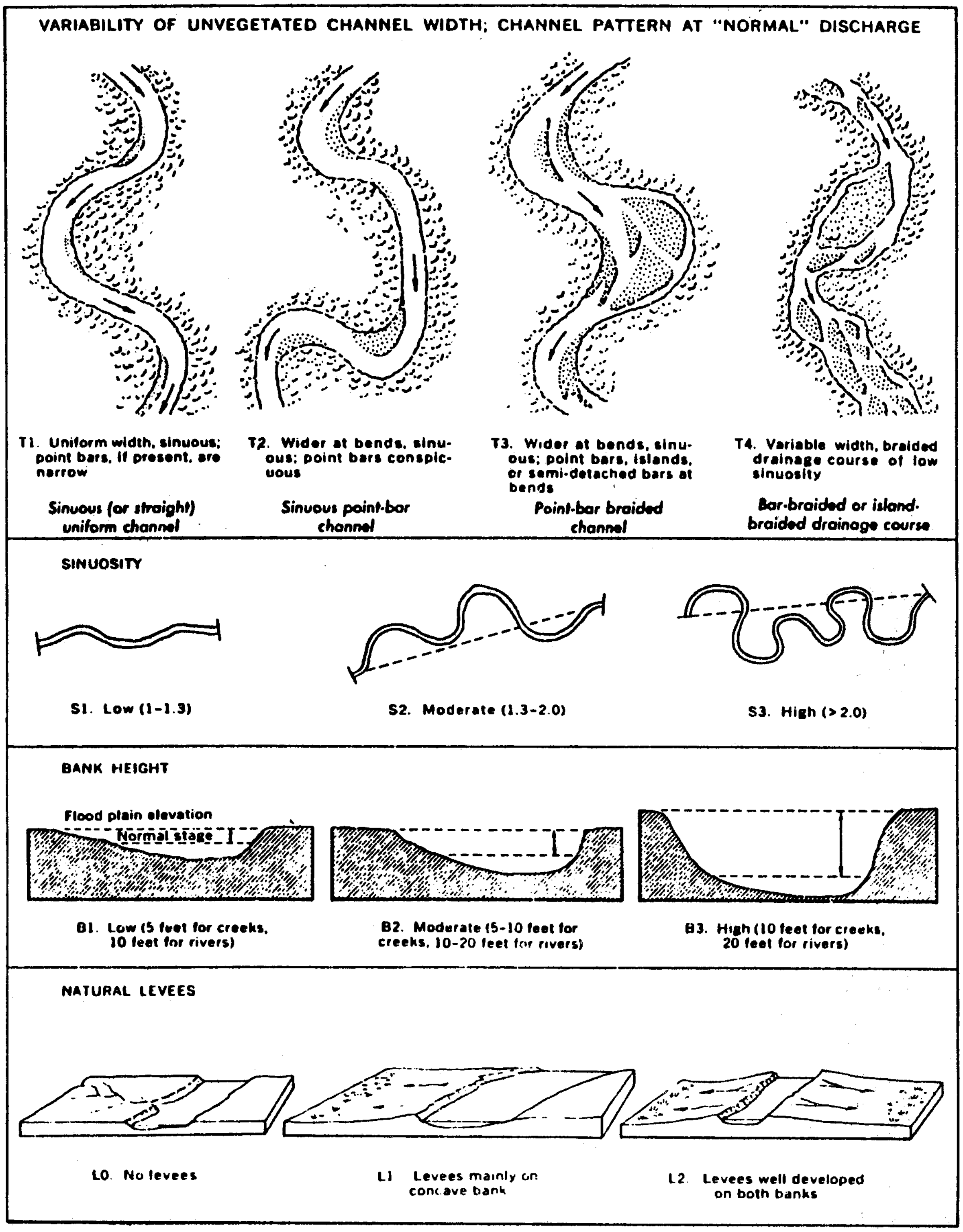
When this classification system is used, a channel is initially placed in one or another of four channel pattern types, as shown in the first section of Figure 4. These types are:

- T1 - sinuous or straight uniform channel
- T2 - sinuqus point-bar channel
- T3 - point-bar braided channel
- T4 - bar-braided or island-braided drainage course

These initial categories are supplemented by other channel descriptors. These include: sinuosity, bank height, natural levees, oxbow lakes, meander scrolls, modern floodplain, and complexity of braiding. In the following sections these basic channel patterns are discussed. They are illustrated in Figure 4.

2.2.1 Variability of Width

Width is considered as "unvegetated channel width". This is determined initially from aerial photography and is later field checked. A relatively uniform channel width often indicates erosion-resistant banks which may result from suitably high clay content or may be due to a thick vegetation cover. Recent work indicates that bank materials which have greater than 5% clay are significantly more resistant to erosion than those with less than 5% clay (Knighton, 1974).



NOT REPRODUCIBLE

(CULBERTSON et al., 1967)

Stream Channel Characteristics

Figure 4

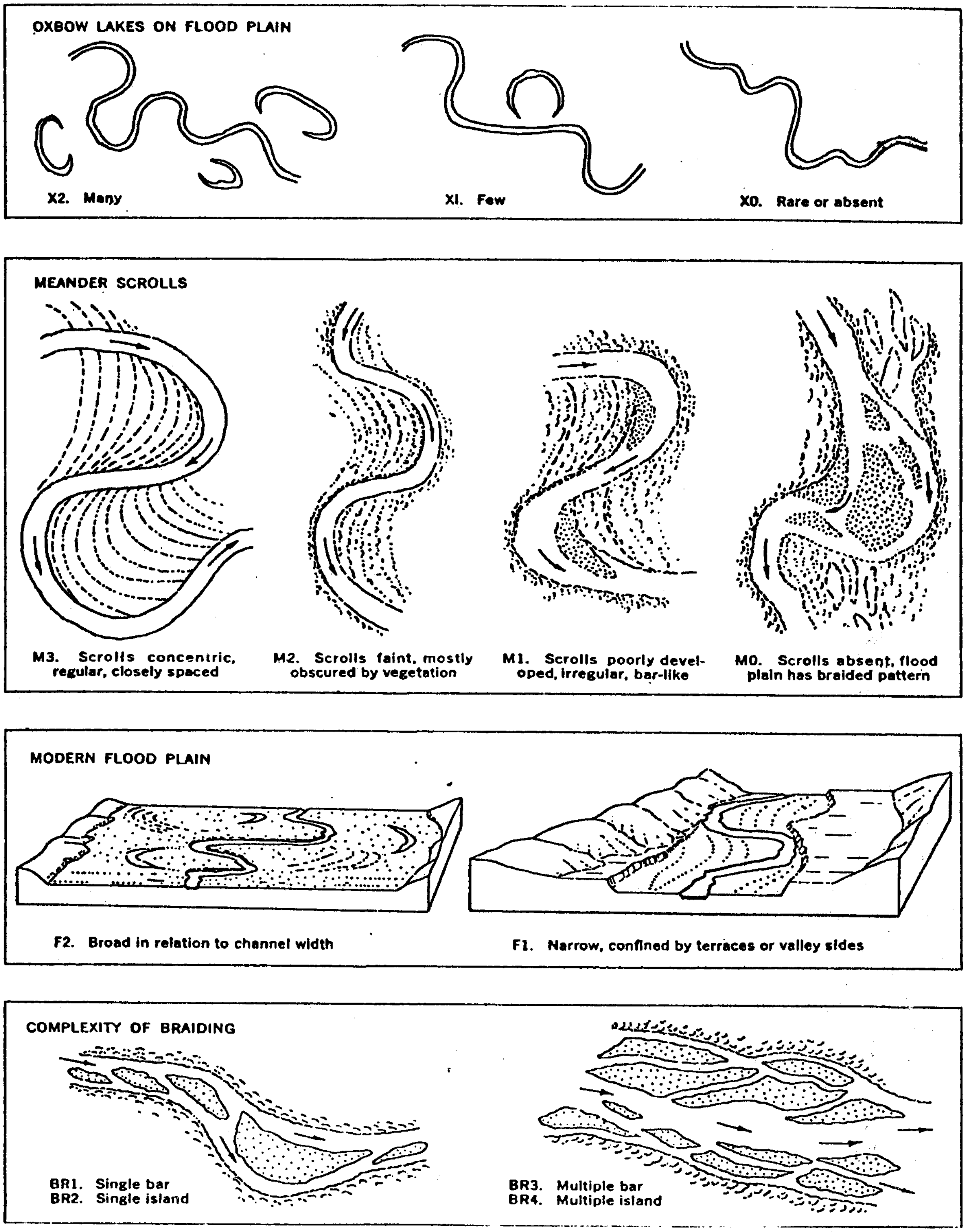


Figure 4 (Cont'd)

2.2.2 Sinuosity

Sinuosity may be calculated from map work or from aerial photography. Unless air photo mosaics are available for the river reach being studied, topographic maps are best for sinuosity calculations. The date of mapping should be compared with hydrological records to determine if any extreme discharge events have taken place subsequent to mapping.

Sinuosity is calculated by setting up a ratio of the river length to the airline distance. Both distances are commonly measured in the same units. The sinuosity classes in Figure 4 are divided into low (1.0-1.3), moderate (1.3-2.0), and high sinuosity (2.0 and above). In classification, sinuosity is designated as one of these three categories, S-1 to S-3. The higher sinuosity class often indicates a shallow, wide stream.

Sinuosity may be used in general terms to compare segments of individual rivers to one another or a river to another river. The sinuosity of a river is the end result of the interplay of gradient, size of bed-load material, and stream energy. Since these factors may not be weighted equally at all times, precise statements or predictions based on sinuosity ratios are not always possible. Generally, however, straight stream courses indicate areas of erosion resistant banks, whether caused by cohesive bank materials, bedrock controlled banks, or vegetatively stabilized banks.

2.2.3 Bank Height

This is calculated by measuring the distance between the water surface at normal stage and the surface of the modern flood plain. This distance can be estimated by comparison with objects of known height (cars, houses, etc.) or determined relatively accurately by using stereo air photo coverage of the banks and a parallax bar. The modern flood plain is the lowest flat surface along the river, and can generally be identified on aerial photos by features such as scrolls, oxbow lakes, meander scars, etc. High banks suggest either that the river is actively degrading or that flood flows which overlap the banks are relatively infrequent. Low bank height often indicates frequent flooding, or lack of sediment cohesiveness due to a paucity of clay in the sediments or a lack of bank vegetation.

2.2.4 Natural Levees

These are often best identified on cross-sections which have been surveyed across the flood plain, although moderately well developed levees may be identified from air photos. The significance of the presence of natural levees is that they suggest that a lateral migration of the channel is not likely, unless flow events occur which overtop or breach the levees.

2.2.5 Oxbow Lakes and Meander Scrolls

The shapes of these morphologic features are included in the classification figure. The presence of features such as these indicates lateral migration of the channel. High flows, at or near bank-full conditions are usually responsible for scroll formation so that areas with large numbers of scrolls may be expected to experience such conditions frequently.

2.2.6 Braiding

Bars or islands that divide the flow in a channel are the most important elements of the braided pattern. Variations in the size, the number, and the distribution of these gives rise to many diverse kinds of braiding, of which two major kinds are illustrated in Figure 4. The point-bar braided channel is braided mostly at bends, and most of the islands or bars have apparently originated from point-bar deposits; it is transitional between a braided and an unbraided channel. Where bars or islands are more numerous or more consistently distributed, the term "braided drainage course" is appropriate. According to its degree of complexity, the braiding of a drainage course can be described as single-bar (or island) or multiple-bar (or island) braiding. The term single implies that the braiding at a typical cross section is due to a single bar (or island) rather than to two or more bars (or islands). Vegetal cover distinguishes an island from a bar, and islands are likely to be more permanent than bars. As a river course becomes more braided, it is very likely to become wider and less sinuous, especially if the braiding is due to the growth of channel bars or islands. However, a low sinuosity of the drainage course is not necessarily accompanied by a low sinuosity of the individual channels (sometimes called anabranches) between islands and bars. The channels of glacial outwash braiding are characteristically sinuous, and this sinuosity may be a morphologic indication of aggradation (Culbertson et al.).

In addition to classifying a reach using the Culbertson, et al. method, gradients for both regional and local stretches are included. Width is discussed in the above classification only in relative terms. In order to accurately assess recreational potential at a given section, the actual width or range of widths must also be specified.

2.3 STREAM DISCHARGE

Stream discharge in a basin is basically a function of precipitation and the physical characteristics of the basin. Many methods exist to represent stream discharge data. In terms of the measure which is the most useful for describing the discharge characteristics of a channel at a particular flow, Culbertson et al., consider a flow-duration curve to be the most useful. They maintain that many of the characteristics represented by the curve are reflected in the geomorphology of the channel section. Many authors consider that the channel geometry at a given time reflects the last high discharge event. Leopold et al., (1964) found that in perennial streams, the majority of scour and fill and debris transport occurs at flows which occur less than 0.4% of the time or approximately one and one half days per year. These are at or above bank-full flows.

When using flow duration curves, it is most useful to use average discharge as the streamflow measurement which is expressed versus time (See Appendix A). Average discharge is calculated for various time periods; average daily flow (ADF) is the mean flow over a 24-hour period, annual mean flow (AMF) is the arithmetic mean of ADF's over a period of one water year and average annual flow (AAF) which is the mean of a number of annual mean flows. Of these three measures AAF is the most widely used. It is also possible to estimate AAF for ungaged drainage areas.

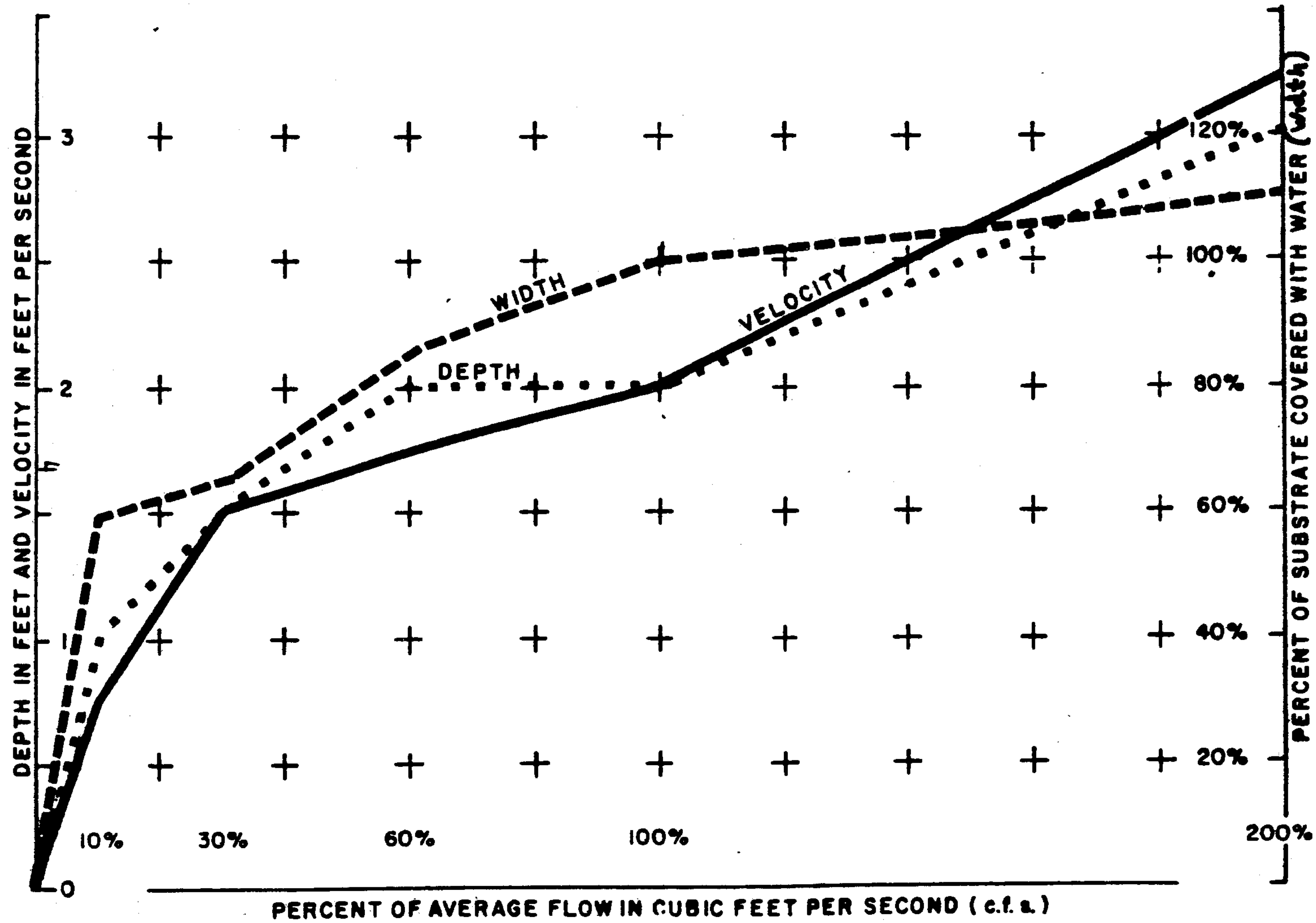
Various workers have used percentages of AAF to describe stream regimens for critical fisheries flows. Tennant (1975) indicates that 10%, 30% and 60% AAF describe the range of fisheries flows from absolute minimum (10% AAF) to optimum (60%). Tennant has examined a number of rivers in diverse physiographic regions and concludes that at the following percentages and AAF, certain generalizations about channel characteristics can be made:

10% AAF: The wetted perimeter is approximately 50% exposed, except in shoal areas where the percentage could be higher. Most side channels have little or no water present.

30% AAF: The majority of the substrate will be covered, except for very wide or shallow shoal areas. Many gravel bars will be partially covered.

60% AAF: Most of the normal channel substrate will be covered with water, including shoal areas. Side channels will probably contain water and most gravel bars will be immersed. (After Tennant, 1975 pp. 19-23)

This information has been summarized by the author in the following graphic (Figure 5). The marked changes in hydrologic parameters at discharges approximating 10%, 30%, and 60% AAF.



(from D.C. TENNANT, 1975)

AVERAGE WIDTH, DEPTH AND VELOCITY
U.S. Discharge (Montana Method)

Figure 5

Although AAF has been used to describe streamflow in many physiographic regions and diverse hydrologic situations, there are instances where AAF does not result in accurate characterization of streamflow patterns. When streamflow data is not normally or nearly normally distributed on a frequency curve, as would be the case for spring-fed streams, percentage AAF may result in describing flows, especially low flows, which may have never occurred in nature.

Various other means of discussing stream discharge such as high and low flow frequencies are not of as much use as is AAF because (1) data needed to calculate these flows are not always available, and (2) various studies have shown (see Tennant 1975, pp. 13,14) that fisheries recommendations based on historic flows may result in zero flow or in such low flows that all aquatic life is placed in an extreme stress situation.

2.3.1 Gaged and Ungaged Streams

Stretch classification can be used to deduct the general hydrologic nature of a stretch; however, the detailed hydrologic parameters necessary for instream flow studies must be obtained from other sources. Generally, these data will be of either a summary nature such as average discharge data or flow-duration curves or a more detailed nature such as individual discharge measurements from gaging station or from an instream flow investigation.

In the case of the natural stream which is adequately gaged there are usually available long term records of average flow by day, by month, and by year. These data can be plotted to reveal seasonal patterns. Usually, monthly averages will be sufficient for this purpose. However, in some cases where seasonal variation trends are sharp it may be desirable to plot the pattern of daily averages for that season.

Most regulated streams will not exhibit ranges in flow as wide as those on a natural river. However, such streams are almost always gaged, which makes it possible to obtain and plot the patterns of flow distribution (i.e., flow-duration curves).

If the stream is ungaged, it is possible to approximate the discharge by calculating run-off from the watershed on the basis of meteorological records of precipitation. The data can be plotted to some degree of accuracy in terms of seasonal or monthly averages. However, this method is usually not amenable to the determination of average daily flow, except perhaps on very small watersheds.

When available, gage data including detailed cross-sections, are important tools for instream flow studies. Ranges of hydrologic parameters (width, depth, and velocity) may be obtained from cross-sectional measurements. If enough data are analyzed, the range of flows critical to various recreational activities can be identified and correlated with long-term flow data.

2.4 DETERMINATION OF REQUIRED FLOWS

An approach to correlation can be made by simply noting the range of flows with a reasonable chance of occurrence. Several points within this range can then be selected and widths, depths, and velocities determined. Then, at each of the selected flows, a list of possible recreation activities can be prepared. This format has a useful side benefit. If the lists are compared in order of increasing flow, several observations can be made.

First, there will be a limited suite of activities available at very low flows. These might include swimming, wading, canoeing (flat water), rowing, and bank fishing in many streams. Second, at some level of flow above this minimum, a larger number of activities will become available. Depth and velocity increases might make possible tubing, sailing, and low power boating without eliminating any of the previous suite of activities. At some flow above this value, tradeoffs will occur. Some activities will be added and others will be deleted. For example, in many streams, the flow necessary to permit high power boating might violate depth and velocity maxima for swimming or wading. At a somewhat higher flow still, entire suites of activities will be replaced by others. The clearest example of this is the 5 feet per second velocity. When this level is reached, the non-power tranquil water boating activities will generally be replaced by the non-tranquil water boating activities and all of the water contact activities except tubing may be lost. At even higher flows, velocities in excess of 10 feet per second will limit low-power boats and tubing, leaving only the white water boaters and bank fishermen. Finally, velocities over 15 feet per second may eliminate even the white water boaters.

Even though the analysis at typical cross-sections may show that a large number of activities are possible in terms of width, depth, and velocity, many activities are also governed by longitudinal considerations. This is where the classification, air-photo interpretation,and field work come into play. Let us suppose that a stretch is found to be suitable for any of the various boating activities. This stretch should then be checked on the maps. If it is very short, its desirability for boating activities will be seriously reduced. For example, a short stretch of flat water bounded by two major rapids may not be suitable for tranquil water boating activities. On the other hand, a longer stretch, including both of the rapids and the quiet stretch may make a very desirable tubing area or non-tranquil water boating area.

Site-specific considerations come into play in dealing with the water contact activities. For most of these, a sandy bottom and some beach area is preferable to a muddy or gravelly bottom and "fall-in" banks. If these latter conditions are found, the activity may not be practical, even though it is technically feasible.

The result of this task will be a listing of possible recreation activities at various flow levels, amended to reflect longitudinal and site-specific requirements.

This tabulation will be the basis for a flow recommendation or a set of recommendations, as is appropriate to the stream being considered.

An example might clarify this process. Take a hypothetical river stretch which is known to have suitable sites for swimming, no obstructions to boating, and sufficient gradient at a few points to make an interesting light white water trip. Further assume that its hydraulic geometry is as follows:

Discharge	Width	Depth	Velocity
50 cfs	25 ft	2 ft	1 ft/sec
100 cfs	40 ft	2.5 ft	1 ft/sec
200 cfs	50 ft	3 ft	1.3 ft/sec
500 cfs	75 ft	4 ft	1.7 ft/sec
1000 cfs	100 ft	5 ft	2 ft/sec
2000 cfs	110 ft	6 ft	3 ft/sec
5000 cfs	150 ft	6.5 ft	5.1 ft/sec

Comparing these physical characteristics to the physical requirements listed in Section 3.1 allows a listing to be made of activities possible at each flow. For instance, at the lowest flow, width is too narrow for sailing, high power boating, and water skiing. Depth is insufficient for swimming, water skiing, and high power boating. Velocity is too low for tubing or any of the non-tranquil water boating. Thus, at 50 cfs, this stream would be suitable for:

All forms of fishing
Canoeing
Rowing
Low power boating, and
Wading

Conditions at 100 cfs are similar to those at 50 cfs. No activities are lost, and none are added.

At 200 cfs, width has increased to 50 feet, depth to 3 feet, and velocity to 1.3 feet per second. These conditions meet the minimum requirements for swimming and do not contravene the maxima for the other activities. This is an example of a flow increment with a pure benefit. An activity is added and none are deleted.

When flow reaches 500 cfs, the conditions obtaining at 200 cfs are still generally valid. Depth, however is at the limit for wading. Thus, 500 cfs is a boundary flow. Wading will be lost above it and no new activities added.

At 1000 cfs, wading is definitely not indicated, but high power boating becomes possible. This is a trade-off flow. Tubing may also be possible at 1000 cfs.

At 2000 cfs, the velocity eliminates swimming.

At 5000 cfs, velocity eliminates flat water canoeing and rowing, but a white water experience for canoes, kayaks, rafts and drift boats becomes possible.

Note that conditions in this stream do not meet the requirements for sailing or water skiing at any flow.

This simple example demonstrates the difficulty of establishing a recommended flow. In the hypothetical stream, one recommended flow might be 300 cfs. This flow, between 200 and 500 cfs, permits the maximum number of activities (fishing, canoeing, rowing, low-power boating, wading, and swimming). On the other hand, it might be desirable to provide for some high-power boating in the stream. In this case, the recommended flow would need to be 1000 cfs. Such a flow would eliminate wading, but allow the high-power boating. The next possible recommendable flow would be 5000 cfs, which would allow white water boating, but eliminate swimming (lost at 2000 cfs) and un-powered flat water boating.

These conflicting needs can be resolved in one of two major fashions. First, a policy decision can be made as to the desired set of activities from those available and the flow recommended which meets those needs. A more creative approach would be recommendation of different minima at different times of the year. For example, on the hypothetical stream, spring flows of 5000 cfs would give a white water experience when temperatures were not suitable for many other activities. Summer minima of between 200 and 500 cfs would allow many forms of water contact and flat-water activities during the prime recreation season. Flows might be reduced to 100 cfs in the fall for a fishing derby.

The final form of flow recommendation will depend in large degree on the economic, legal, and institutional framework in which the stream is viewed. These are discussed in the following sections. The purpose of the flow/recreation relationship process is to determine what is possible at different flows and to identify those flows of especial recreational significance, either as absolute minima or as flows which optimize recreation benefit. This can be done with the tools just described.

SECTION 3

EVALUATING RECREATION BENEFITS

The principles outlined in the previous section provide the basis for establishing flow requirements for various kinds of recreation in a specific riverine setting and provide some examples of how such flows have been provided. These requirements can be cast in the form of recommendations for minimum discharge on both a geographic and temporal basis. Such recommendations may range from leaving the natural flow on certain stretches untouched to the quarantee of a specified flow on certain stretches on weekends during a limited recreation season. In any case, there is almost always an actual or potential conflict with others who may have demands on the water to be considered. For example, natural flow may be protected by designation of a river, or a portion of a river, as "wilderness" under the provisions of the Wild and Scenic Rivers Act. However, when this is contemplated, account must be taken of development alternatives which would be precluded by preserving these areas. These alternatives nearly always involve the creation of impoundments with a set of recreation and non-recreation functions which differ greatly from those provided by free flowing waters.

The recreation that takes place in the slack water behind a dam pool is quite different in character from that normally associated with flowing water. This is related to the physical differences between the two situations. The reservoir tends to be large and deep, surrounded by extensive areas of land developed for recreational use. Recreation at a dam pool usually includes camping, picnicking, and other activities normally associated with parks. Swimming beaches are usually provided as are boat launching facilities. Frequently, fish are stocked. The pool is used for sailing, power boating, water skiing, and fishing from small boats. These activities attract large numbers of people, often leading to some degradation of quality because of over-crowding. They also imply investments, often rather substantial in nature, in development, maintenance, and operation of facilities.

Recreation on rivers may, in particular places, include any or all of these activities. In an urban situation, especially where there are no nearby natural or artificial bodies of standing water, river recreation may be developed to provide the kinds of activities normally associated with lakes. But, in general, the dominant forms of river recreation tend to represent less of a mass approach. Canoeists like a certain degree of solitude. Many fishermen demand it. As a rule, so long as access to the river is physically possible, the person engaging in recreation on a river does not depend upon large investments in facilities. In some cases, he may ask for none.

The dam pool recreationist requires a modification of existing conditions; someone must build a dam for him. The river recreationist would prefer that the river be left in its natural state. The former depends upon economic development to provide his recreational opportunity; the latter, in most cases represents the conservationist-preservationist ethic and derives much of his recreational value from enjoyment of the special qualities of the environment in which he operates. To a certain extent, one dam pool is much like another; the recreation that takes place on one could as well be carried out on another. Such recreation may be said to be activity specific. In contrast, no river is exactly like another; while there may be similarities, each is unique. Moreover, while the trout fisherman is interested in catching trout, this interest is related as much to the surroundings as to the activity itself. River recreation is to a large degree resource specific more than activity specific.

Thus, in many ways recreation requiring instream flows takes on the character of a natural resource and depends in a major sense on the preservation or enhancement of existing natural conditions. It is generally true of natural resources that they are specific to a particular place; as a rule they cannot be moved or replicated. Their preservation represents a collective good which is not measured by the market and whose use is non-consumptive. By and large, protected resources also represent merit goods provided for public use at public expense (which may simply represent the economic cost of non-development rather than any actual outlay) and are normally not capturable for private monopolization without a change in character. Natural resources are conflict sensitive; they are in fixed supply and essentially non-reproducible once significantly altered. Preservation of natural resources provides a retention of options for the future; the development foregone today remains a possibility tomorrow. Finally, natural resources are not fixed in value. As population grows and some natural areas are converted to other uses, the value of remaining areas tends to grow, not diminish.

If flow in streams is characterized as a merit good, in fixed or shrinking supply, and growing in value, then water in a reservoir must be characterized as a market good, in growing supply, and perhaps of decreasing marginal value. As a market good, water in a reservoir can be assigned a value in dollars; this is not always possible with instream flow, although some forms of dollar valuation have been attempted. This, then, is the essential conflict between instream flow and the creation of reservoirs; one can be valued easily in dollars, while the other can only be imperfectly valued in these terms. Water resource planners have attacked this problem in various ways, but there are still no simple answers. There is, however, a framework in which such evaluations can occur.

3.1 PRINCIPLES AND STANDARDS

In September of 1973, the Water Resources Council published a two-part document: Water and Related Land Resources; Establishment of Principles and Standards for Planning. Principles is based on the position that:

> The overall purpose of water and land resource planning is to promote the quality of life by reflecting society's preference for the attainment of the objectives defined below:
>
> A. To enhance national economic development by increasing the value of the Nation's output of goods and services and improving national economic efficiency.
>
> B. To enhance the quality of the environment by the management, conservation, preservation, creation, restoration, or improvement of the quality of certain natural and cultural resources and ecological systems.

Further, it is expected that attention will also be paid to meeting the aims of regional development and of social well-being. These basic objectives, established in Principles, are to be implemented by methods contained in Standards, which will be the focus of this discussion of instream recreation economics.

The mandate of Standards is broad. It applies to "Federal participation in comprehensive framework studies and assessments and regional or river basin planning of water and land resources... [and] to the planning and evaluation of the effects of... water and land programs, projects, and activities carried out directly by the Federal Government and by State or other entities with Federal financial or technical assistance..." Thus, Principles and Standards governs the consideration of virtually all Federal activities having to do with water resources management.

The form of the evaluation called for in Standards is similar in form to the cost benefit analysis first called for in the Flood Control Act of 1936, which established the criteria that total benefits from a Federal Project must exceed its costs. The approach developed from this statute used a national efficiency measure of costs and benefits. Principles and Standards have broadened the definition of cost and benefit considerably, providing a framework in which non-monetary values can be considered as readily as monetary values.

The following sections discuss the Standards in detail, with the aim of identifying the position of riverine recreation in this evaluation framework and the methods by which its value might be fairly estimated.

3.2 OBJECTIVES

The primary objectives of Federal water programs are to increase "the value of the nation's output of goods and services" and to manage, conserve, preserve, create, restore, or improve "the quality of certain natural and cultural resources and ecological systems." These aims are derived from and supported by a number of congressional directives, many of which bear directly or indirectly on the consideration of recreation in this structure of objectives.

The Federal Water Project Recreation Act of 1965 specifically provides for the consideration of recreation and fish and wildlife enhancement programs as part of water project action. These programs need not only apply to the recreation in a dam pool, but can include other recreation forms, such as downstream flow provisions for instream recreation. Further congressional support for flow can be found in the Clean Water Restoration Act of 1966, which provided for river basin planning activities directed at the improvement of water quality. A part of this improvement can be had by providing instream flow for dilution, although policy developed since that time has forbidden such provisions as a sole purpose of an effort. Nonetheless, such water quality improvement can often be a serendipitous benefit of flow provided for recreation, thus adding to the total benefit of the flow increment. This goal would also serve the ends of the Federal Water Pollution Control Act Amendments of 1972 which requires that "water quality and area-wide waste treatment management planning include multi-objective water resources and land use planning."

Similar opportunities arise from congressional directives on flood control. The National Flood Insurance Act of 1968 makes the availability of Federal flood insurance contingent upon State adoption of land use controls in flood-prone areas. This focus on administrative and regulatory approaches to flood damage reduction has led to a concurrent reduction in the stress placed on structural flood control. Additionally, the Flood Control Act of 1970 requires consideration of adverse economic, social, and environmental effects relating to any proposed project. These two Acts, taken together, provide for serious consideration of non-structural flood control alternatives. Many of these non-structural approaches could also serve to provide for instream recreation in that structural measures might not be required on a particular stream.

Specific guidance for the treatment of flowing water is found in the Wild and Scenic Rivers Act of 1968 which "provides that in planning for the use and devlopment of water and related land resources, consideration be given to potential wild, scenic, and recreational river areas in river basin and project plan reports and comparisons are to be made with development alternatives which would be precluded by preserving these areas." This natural resource emphasis finds its strongest statement in the National Environmental Policy Act of 1969 and the Environmental Quality Improvement Act of 1970 which together provide for detailed consideration of the effects of major Federal actions on the quality of the human environment.

Thus, congressional directives can be seen to underly the National Economic Development objective and the Environmental Quality Objective, as expressed in Standards. These same directives provide for the auxiliary consideration of Regional Development and Social Well-being. Finally, all of these objectives have within them components which can be admirably served by the provision of instream flow for recreation. What needs to be done is to place this flow, and its recreation, within the economic framework of monetary cost-benefit analysis and the "quality" framework of the non-monetary cost-benefit analysis of the two main objectives.

3.2.1 National Economic Development

The National Economic Development (NED) objective is the provision in Principles and Standards for an analysis of the monetary costs and benefits of a Federal project. It is here that the dollar valuation of costs and benefits must be considered, both as they relate to each other locally and as they influence national efficiency in production of goods and services, either for direct consumption or for investment. The primary component of this objective is the value of increases in production of goods and services. Examples given in Standards include "increases in crop yields, expanding recreational use, and peaking capacity for power systems" as primary effects associated with water and related land resource developments. Secondary effects might be "increased earnings from changes in land use" and other derivative benefits. Finally, external economies worked as a result of a project or program can be considered in NED. Thus, recreation is considered as a consumer good, amenable to pricing in some fashion reflective of its "value to the user." There is, however, implicit room within the NED objective for consideration of recreation as a merit good, as well, since NED "is also affected by the availability of public goods which are not accounted for in the national product and income accounting framework."

3.2.2 Environmental Quality

The Environmental Quality (EQ) objective "reflects society's concern and emphasis for the natural environment and its maintenance and enhancement as a source of present enjoyment and a heritage for future generations." Specific areas of concern are:

open and green space
wild and scenic rivers
lakes
beaches
shores
mountain and wilderness areas
estuaries
archeological sites
historical sites
biological resources
geological resources
ecological systems
quality aspects of water, land, and air.

Further, EQ objectives may be served by "avoiding irreversible commitments of resources to future uses." From this "shopping list" it can be seen that although the actual recreation activities which occur in flowing water are considered as a part of the NED objective, the resources on which these activities depend are found in the EQ objective. This accords well with the enigmatic position of instream recreation which, as discussed earlier, might be characterized as a merit good whose value is but imperfectly accounted for in terms of dollars.

3.2.3 Recreation and the NED and EQ Objectives

The recreation planner, in dealing with instream recreation, is faced with a difficult commodity. The use that he contemplates is non-consumptive; the water is still available for other uses after it has floated a canoe down a stretch of a river. Yet, the location and timing of the flow are critical to the activity. High flows on week days or at night may provide little or no benefit. Thus, while the recreation planner might not wish to consume water, his requirements for timing of flow may so stricture its use that other benefits may suffer. This often places recreation at odds with more conventional goods and services in the cost-benefit analysis called for in the NED objective. Thus, the instream recreation planner must be able to establish the dollar value of his "commodity" in relationship to the value of other possible commodities that might be created with the same water, whether these be regular market goods (such as power generation or water supply) or other forms of merit good (such as reservoir recreation). The NED objective, then, must be viewed as a competitive market, in which dollar value will allocate flows.

The EQ objective serves as a balance to the dollar judgements rendered by the NED objective. It is in EQ that the resources underlying instream recreation are found. They are the "wild and scenic rivers,... beaches, shores,... biological resources,... and ecological systems" that the EQ objective is designed to manage, conserve, preserve, create, restore, and improve.

This provides the recreation planner with a unique opportunity. His resource has a dollar value which fits well in the present oriented value structure of the NED objective and a resource or perservation value ideally suited to the EQ objective. A discussion of the benefits and adverse effects on the NED and EQ objectives will demonstrate how this comes about and how it might be used to provide flows for instream recreation. Consideration will also be given to the competitive nature of the water market and how recreation might successfully compete with seemingly more valuable commodities.

3.3 EFFECTS ON OBJECTIVES

<u>Standards</u> requires that there be a complete display of beneficial and adverse effects for each alternative plan for a particular water resource project. These effects may be measured in both monetary and non-monetary terms and should, insofar as is possible, reflect the priorities of the various sectors affected. There is explicit recognition of the fact that such priorities may vary from project to project or among various groups interested in a single project. In order to limit the scope of these disagreements, <u>Standards</u> calls for a uniform treatment of costs and benefits in terms of their relationship to the objectives, the incidence in time and space of the effects, and the net value of each effect (the difference in magnitude of the effect with and without the alternative).

3.3.1 NED Benefits

Benefits to the NED objective may take two forms: increases in the output of goods and services as a direct result of a plan, and increases resulting for external economies made possible by the plan. The value of these outputs may be measured directly, where possible, or estimated by willingness to pay, change in net income, or the price of the most likely alternative to the plan output.

Willingness to pay is suggested as the proper measure for the value of final consumer goods and services resulting from a plan. These include community and residential water supply, community and residential electrical power, and recreation.

When a plan results in goods and services that are used as intermediate products, the value of those goods and services is to be measured as the net increase in income to the producer of the final good or service. The net increase is to be calculated as the difference between incomes with the plan and those without the plan. Standards suggests that the benefits accrued to agriculture, through the provision of irrigation water, the alleviation of flood damages, and the like, may be of this type.

When there is no direct measure of increased income resulting from an intermediate good or service, the cost for the most likely alternative to the plan's output can be used to estimate the value of the good or service provided. Examples of this type of output are: industrial and commercial water supply; urban flood damage alleviation; industrial, commercial, and agricultural electric power; transportation; and enhancement of commercial fisheries. In each of these cases, the actual value of the goods provided by a plan may not be readily identifiable, but the cost of surrogate goods or services can be found from market prices.

Two considerations of NED benefits are of value to the recreation planner. First is the accurate evaluation of his commodity, recreation. Second is a clear understanding of the values of other commodities, in particular those which may be inadvertantly over valued in cost-benefit analysis.

3.3.1.1 Measures of Instream Recreation Benefits

Standards proposes that "the increase in recreation provided by a plan, since it represents a direct consumption good, may be measured or valued on the basis of simulated willingness to pay." This can be estimated by travel costs, expressed in terms of numbers of miles traveled by automobile to use the facility and the cost per mile. While it is suggested that there are other measures which may and should be employed if they promise "to provide the best measure or expression of willingness to pay by the actual consumer of the recreation good or service...", these are not specified.

Instead, a schedule of monetary values which may be used in the absence of more precise values is offered. This consists of two kinds of Recreation Day. The "General" Recreation Day is clearly from the context aimed at typical in-reservoir activities such as swimming, picnicking, boating, and most warm water fishing. Such activities are seen as attractive to the majority of recreationists and to require investments in facilities to support the activities. The "Specialized" activities, on the other hand, are often characterized by low intensity of use and often by substantial personal expenditures on the part of the participant. Examples given are big game hunting and salmon fishing. The unit day values for "General" recreation lie in the range \$0.75 to \$2.25, with hunting and fishing suggested as candidates for the higher end of the scale. The "Specialized" recreation day unit values range from \$3.00 to \$9.00.

These prices per recreation day are often used in the absence of other information for all forms of recreation associated with a plan. This may work to the disbenefit of instream recreation, which may often have value far in excess of the suggested values in Standards.

Fishing is an excellent example of an activity that appears to be undervalued by the Recreation Day values in Standards. A recent study (1972 data) carried out by Georgia State University suggests strongly that the true value of a day spent in fishing, even fresh warmwater fishing, is more than an order of magnitude higher than that provided by the General Recreation Day scale and from four to five times the upper limit for the specialized type of activity. The study is discussed in more detail in Appendix B. However, it may be summarized briefly here. The analysis showed that all non-saltwater fishermen placed an average "value received" from a day's fishing in warm and cold freshwater at $38.92. For those whose primary preference was fishing natural streams, the imputed value received was $43.18 for warm water and $35.39 for cold water. Fishermen were also asked how much money they would demand to give up a day's fishing. In this case freshwater fishing was given an average value of $46.74 per day. The fishermen who preferred natural stream fishing as a location valued warm water fishing at $50.25 per day and cold water fishing at $41.09. This study also determined the amount of pay given up by fishermen as a measure of an "opportunity cost" inasmuch as the participant chose to sacrifice cash income to engage in recreation. The Georgia State study found that a number of individuals questioned had, indeed, done exactly this. The cost in terms of lost pay ranged from $8.46 for the lowest income group to $137.92 for the highest. The average for the entire group reporting loss of pay was $48.10.

White water rafting is another sport which may also be undervalued. It can be very expensive. The cost, of course, varies enormously according to the quality of the experience, the length of the trip, the season chosen, and the distance traveled by participants to reach the river. On "big-water rivers", such as the Colorado, the activity requires the services of professional outfitters and guides. The passengers may assist in the operation, or simply go along for the ride. The cost per person is directly related to the services provided. These can range from requiring the passenger to provide his own gear and to assist in navigation to an everything-provided run, complete with string quartet for entertainment during the evenings. A recent article in a popular magazine estimates the average cost at about $50 per day per person; it cites an example of a family of six from St. Louis which took a nine-day trip down the Grand Canyon. The direct cost was $450 per person, or $50 a day; indirect costs for hotels, meals, and air fare before and after the trip amounted to another $24 a day each. The total cost to the family was about $4,000. While this is an extreme example, perhaps, it should be noted that for many such rafting expeditions the number of applications exceeds the capacity to mount rafting trips.

Tubing, floating down a stream while sitting on an inner tube, is a sport that is growing in popularity also. It is, for example, the major recreational activity on the Boise River which was investigated during this study. In an urban context such as Boise, Idaho, where the sport is primarily one engaged in by children, the outlays for equipment are minimal. The monetary value of the recreation experience, even assuming that a parent has to drop the tuber off at the put-in point and pick him up at the take-out point, is quite low, as with most other forms of "mass" recreation. Tubing in white water or near white water rivers is another story. This requires more than the purchase of a second-hand or new tube and the costs of transportation to a nearby stream. The water may be cold enough to require wearing a wet suit. The transportation distances involved may be fairly substantial. Life preservers are also indicated, and, in very rough waters even a kayaker's helmet may be required. The data do not provide a basis for estimating value of a day so spent, other than to suggest that it may lie well above the ranges suggested in Standards.

Canoeing on rivers is also a rapidly growing sport. Canoe rentals are usually priced at about $10 per day. This may or may not include livery service back to the put-in and and boat pick up at the take-out; usually, there is an extra charge for this. It is rapidly growing in the east. In fact, a recent newspaper article suggests that (nationwide) 2,500,000 people are engaged in river canoeing now and that the number of participants is growing at an impressive rate of 500,000 per year. While relatively inexpensive as compared to rafting of a major river, it is still in excess of the maximum value assigned by Standards.

Thus, the recreation planner may be well served by seeking alternative measures of the willingness to pay for recreation activities in streams. These may be only slightly above the imputed values of Standards, as in the case of canoeing or tubing, or they may be several times larger, as is the case for fishing or rafting on a major white water river. Such approaches are recognized by Standards when it states that the measure used to determine willingness to pay should be that "which appears to provide the best measure..."

3.3.1.2 Analysis of Competing Benefits

Standards provides for a sensitivity analysis to determine the influence of various assumptions on the final costs and benefits of a plan. Among those assumptions which might be varied are the values assigned to benefits competing with recreation for instream flow. In some instances, it is possible that values applied to certain benefits may be overstated. Two examples of this are cited below.

Value of Irrigation Water

As early as 1958 Eckstein, in his classic work on Water Resources Development, noted that irrigation water was generally provided at an uneconomic price and that the situation was compounded by the fact that irrigation opened up new areas to production for commodities which were already in surplus. This, he noted, added to the cost of price supports under the agricultural stabilization programs. Disputing the Bureau of Reclamation's computational methods, he estimated that the incremental cost of price supports attributable to bringing new lands into production for commodities included in the program was about equal to the entire annual direct appropriation for irrigation.

More recent research on this topic is discussed in a paper published in 1969 by James T. Bonnen. Summarizing work done by others, he notes that western farmers pay an annual price of from $30 to $135 per acre below the cost of supplying their water. The value added by production is stated to be "well under a hundred dollars per acre-foot." This is well below the value of the water if used for other purposes, including recreation. Fred Johnson (1976 A), of the Pennsylvania Fish Commission, indicates that the application of 3.5 acre feet of water to an acre of land in the North West "provides at most a $100 crop." The losses to power generation at each of the dams downstream of the diversion is estimated at from $30 to $100.

Bonnen goes on to show that the uneconomic use of the water is not the major problem, although he also notes that once so assigned to irrigation, recapture becomes difficult for economic, legal, and political reasons. Analysis of production on irrigated land in the west showed that the program had three adverse effects. It increased support payments from $20 to $474 per irrigated acre. It stimulated production shifts from one region to another; this was estimated to amount to $350 million for potato farmers. It reduced non-reclamation farmers' income by shifting less productive but non-irrigated land out of production at an estimated loss of income of from $50 to $170 million annually to the farmers affected.

The Costs and Benefits from Power Generation

Proposals to develop additional power generating capacity on the Snake River in Hells Canyon, Idaho, led to major litigation. As part of this litigation, intensive economic analyses were conducted of the several proposals under consideration. These are highly complicated and technical and have been reported upon by Krutilla and Eckstein in Multiple Purpose River Development (1958) and Krutilla and Fisher in The Economics of Natural Environments (1975). Several important and potentially useful findings emerge from these studies.

The analyses showed that the power development, which was to involve generating by a private company (Idaho Power), led to less than optimum use of the generating capacity. This was related to Idaho Power's marketing capability. The most efficient scheme did not meet its needs. It also would have provided downstream generating capacity at other installations from which the company would have received no benefit.

Going further, the studies showed that peculiarities of tax laws and accounting procedures in Idaho led to a false estimation of the benefit/cost ratio. Taking this into account led to a reduction in this ratio. Nonetheless, benefits still exceeded costs.

However, benefits assigned to recreation behind dam pools accounted for a substantial portion of the total. These were shown to be overstated. This reduced the benefit/cost ratio further.

At this point, the analysis turned to an imaginative examination of assumptions about the value of power. The basis for the analysis was that long term, capital-intensive, high technology projects are overtaken by technical advance. Before their useful life has ended, more efficient means of production will come into play. This means that conventional discounting to produce present value overstates the benefits and understates the costs. Bringing this element into consideration drove the benefit/cost ratio for all but one of the alternatives below unity.

The latter project, like all the others, would have led to a considerable impact on the free flowing river in terms of impoundment. The values at stake were environmental. The basic measure chosen to assess them was recreational use. The approach adopted was novel and ingenious. Instead of attempting to measure the expected use directly (as a function of some hypothesized demand and assigned imputed price per recreation day), a new tack was chosen. The starting point was the assumption that environmental amenities are in short supply and that the supply is shrinking, not growing. In the meantime, increases in population and in disposable income create a growing demand for the services such amenities provide. A model was created to account for this growth. Then, the benefits required from non-development over the life of the project to eliminate the positive net benefits in question were calculated. That is, assuming the growth of environmental values in the model at some rate "a" and discounted at rate"i", how many dollars of first year recreation benefits would be required to make the present value of preservation equal to that of development? The results of this complicated and subtle analysis were to show that it would take from about $40,000 to about $150,000 in first year preservation benefits to offset the development benefits. Data from the U.S. Fish and Wildlife Service and Idaho Wildlife biologists suggested that the actual recreational values, in current use, that were at stake were on the order of $900,000 plus or minus 25%. Some of the dollar values shown per recreation day were slightly in excess of those established by the imputed prices of Standards. However, they were considered to be on the low rather than on the high side and considerably lower than those being provided by current research results.

The extremely sophisticated level of analysis employed in the Hells Canyon studies lies beyond the reach of most project evaluation. The discussion given here represents a large degree of simplification, if not over simplification. However, the basic approaches taken may be considered in situations where the potential loss appears critical. The value of the benefits from the investment may be overstated for power projects as well as for irrigation. Technological advance may reduce the stated benefits below the discounted level assigned. And the value of environmental amenities lost irretrievably needs to be considered in terms of their future value prior to being discounted.

3.3.2 Adverse Effects on NED

The loss of a free flowing stream can be one of the "resources required for or displaced by the plan." In this context, the value of this resource must be established. As indicated above, one measure of its value might be the instream recreation benefits foregone as a result of the loss. Another measure, perhaps more direct, might be the replacement cost of the stream.

As a general rule, the decision to develop is more or less irreversible. The effect of a major impoundment tends to be so profound in an ecological sense that simply draining the pool and restoring free flow in the stream will not result in a return to the previous conditions unless one considers a geological time frame.

However, one could conceivably provide a surrogate asset to replace one that has been lost to development. American Whitewater recently reported on a study of such a possibility. The Corps of Engineers (Huntington District) examined the feasibility and cost of constructing an artificial white water training course in 1973. The course location was near the Ohio River. The design called for providing 2,000 feet of rapids (varying from Class II to V). The facility would have consisted of a concrete chute, curved, with instream boulders as well as flow control gates and access points for users. The cost estimate was $5,000,000 or $2,500 per foot. As the article points out, this would have been for a sterile and completely artificial facility; none of the normal environmental amenities associated with natural white water streams would have been provided (or provideable, in fact).

Similar replacement costs might be estimated for other forms of instream recreation, such as fishing. In attempting such an estimation, it should be kept in mind that a reservoir environment cannot be substituted for a riverine environment. As the introduction to this section points out, the needs and aims of the recreationist using the two are quite different.

3.3.3 Environmental Quality Benefits and Adverse Effects

The Environmental Quality account is established to deal with those effects of a plan which are of a non-market character, primarily "the management, preservation, or restoration of one or more of the environmental characteristics of an area under study..." Beneficial effects are considered to be increases in the quantity of a resource or improvements to its quality. Adverse effects are losses in quantity and degradation of quality. This account provides the recreation planner with the opportunity to list as a benefit the preservation of his resource, divorced from the economic value which the activities that it supports may have. In this account, the existence of the resource is the benefit. Further, the preservation of freedom of choice, implicit in resource preservation, is singled out as a particular benefit to the EQ account. Several classes of environmental effects are considered by the EQ account, most of which will reflect a benefit for preservation of flowing water for recreation use.

3.3.3.1 Open and Green Space

The preservation of open and green space is to be considered in terms of the total acreage preserved by a plan, the distribution of that acreage, and its nearness to urban and suburban areas requiring access to green space. The river banks preserved in the pursuit of recreation benefits may serve as open space for the areas through which the river flows. Such additional benefit should not be overlooked by the recreation planner in assessing the benefits and adverse effects of a plan on recreation.

3.3.3.2 Wild and Scenic Rivers

The rivers which fall under the rubric of Wild and Scenic may be the prime recreation rivers in a region for the instream recreation activities of interest here. Further, even though a stream may not be "Wild and Scenic" in the legal sense, lengths of streams which are free flowing may be listed as a benefit to a plan. Conversely, the loss of free flowing waters might be listed as an adverse effect. The measures of benefit suggested in Standards are part of the data base which will be gathered for a river study, allowing the inclusion of this benefit with little or no additional effort. The measures proposed are total mileage of stream, whitewater mileage, water quality, character and extent of streamside lands, and nearness to communities. Once again, the instream recreation planner has the opportunity to include the resource he requires in the EQ account as a benefit over and above the dollar benefit derived from the actual recreation.

3.3.3.3 Beaches and Shores

Standards suggests that "the juxtaposition of attractive beaches, distinctive scenic shorelines, and adjacent areas of clean offshore water provides positive public aesthetic values and recreation enjoyment." The recommended measures of benefit are miles and acreage of beaches and shores, acres of marshland, and number of embayments. These terms seem to imply the resources normally associated with a reservoir, but may also apply to river reaches considered for instream flow provision. This is particularly true of such attributes as distinctive scenic shorelines and marsh areas. As is the case with open space, the recreation planner has the opportunity to clearly express the non-monetary value of this resource and should do so.

3.3.3.4 Geological Resources and Selected Ecosystems

The stream valley containing a recreation river may present unique opportunities to observe geological features. These may be the fluvial and alluvial features associated with a meandering, lowland stream, or the exposure of bedrock in well-incised mountain streams. In either case, the recreation planner can list such features as additional benefits to instream flow maintenance, since impoundment would cover them and eliminate them from the stock of such features in the region.

The stream itself may often represent a "selected ecosystem", since flowing water habitat is increasingly being lost either directly to impoundments or indirectly through flow modification and quality degradation.

3.3.3.5 Enhancement of Water Quality

As discussed above in Section 4.2, there is some backing in Congressional directives for considering an improvement in water quality as a benefit of a plan. Standards places this benefit in both the NED and the EQ account by noting that "the beneficial effects of water quality improvement will be reflected in increased value to water users and will be recorded under the national economic development or regional development objective... There will be other water quality beneficial effects, however, that cannot be measured in monetary terms but are nonetheless of value to the Nation. Examples of such benefits are usually in the aesthetic and ecological areas so important to mankind." The beneficial effect on water quality will most often be had by reservoir releases designed to provide dilution to downstream sources of contamination. This is an opportunity for cooperation between two interests. If the recreation planner requires a certain flow for instream recreation, this same flow might improve water quality, thereby adding this benefit to the benefit realized solely from recreation.

3.3.3.6 Option Retention

The final element of the EQ account is the "preservation of freedom of choice to future resource users by actions that minimize or avoid irreversible or irretrievable effects..." This component is admirably served by the maintenance of instream flow. In most cases a decision to maintain flows does not preclude future development entirely; it simply postpones it, perhaps, but not necessarily, permanently. Should conditions change, the resource will still be available. Indeed, it may be worth more if developed later rather than sooner, since later use, if necessary, may reflect changes in both technology and needs not contemplated at this time. Thus environmental quality may take account of principles of efficiency.

In each of the above areas, the resource required for instream recreation is considered as a benefit, or its loss is considered an adverse effect, regardless of the economic analysis of recreation used in the NED objective. This, then, is the opportunity for double counting of instream flow. Such an approach helps in the task of assigning an accurate value to this unique resource which undeniably has both monetary and non-monetary value.

3.4 REGIONAL DEVELOPMENT AND SOCIAL WELL-BEING

The NED and EQ objectives are specified in Standards as the basis for decision-making. Two additional accounts, Regional Development and Social Well-Being, are established as public information objectives. Both of these accounts have in them elements which might serve the provision of instream flow for recreation well, either in the positive sense of highlighting its value, or in the negative sense of displaying reductions in value for other possible water uses. The following two sections briefly describe the opportunities these accounts offer to the recreation planner in making the presentation of the worth of this commodity.

3.4.1 Regional Development (RD)

The effects to be considered in the RD objective are regional income, regional employment, population distribution, regional economic base and stability, and environmental conditions of special regional concern. The first and the last of these offer special opportunities to the recreation planner.

Section 3.3.1.2 has discussed the analysis of competing benefits for water. Of particular concern, there was the value assigned to irrigation water. It was noted that much of the benefit assigned to irrigation might result more from transfer effects than from any real growth in output. The RD objective specifically calls for an anlaysis of such effects and can reinforce the analysis carried out in the NED objective. In the requirement for consideration of the regional incidence of NED benefits and the location effects of these benefits, RD is well suited to a discussion of such effects and a clear display of both benefits and disbenefits that may be of interest in a particular region.

Environmental conditions of special regional concern provide an opportunity to stress the regional preference for particular types of resources or particular individual resources that are held in high regard within a region. This stress does not substitute for consideration of a resource in the EQ objective but rather provides additional information about the regional view of the importance of natural resources. As with the regional incidence of benefits, this element of the RD objective allows for expansion upon themes contained in the NED and EQ objectives.

3.4.2 Social Well-Being (SW)

This objective offers another form of consideration of the benefits and adverse effects of a plan. The effects are still those considered in the NED and EQ objectives but the social structure and aims of the Nation and of the region being studied are used to determine benefits and adverse effects which are not conveyed completely in two major objectives. Two of these types of influence are of particular interest in considering instream flow: effects on security of life, health, and safety; and educational, cultural, and recreational opportunities.

Beneficial effects on security of life health, and safety include "reducing the risk of flood, drought, or other disaster..." and "reducing the concentration and exposure to water and air pollution..." Both of these ends may be served by measures which may also benefit instream recreation and can thus lend support to provision of the required flows. In the first instance, non-structural measures to limit flood damage (such as wetland acquisition and flood plain zoning) may provide for additional recreation opportunities. Conversely, the provision of recreation opportunities may enhance the value of non-structural flood control efforts. Regardless of which "action" is considered, such joint benefits can be expressed in this objective.

Much the same can be said for the educational, cultural, and recreational opportunities element of social well-being. The suggestions in Standards for items in this element include lakes and reservoirs specifically, but as with shores and beaches in the EQ objective,social well-being may be enhanced by the recreation provided on flowing streams, as well. In fact, if flowing water is taken to be a merit good in shrinking supply, social well-being might be better served by preservation of such waters in preference to converting them to reservoirs. Such an argument was raised in the Hells Canyon Study discussed in Section 3.3.1.2 and was instrumental in the presentation of the results of that study.

3.5 GENERAL EVALUATION STANDARDS

Standards specifies those major assumptions which are to be made in approaching the analysis of costs and benefits of a particular plan. The foregoing sections have dealt implicitly with many of these general principles, but a reiteration of a recreation planner's approach to these might be of use. Of particular interest are the price relationships and discount rates called for in Standards and the implicit questioning or certification of these required for an analysis of risk and uncertainty.

3.5.1 Price Relationships

Standards indicates that "relative price relationships and the general level of prices for outputs and inputs prevailing during or immediately preceding the period of planning generally will be used as representing the price relationships expected over the life of the plan. Exceptions to the general rule will occur when the output or input of a plan affects prices..." This concept may well be crucial to fair evaluation of instream recreation, especially when it is in direct competition with reservoir recreation. Such an analysis hinges on the demand estimates for the two types of activities.

The demand estimates for reservoir recreation are often based upon extrapolation from usage of nearby facilities. This tends to lead to a skewing of demand. The basic assumption is that if something is used, more of it is needed. The free flowing stream that is to be affected usually will have a lower usage rate because of the general character of instream recreational pursuits. However, a proper application of Standards requires taking into account the availability of comparable substitute facilities. Viewed in this light, loss of a free flowing stream to provide more flat water recreation may not be justified.

Something relatively rare or unique may be sacrificed simply to provide "more of the same" of something that is in fairly abundant supply. That the pool will receive more use than the stream is not sufficient. This assumption may accord with "head counting" democratic principles, but it is not sound economics. The elasticities of demand may be quite different for the two forms of recreation. Additionally, as pointed out above in Section 3.3.1.1, the simulated market prices applied to General and Specialized activities may be from a few percent to several times smaller than the actual value assignable to the many forms of recreation in flowing streams. This means that the total value of use by a small number of people for the stream may be larger than that associated with the much larger use of the reservoir which supplants it (Knetsch, 1969).

3.5.2 Discount Rate

The discount rate specified in Standards is to be applied to all future benefits and costs of a plan to reduce their value to current dollars. Two possibilities are available to the recreation planner when dealing with his commodity. The first is that used in the Hells Canyon Study, where the discount rate was applied "backwards" to calculate the dollar amount of existing recreation benefits needed to offset all other future benefits from the proposed damming of the Snake River. It turned out that the existing recreation on the reach far exceeded in value that amount needed to offset benefits from impoundment. The same may be true in other cases, as well. The second approach to the discount rate is not to apply it to some classes of benefit or cost at all. An argument can be made that the values associated with flowing water are growing and that discounting them to present value may severely underestimate their true worth. If this view is accepted, then values derived from instream flow must be carried un-discounted or even negatively discounted in a cost-benefit analysis.

3.5.3 Sensitivity Analysis

Room for considerations of prices and the discount rate is provided for in Standards when it calls for planning organizations to "examine the sensitivity of plans to data availability and to key items for which alternative assumptions might be appropriate. Examples of such items include prices; discount rates; and economic, demographic, and technological trends." Finally, Standards calls for a full review of all aspects of a plan if it is not implemented within 10 years of the initial analysis. Thus, a full analysis of a plan or of a project as part of a plan must be based on up-to-date information, and it must question its own assumptions. Both of these requirements can serve to help insure that the actual value of instream flow is recognized and incorporated into project planning, design, and implementation.

3.6 APPROACHES TO PROVIDING FLOW FOR RECREATION

The foregoing sections have demonstrated how the value of instream flow can be assessed in the framework of Principles and Standards. It has been shown that:

Values assignable to instream recreation are often considerably larger than the General and Specialized recreation day values suggested in Standards.

The actual values of certain competing water uses may be lower than generally thought.

The replacement cost of flowing water may be very large.

The EQ account offers the recreation planner the opportunity to place a non-monetary value on the simple existence of the resource in addition to dollar benefit derived from the activities.

The preservation of flowing streams takes account of efficiency by preserving freedom of choice until a time when more sophisticated technologies may make a resource more valuable.

The Regional Development and Social Well-being accounts provide opportunities for special evaluation of the benefits derived from instream flow.

Demand shifts may cause the future value of instream recreation to rise considerably.

And the use of a discount rate may underestimate the actual value of instream flow.

How can the recreation planner make use of these observations in seeking to preserve or aquire flow for instream recreation?

3.6.1 Preservation of Natural Flow

Recreational benefits, actual or potential, may furnish a powerful argument for protecting natural flows on a river through designation under the provisions of the Wild and Scenic Rivers Act. However, such designation will conflict with the desires of others to interfere with flow to provide such benefits as power generation, storage and withdrawal for irrigation, flood control, or municipal and industrial water supply. The same sort of conflicts will arise when a proposed project under evaluation threatens the existing flow regime in a river or river reach. Even if designation of the river as "wild", or "scenic", or "recreational" may not be appropriate, the recreational values that would be lost as the result of an impoundment's altering flow may be of sufficient magnitude to offset the stated benefits of the project.

3.6.2 Building Flow Provisions into the Project

Under some circumstances, it may be possible to compromise the two positions by building a requirement for instream flow maintenance into the project. In such cases, part of the capacity of the structure is used to furnish water for downstream recreation. From the standpoint of the prime beneficiaries of the dam and reservoir this water may be considered wasted since it does not, or may not, provide power, or irrigation water, or supply for off stream uses by industry or municipalities. On the other hand, if it can be shown that the benefits from the instream flow are high, this may be enough to justify instream flows on an economic basis.

3.6.3 Storage and Release of Excess Run Off

Under certain special circumstances, it may be possible to justify construction of structures high in the watershed whose sole purpose is to impound a portion of yield during high run-off periods for later release to provide instream recreational flows. Even on many regulated rivers, a substantial amount of water may be lost because the existing structures lack the capacity to store it during such periods of high run-off. The recreation benefits from such a course of action might be enough to justify the new construction without adversely affecting spring "flushing flows" required to maintain a "healthy" river and to meet fishery needs. This approach might also provide an additional benefit by reducing flood damages which are present in most years but not significant enough to justify a major flood control project.

3.6.4 Modification of Dam Operating Procedures

Required instream flows for recreation may be provided in some circumstances by modifying the operation of existing flood control or multi-purpose dams. For example, many flood control structures normally pass all the flow entering at the head of the control pool directly into the receiving stream; impoundment occurs only when there is a danger of flooding downstream which can be lessened or eliminated by temporary storage. Much of the water now passing through during periods of high flows might be impounded temporarily to provide flow augmentation at a later date. This could usually be accomplished at very little direct cost. Such temporary retention might reduce the minor flooding effects of some high flows providing an added benefit.

There would be some theoretical flood damage cost to be charged against the operation, however. This would relate to the possibility that retention for flow maintenance purposes could reduce the capacity of the system to deal with unusual snow melt or precipitation events. Careful attention to conditions on the watershed, both upstream and downstream of the structure, would be necessary to minimize this risk. If this were done, it should in most cases be possible to change release schedules to accommodate the primary flood control mission of the dam. However, some risk would remain, and the possible cost in terms of estimated flood damage would have to be charged against the benefits accrued to recreation.

3.6.5 Acquisition of Flow from Existing Structures

Even where all or almost all of the water behind an impoundment is destined for other use, such as power generation, irrigation, or maintenance of a recreational capability in the pool, there may be opportunities to "recapture" some of the storage capacity represented by such dedication. At power dams this might be accomplished by alteration of minimum release requirements during relicensing. On irrigation projects storage capacity might be acquired by appropriation where it is not already committed or by negotiated purchase or condemnation where it is. Such acquisitions of flow will have to overcome legal and institutional roadblocks. Solid benefit justification is perhaps the best, or may be the only, hope for accomplishing this.

SECTION 4

LEGAL AND INSTITUTIONAL FACTORS

Outdoor Recreation in America, the report issued by the Outdoor Recreation Resources Review Commission in 1962, devoted but one paragraph to the important subject of state water law:

> State water law is a complex and controversial legal area, which cannot be treated here. It does seem clear, however, that if public demands for outdoor recreation are to be satisfied, the right of the public to use water for outdoor recreation must be promptly recognized.

Eleven years later, in 1973, the National Water Commission issued its final report, Water Policies for the Future. It devoted nine pages to the question of improvement in state water law. It noted that "legal rights should be created in the public for... social uses..." To this end it made two specific recommendations:

> State property rules relating to water should authorize water rights to be acquired for all social uses, non-economic as well as economic. In particular, recreation, scenic, esthetic, water quality, fisheries, and similar instream uses are kinds of social uses, heretofore neglected, which require protection. As these values, and rights in them, are recognized and protected in natural lakes and streams, their benefits should be clearly mandated for general public use, particularly when they are uniquely suited to such uses.

and

> Public rights should be secured through State legislation authorizing administrative withdrawal or public reservation of sufficient unappropriated water needed for minimum streamflows in order to maintain scenic values, water quality, fishery resources, and the natural stream environment in those watercourses, or parts thereof, that have primary value for these purposes.

The text of the report cited a number of examples to show that attempts to achieve such ends under existing laws had been successfully challenged. The major source of difficulty is the western system of water law known as the "Appropriation Doctrine."

4.1 WATER LAW DOCTRINES

While there are variations from State to State, in general, two doctrines govern water law in the United States. The "Riparian Doctrine" which rules in most of the country east of the 100th meridian is derived from ancient common law. It is based on ownership of land adjacent to (and sometimes under) the water. It is a property right which goes with the land. Within the bounds of reasonableness, the riparian owner is entitled to an undisturbed flow through his land and has a similar obligation to downstream landowners. This basic doctrine was brought to the colonies from England and accompanied settlers to the West. However, there it failed to meet needs in an open country where water was in short supply. Accordingly, there developed in the western states a new doctrine which permits acquistion of water for consumptive use. This is the Appropriation Doctrine.

4.1.1 Elements of the Appropriation Doctrine

The basic concept underlying the doctrine is that water should be put to economic use. The technical term employed is "beneficial use" which appears in the basic water law of appropriation states. A water right is not gained by owning appurtenant property. Rather, assuming the intended use to be "beneficial", the right is established by filing a claim. Priority of right is based on the date of the claim: "First in time, first in right." This means that flows passing by a certain point but appropriated downstream may not be disturbed, even though the adjacent landowner has a need for the water. It also tends to mean that when flows are not sufficient to support all appropriated amounts, as may happen in a dry year, those with the prior claim are allowed to withdraw their water first, and some claimants may be excluded entirely.

One other important element must be considered in respect to the doctrine. Since it was established to permit consumptive use, a diversion of the water from the natural streambed is normally considered essential to perfecting the claim.

The doctrine is further complicated by the fact that most states where the Appropriation Doctrine applies have set a system of priorities of use. In some states these are embedded in the state constitution, while in others they are stipulated in legislation. Water for domestic use is always first. Agriculture (irrigation) usually comes next; although in Idaho, mining has preference in an organized mining district. Industry and manufacturing tend to follow. Power is usually low on the list. Recreation and aesthetics are generally assigned low priority or are ignored. In Arizona "recreation and wildlife, including fish" is last in priority. In Kansas recreation follows industrial but precedes waterpower. In North Dakota "fish, wildlife, and other outdoor recreational uses" are at the bottom of the list. In Texas recreation is next to last, followed by "other beneficial uses." In Oregon "other beneficial uses" appears to cover everything after human consumption and livestock consumption; the statute contemplates nonconsumptive as well as consumptive uses in determining the highest and best beneficial use of the water.

This brief summary of the Appropriation Doctrine hardly does justice to a subject which has been the source of immense amounts of litigation for more than a hundred years. However, a full and detailed treatment of the subject is not necessary for the present purposes. Those wishing to consult a recent compendium on the subject should refer to Wells A. Hutchins' Water Rights Laws in the Nineteen Western States (3 Vols., 1971).

4.1.2 Application of the Appropriation Doctrine

Water law is governed entirely by the appropriation doctrine in eight states: Montana, Idaho, Wyoming, Nevada, Utah, Oklahoma, Arizona, and New Mexico. These are all high altitude states with arid regions. In eleven states both the appropriation and riparian doctrines are recognized: Washington, Oregon, California, North Dakota, Nebraska, Kansas, Oklahoma, Texas, Mississippi, and Florida. It will be noted that with the exception of the last two, all are west of the Mississippi River; in these latter states the riparian doctrine is primary. It will also be noted that the others are either on the west coast or on the eastern edge of the Great Plains.

4.2 CONFLICT BETWEEN APPROPRIATION WATER LAW AND INSTREAM FLOW

The provision of instream flows in western states is greatly complicated by the embedding of appropriation doctrine with its specification for beneficial uses in state constitutions and statutes. Courts have been reluctant to agree that simply permitting water to remain in the stream is a "beneficial use", per se, of water. Until recently even in the face of clear legislative statements of intent, courts have seldom held that uses not requiring diversion and off-stream consumption are beneficial. A recent case in Idaho illustrates the basic problem.

4.2.1 The Malad Canyon Case

In 1971 the Idaho legislature passed an act directing the state's Department of Parks to appropriate all unappropriated flow of the natural waters in Malad Canyon in conjunction with establishment of a state park in the area. The preservation of water in the area "for its scenic beauty and recreational purposes" was declared to be not only a beneficial use but a use of higher priority "than any other use except that of domestic consumption." When the Parks Commission attempted to perfect the appropriation through filing of a permit application, the application was challenged on three counts:

Could a State agency appropriate water?
Are instream uses beneficial under Idaho law?
Is an actual physical diversion necessary for a valid appropriation?

The application was upheld in the District court and brought before the Idaho Supreme Court on appeal. The latter affirmed the judgment of the lower court on all counts. However, it was a split decision. Two of the five justices dissented. Of the majority, one issued a special concurring opinion in which he was joined by another justice. Thus, only the Chief Justice held unequivocally that the Malad Canyon appropriation was valid. Mr. Justice Bakes in his separate opinion held that the use established by the statute was a beneficial use in the present circumstance. However, this would hold "so long as, and only so long as, the circumstances of water use in the state have not changed to the extent that it is no longer reasonable to continue this use at the expense of more urgent needs." This use should "receive the same treatment as all other non-constitutional beneficial uses." Mr. Nathan Higer, an attorney for the Idaho Department of Water Resources interprets this to mean that "the practical ability of the state to accomplish minimum stream flows is in grave doubt without constitutional amendment. For as we all know, minimum flows are worth nothing if they can later be avoided in the name of higher beneficial uses." (Paper presented at a recent conference on instream flows at Boise, anonymous, ed. 1976).

Two things are noteworthy in the Malad Canyon case. First, the flow originating from the springs in Malad Canyon which had not been previously appropriated was appropriated by the state in its entirety. But this appropriation covered only the flow within the clearly defined area of the state park. Once the water left the canyon park area it was subject to full appropriation through diversion. Thus, the instream flow provided was severely limited.

Second, the division of the Idaho Supreme Court noted above suggests that even this modest goal may be subject to frustration at some later date should an appropriator satisfy a court that he needs the water for a more "beneficial" use. Thus, even a clear legislative intent to assign a small flow in a limited area to use by a state agency acting as a trustee for the public is brought into question.

Viewed at first as a victory for the proponents of providing instream flow through the appropriation process, the Malad Canyon case appears on second thought to offer little firm hope for the future. Several legislative proposals to follow up on this matter were made in 1976. None passed. These would have declared as a matter of public policy that the considerations of public health, safety, and welfare require protection of streams from loss of water and that instream flows are a beneficial use of water. The bills then established procedures for filing and approving the permit application. The bills differed only in the parts of the state to which the law would apply. Should such a statute be enacted it would permit a clear-cut court decision on the issue of instream flow as a beneficial use that would not be so limited in its application as was the Malad Canyon appropriation. Mr. Higer believes that in the face of such an expression of legislative intent, the courts would not intervene.

4.2.2 Other Approaches

Several years ago the Idaho Fish and Game Department received a permit for an appropriation of up to 50,000 acre-feet of previously unappropriated water on the Boise River for release during low flow months after the end of the irrigation season to maintain minimum fishery flows on the river. In this instance, the water had already been "diverted" by impoundment behind Lucky Peak Dam, so the appropriation has not been challenged. However, in light of the decision in the Malad Canyon case, it seems possible that this might be done at some future date as requirements for water to be applied to beneficial uses enumerated in the state constitution appear.

The experience of Idaho Fish and Game suggests an avenue of approach which, in fact, is being used with more frequency. Most irrigation structures are Federally funded. It is often possible, during the planning phase for a new project, to build into the project agreement with the state involved to have some state agency appropriate enough of the impounded water to insure adequate flows for fishery and recreation purposes. Such flows could be seasonally adjusted to meet varying needs.

Another, and innovative,concept was brought forward in 1976 in a bill that was drafted but never filed in the Idaho legislature. The basic idea involves the construction of new dams to store water during periods of flood flow for later release during low flow periods to meet minimum instream needs. Since the water so impounded would normally not be used but pass downstream, the appropriation would not interfere with any other established right. Additionally, the appropriator could specify the point downstream which the released water must reach, freeing it from danger of appropriation after it left the dam. Attorney Higer suggests that this approach "may present the practical means of avoiding conflict over the availability of water because the appropriation is made at a time when water is abundant and released when water availability is critical".

This particular concept appears to offer considerable promise where hydrological conditions and the possibility of building the necessary impoundment structures co-exist. It should be examined further to see if it could be widely used. Federal aid from the Land and Water Fund might represent a vehicle to foster the development of such projects in Idaho and in other western states with similar problems.

4.2.3 Recapturing Irrigation Water

The general rule governing appropriation of water is that the highest and best use could prevail. In the Malad Canyon case Mr. Justice Bakes suggested that aesthetic values and recreation are low on the list. But this could change, in Idaho and elsewhere. The economic analysis presented in Section III of this report suggests that use of water for irrigation purposes is essentially uneconomical. The same point is made in Water Law Atlas: A Water Primer 1968 by Thomas A. Garrity, Jr. and Elmer T. Nitzschke, Jr. where it is suggested that arid region agriculture represents a use of water for irrigation that is not "as economical a use of water in the west as many other possible uses."

The idea of recapture is attractive but it seems unlikely that it will come to fruition. It would require a drastic alteration of the perception of water priorities in the appropriation law states, including modification of both statute law and, in some cases, the state constitution, to place a higher value on fish, wildlife, and aesthetic and recreation values than agricultural production, no matter what the justification in terms of total contribution to social welfare. Even if this could be done, it would be expected that the courts, which have in the west almost uniformly held that beneficial uses mean economic uses in the narrowly defined sense of the term, would be reluctant to approve the change. This would be especially true in the case of pre-existing water rights. As Bonnen pointed out in the paper cited in Section 4, once allocations have been made "it is difficult to transfer to other uses later." The same general point is made in a duscussion of this point in the Technical paper, "Legal and Institutional Structure", of the Platte River Basin - Nebraska: Level B Study. It is noted that, while economists can agree that water use should reflect the highest and best use of the water, "defining highest and best use could become a tug of war between urban and rural legislators." The report suggests that "highest and best use" can usefully be considered only within the context of the preference system. The priority assigned to instream flow in this system varies from low to zero. The vested interests in use of water for irrigation purposes might, in some instances, be successfully challenged to meet industrial needs. That this could be achieved for the sole purpose of flow maintenance appears most unlikely.

4.3 INTERSTATE COMPACTS

The water problem is further complicated in the west by the fact that many streams cross state boundaries. In an effort to insure equitable allocation of the water, the states have frequently negotiated interstate compacts. For example New Mexico has engaged in eight such interstate compacts. According to an article on the "State Water Plan" by New Mexico's State Engineer, S.E. Reynolds, published in the Proceedings of the 18th Annual New Mexico Water Conference, "All of our significant streams are now involved in such agreements." Surface water lying in areas declared by the New Mexico State Engineer to consist of underground basins is subject to public use but closed to appropriation. All of the other surface waters in the state are either committed to delivery to other states under compacts or are fully appropriated. (USDA, Economic Research Service and other agencies, Upper Rio Grande Basin: Water and Related Land Resources. 1974)

Interstate compacts are binding documents which specify not only quantities of water to be delivered from one state to another but may also, as in the case of the Rio Grande Compact, set limits on new reservoir storage in the compacting states. They represent efforts to compose conflicting interests among the parties, usually after a long period of disputation. Once an agreement is reached, it is ratified by the respective legislatures and then enacted into law by Congress. Provisions for revision are included, but they require unanimous agreement of the representatives of each state and confirmatory opinions from the respective Attorneys General. This process permits technical changes, as was accomplished for the Rio Grande Compact in 1949, but the process does not seem amenable to changes to provide for minimum instream flows since such flows could threaten the basic distribution of the water covered under the compact. A substantive alteration of a tri-state agreement might be more difficult to achieve than alteration of an individual state constitution.

4.4 EASTERN PROBLEMS

In the humid eastern half of the country water supply tends to be abundant. There is more runoff entering ground water storage and surface streams and lakes. Withdrawals are relatively insignificant in comparison to the arid regions because irrigation is not as important in eastern agriculture. There is no basis for appropriation of flow, with the aforenoted exceptions of Mississippi and Florida which recognize a limited form of the appropriation doctrine.

There are some problems with instream flow, however. Withdrawals for industrial use and for municipal water supply have affected some rivers and streams. Most states have established minimum stream flow criteria to meet EPA water quality regulation requirements.

Where there are problems they are generally related to hydroelectric power dams. Flows from such dams often exhibit extreme side swings. Rivers below some TVA dams are nearly shut off when generating is not taking place. On the Chattahoochee above Atlanta the FPC license for the Georgia Power Company installation at Buford Dam requires minimum release of 500 cfs to assure adequate quantity and quality of water for downstream municipal supply. However, the flow can jump to about 9,000 cfs in less than an hour in response to generating requirements.

4.4.1 The Delaware River Controversy

Following a Supreme Court decree of 1954 guaranteeing New York City water for municipal use from the Delaware River watershed, New York City and the states of New York, Pennsylvania, Delaware, and New Jersey entered into an interstate agreement, the Delaware River Compact, which was signed in 1960. Alteration of the existing agreement requires consent of all parties. New York City has the right to withdraw an average of up to 800,000,000 gallons per day from three reservoirs on the upper watershed in New York State. There are also requirements for minimum releases for conservation purposes from each of the three reservoirs, plus a requirement that sufficient water be released to insure a flow of 1750 cfs at a specified gage downstream in New Jersey. The City of New York decides which reservoir will provide these releases. New York uses some of its required release for the purpose of power generation.

The operation of the three dams has created problems for Pennsylvania. The required absolute minimum flows from the dams are not sufficient to maintain healthy stream conditions below the dams. The erratic releases from the dams affect fisheries and instream recreation such as canoeing and boating adversely on the upper Delaware River. Minimum allowable releases of warm water are suddenly overwhelmed by torrents of cold water. Water temperatures 71 miles downstream from one of the dams varies by as much as 5°F as a result of this upstream modulation of flow. The rapid changes in stage and velocity associated with releases make the upper part of the river a poor recreational resource. The Pennsylvania Fish Commission has sought without success to effect a change in the release patterns. A study by Fred Johnson (1975), showed that fisheries and recreational benefits estimated to be in excess of $20,000,000 per year could be realized in Pennsylvania by rather minor adjustments in the New York City release schedules. The City's response was that making the suggested release changes would cost it about $75,000 a year, and that it would not make such changes without compensation. Even if Mr. Johnson's estimate of benefits is incorrect by an order of magnitude, the variance between benefits currently sacrificed against the cost of the benefits which would have to be sacrificed to provide amelioration is enormous. This example is a good indication of the kind of legal-institutional roadblock which can upset the most rational and economically defensible attempt to guarantee instream flows for recreation. In view of the benefit-cost ratio if the change were to be effected, it would certainly pay the Commonwealth of Pennsylvania to provide New York City with the compensation demanded. Probably both legal and political considerations rule out such a course of action.

4.5 PROBLEMS OF ACCESS AND PASSAGE

Though only indirectly related to instream flow, difficulties of obtaining access to the water do affect recreation in rivers. In riparian states the landowner owns the banks and, as a rule, the stream bed to the middle of the channel. In most states he can forbid trespass to get to the water. When rivers have been declared navigable, a right of passage is theoretically guaranteed; but this may be restricted to travel by boat, foreclosing wading-fishing or landing a boat to get around obstructions.

Two examples of the kinds of problems which may arise are worthy of note. The lower portion of the Russian River in California has been impounded by dams in several places to create commercial resort recreation pools and beaches. Canoeists cannot pass over or through the dams, making a portage around them necessary. The owners refused to permit this. One commercial canoe livery operator, Mr. Bob Trowbridge, took the resort owners to court and obtained an agreement allowing canoeists to use a small portion of the beach near the dam for purposes of portage.

A second instance arose on the North Platte in Nebraska between Lake McConaughy and the city of North Platte. In this area the river passes through agricultual land, largely devoted to cattle raising. To prevent the cattle from straying into adjacent property, while still allowing them access to the river to drink, ranchers have strung fences across the river. These make passage by canoe difficult, and in some cases hazardous. In general, however, it appears that most landowners in the region do not object to boaters landing and carrying their craft over the obstruction. Since Nebraska retains some elements of the riparian doctrine, this does not constitute a legal "right", however.

Access to rivers can be obtained by governmental action. Where no satisfactory sites are already in public ownership, these can be obtained by lease or purchase. Acquisition of such property is an important element in recreation planning.

Assuring the right of passage and portage, while not so common a problem as obtaining access, may prove more difficult to solve where landowners remain obdurate. There are several possible approaches which may be worthy of further study. Legal challenges to obstructionists by Fish and Game and Park Departments offers one avenue of approach. Legislative action to guarantee reasonable use by the public is another possiblity. Purchase by governmental bodies of rights, much like a scenic easement, might also be possible; this would allow public usage without affecting the riparian owner's basic property rights in any substantive way.

4.6 CONCLUSIONS

Ultimately, one must agree with the Outdoor Recreation Resources Commission that state water law "is a complex and controversial legal area." Solution of the manifold difficulties raised by State and local law to the maintenance and use of instream flows must be treated on a case-by-case basis.

In the appropriation law states, basic changes in statute law may be required. Even so, courts may be reluctant to accept the use of water implied by flow maintenance. Where appropriation rights and a preference system are incorporated in the state constitution, as in Idaho, this may ultimately necessitate changes in such organic documents. Achievement of such alterations may prove difficult to bring about. However, if the need becomes evident and is accepted by the public, the task may not prove to be insuperable.

In riparian law states, the problem of fluctuations in flow, primarily from power dams, creates another difficult problem. Provisions for minimum flow can be incorporated in new projects; FPC licensing for private projects offers one avenue of approach, while for public projects the recreation benefits can be used to help justify the impoundment, as in the TVA examples cited in Section I. Re-licensing for FPC regulated dams offers a potential opportunity to improve flow, especially low flow, procedures.

Flood and irrigation impoundments may have provisions built in for instream releases during low flow periods. Clearly the planning phase of future projects should give serious consideration to such provisions.

Guarantee of access to rivers is a problem that must be faced in many places. The solution may vary but seems achievable. Public access rights occasionally represent a major obstacle to instream use. There appears to be no single solution to this problem. Public acquistion of passage rights analagous to a scenic easement, by gift, lease, or purchase, appears to be one fruitful approach. Legal action in the courts or changes in statutes may be required in some cases.

Provision of flow in rivers under interstate compacts appears to be the most difficult problem of all. Such compacts are usually arrived at only after years of negotiation and frequently represent compliance with a court order. Technical changes can be made without great difficulty, as in the Rio Grande compact where changing flow conditions required an alteration of gage sites. Any fundamental alteration of the rate or amount of flow passing from one state to another, however, seems much less likely of success. Changes in interstate compacts require unanimity. One party will not be willing to give up water for the benefit of another signatory without compensation. It may be that the receiving state could "purchase" the necessary flow to guarantee the benefits. Such purchase could amount to payment of an annual fee for the water or outright acquisition of the flow in perpetuity for a negotiated sum. Financing such arrangements might be provided from levies on state fishing, hunting, or boat license fees, from general revenues, or from one or both of these with additional contributions from the Land and Water Fund.

SECTION 5

SUMMARY

In the Introduction of this study are presented data that establish the fact that there has been very little provision of instream flow from water projects in the United States on behalf of recreation. The few that do exist are found mainly in the East, particularly within the TVA system. In the West minimum flows are sometimes provided, but in most cases they are for the purpose of contaminant dilution or support of fish and wildlife. Occasionally boating occurs but it is incidental. It is noteworthy, however, that planners in the western regions of the country are now including in their long range studies considerations for the full range of aquatic activity (e.g., the Nimbus Dam, American River, California).

The preceeding sections dealt with the essential questions for planners and policy makers:

> How much flow is required in a given river to provide recreation?
>
> How can the provision of such flows be justified in the terms of project evaluation criteria imposed by Principles and Standards?
>
> What legal and institutional obstacles may stand in the way of providing such flows?

Section II addressed the first question at length. It is there that the physical conditions within a stream that are necessary for many types of recreation are specified. They are expressed in terms of the width, depth, and velocity of flow for a set of possible recreational activities. Additionally, those auxiliary site and longitudinal considerations which will make a particular activity more or less desirable are identified. The tools of hydrology and hydraulic geometry, buttressed by limited field observation, are shown to be sufficient to relate these requirements to the flow (discharge) in a particular stream. This permits recommendation of a flow (or flows) to support recreation, either as an absolute minimum level or as a level optimizing recreation opportunity. This technique has been developed and tested on seven rivers distributed throughout the continental United States and found to work well in both natural and regulated streams. The specification of recommended flows for recreation, however, is not of itself sufficient. Provision must be made for obtaining or insuring those flows.

The maintenance of flow in a natural stream means that recreation must enter seriously into the market that allocates waters from streams. The other consumers in this market (water supply, irrigaton, power, and industry) have generally been accorded favored positions because their output is measureable in dollars in a straightforward manner. <u>Principles and Standards</u> allows a direct measure of recreation values, but suggests only travel costs or recreation day values for such measures. It does however, provide for the use of other measures, if they can be documented. And it does provide a means, through the EQ account, of valuing the simple preservation of a stream, since this can maximize future options. Section III explored these various avenues of competition for water by recreation and points to a number of potentially fruitful approaches. They are:

> Correct inflated benefits assigned to competing uses,
>
> Value recreation of from 4 to 10 times higher than the maximum recreation day figure provided by <u>Principles and Standards</u>,
>
> Assign a portion of the cost of recreation flow to other uses (fisheries, water quality, etc.).

The application of these approaches must be on a case-by-case basis, but it does appear that it will be possible to economically justify provision of instream flow for recreation in many situations.

Finally, Section IV explored the legal and institutional constraints which might bar even an economically justifiable instream recreation flow from being maintained or acquired. These difficulties are most severe in the pure appropriation states. Even the partially successful Malad Canyon case in Idaho was not able to secure a claim to instream flow against possible future uses. It appears that changes to state constitutions and to interstate agreements may be required to allow a direct and certified appropriation of water for recreation. In the riparian states, especially in the East, the quantity of water is less often the issue than is the pattern and rate at which water is released from retention structures. These difficulties may be amenable to solution by negotiation or by recompense for losses occasioned by release pattern changes. Recent work in Pennsylvania indicates that such situations may exhibit very favorable benefit/cost ratios in that dollar losses for power generation, for instance, may be amply repaid in dollar increases in recreation values. Funding for such endeavors, however, is difficult to obtain from already over extended public coffers.

This document by no means insures that instream flow can be provided for recreation in a particular case. It does insure that the recreation planner will be able to determine accurately how much (or how little) water is needed for instream recreation, that he will be able to establish the value of that water, and that he will be aware of possible obstructions to obtaining the needed flow.

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Discusses various criteria and standards for swimming and diving. Considers site selection, design and maintenance of recreational areas.

Strahler, A.N., 1957, "Quantitative Analysis of Watershed Geomorphology", Transactions American Geophysical Union, V.38 (6), December, 1965, p. 913-920.

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This contains a complete description of the "Montana Method". The uses and limitations of expressing flow data in percentage AAF terms is discussed. This is an important paper for any instream flow investigation.

Tennessee Valley Authority in Cooperation with Chota Canoe Club and East Tennessee Whitewater Club, Little Tennessee Valley Canoe Trails, TVA Canoe Trails, 301 W.Cumberland Avenue Knoxville, Tennessee 37902.
A description and map of Scenic and Recreation streams and rivers for canoeing along the following rivers: Nantahala, Little Tennessee, Oconaluftee, Raven Fork, Tuckaseegee and Tellico. Recommended stretches length; difficulty classification; minimum, optimum and excessive cfs also listed for each river.

Thompson, D. L., Ed., 1972, Politics, Policy, and Natural Resources, Free Press, New York, NY, 452 p.
Especially useful article by Arthur Maas on flaws in conventional welfare economics when applied to non-market items such as natural resources.

Thompson, J. and R. Fletcher, 1972, A Model and Computer Program for Appraising Recreational Water Bodies. Department of Forest Science Utah State University, Logan, Utah.
A model for predicting recreation use in reservoir situations. It is primarily interesting for its extensive treatment of the physical requirements for various water-based activities.

Thornbury, W. D., 1969, Principles of Geomorphology, 2nd ed., Wiley and Sons, New York.
A basic text on geomorphology with good sections on drainage basin characteristics and fluvial geomorphology.

Urban, John J., 1970, White Water Handbook for Canoe and Kayak, Boston, Appalachian Mountain Club.
Essentially a "how to do it" guide for would-be canoeists and kayakers.

U.S. Department of Agriculture, Forest Service, 1973, National Forest Landscape Management, Vol. 1, Agriculture Handbook No. 434, U.S. Department of Agriculture, Washington, D.C., February 1973.
A non-technical overview of key elements in analysis of scenic qualities and of methods for landscape management. Aesthetic criteria are presented in abstract, not concrete, terms.

U.S. Department of Agriculture, Forest Service, 1974, Outdoor Recreation Research: Applying the Results. "Papers from a workshop held by the USDA Forest Service at Marquette, Michigan, June 19-21, 1973", General Technical Report NC-9.

The papers presented in this volume deal primarily with land-based recreation problems relating to camping and other uses of forest lands. A review of "Economic Bases for Allocating Resources in Outdoor Recreation", suggests that while a market approach is helpful "it is not clear how best to determine supply and demand in practice".

U.S. Department of the Interior, Bureau of Land Management, 1972, Quality Evaluation of Recreation Use Opportunities.

Description of the system being used by the BLM to evaluate the inherent recreation use value of their lands. This system rates the quality of experience to be expected while participating in a specific recreation activity at a particular area. The effect this use may have on the resource itself or other resource uses is not considered.

U.S. Department of the Interior, Bureau of Outdoor Recreation, 1974, Proceedings of the Outdoor Recreation Research Needs Workshop, Harpers Ferry, West Virginia, September 4-6, 1974.

This conference was devoted to the identification of needs for basic research to improve management and planning of outdoor recreation resources. There is nothing specifically related to riverine recreation or instream flow requirements.

U.S. Environmental Protection Agency, 1973, Aesthetics in Environmental Planning, Environmental Studies Division, Washington Environmental Research Center, Report No. EPA-600/5-73-009.

A contract report by Stanford Research Institute. Presents a very useful review of aesthetics including: historical development of the concept of aesthetics; a review of methods for measuring aesthetics; and a review of planning agency guidelines for incorporating aesthetics into the planning process. The review of measurement methods is excellent. Very good bibliography.

Virginia Polytechnic Institute, 1970, Legal Aspects of Water Storage for Flow Augmentation, U.S. EPA Water Quality Office.

Concentrates on flow augmentation to improve water quality and cites problems associated with this. Riparian law does not recognize the natural stream as a conveyance for water held in right so that riparian owner can alter the the condition (through use) of the water. Appropriation law states that augmented flows are liable to diversion and use through the appropriation process.

Wesche, T.A., 1973, Parametric Determination of Minimum Streamflow for Trout, Water Resources Research Institute Report, University of Wyoming, Laramie, WY, 102 p.

Primarily of interest for its treatment of relationships between physical characteristics of a stream as a function of flow.

Wood, Roy K., 1966, Low Flow Regulation as a Means of Improving Streams for Recreation and Related Purposes, Division of Water Resources, BOR, USDI.

Minimum desirable boating flow is that which will just float 2 men in a typical craft over the shoals. Maximum is level of undue hazard. Some interesting cost-sharing ideas.

Wood, Roy K., 1969, "Policy and Procedural Problems Related to Flow Regulation for Water Quality and Allied Purposes", Statement before the Meeting of the Southeast Basins Inter-Agency Committee, Atlanta, Georgia, January 15-16, 1969.

Presents a rather general discussion of the question of releases to improve water quality and related fishery and recreational uses. Cites a specific example indicating that the increased recreation benefits in the river "will not be sufficient to offset the loss of potential values in the reservoir" attributable to impoundment level fluctuations.

Wood, Roy K. and Donald E. Whelon, 1962, "Low Flow Regulation as a Means of Improving Stream Fishing", U.S. Study Commission, Southeast River Basins, in Proceedings: 16th Annual Conference Southeastern Association of Game and Fish Commissioners, October 14-17, 1962.

Presents information on spring bottomland flooding to improve warm-water fish production and flow control later in the year to improve harvest.

APPENDIX A
RIVER STUDIES PROGRAM

RIVER STUDIES PROGRAM

1.0 INTRODUCTION

The river studies program was based on a number of propositions. It was assumed that there is a set of physical parameters governing the potential for a specific kind of recreational activity in a riverine setting. These can be expressed in discrete terms, usually a range centered about an optimum. For any river these physical parameters will tend to vary with stream flow. The impact of flow variations on such parameters is to some extent predictable, since it is governed (at least in the gross) by well-known principles of hydrology. Accordingly, it is entirely feasible to develop a set of analytical techniques, based on map studies and analyses of hydrological data, which will permit one to predict what will happen to existing or potential recreation in a river if flow is modified by reduction or augmentation. Field observations may be necessary at known or potential recreation sites, but these will consist primarily of taking a set of simple physical measurements at the site. These measurements when correlated with flow at the time they are taken, will permit extrapolation to parameter changes that will follow from a modification of the observed flow. And, finally, these predicted changes in physical parameters can be related back to recreational potential.

In order to test these hypotheses, a total of seven rivers were studied between October of 1975 and August of 1976. These rivers, shown in Table A-1, were selected to provide a wide variety of test situations and to allow the interactive development of pre-field, field, and post-field analysis techniques of general applicability to the study of the relationships between flow and recreation.

TABLE A-1

RIVER STUDIES SCHEDULE

RIVER	DATES OF VISIT
Chattahoochee (Atlanta, GA)	10/21 - 10/25, 1975
Saco (Bartlett and Conway, NH)	4/22 - 4/26, 1976
Rio Grande (Alburquerque, NM)	5/16-5/19, 5/22-5/23, 1976
Huron (Ann Arbor, MI)	6/24 - 6/27, 1976
North Platte (North Platte, NE)	6/28 - 7/1, 1976
Boise (Boise, ID)	7/29 - 8/2, 1976
Russian (Cloverdale, CA)	8/5 - 8/8, 1976

2.0 RIVER SELECTION

2.1 Criteria

A number of criteria were established to use in screening candidate rivers for inclusion in the field study experimental program.

Recreation: There are a number of kinds of riverine recreation which may be affected by flow. These include: boating in tranquil waters; water contact activities; fishing; water-enhanced activities; and wetland-related activities. A variety of recreational situations was sought.

Location: A distribution over the mainland, contiguous States was desired.

Size: The experimental program required consideration of a range of river sizes.

Physical Characteristics: The field study program needed to encompass a range of river types.

Urban/Rural Location: A variety of settings were sought for the rivers to be studied.

Regulation: The presence of regulating structures was considered desirable.

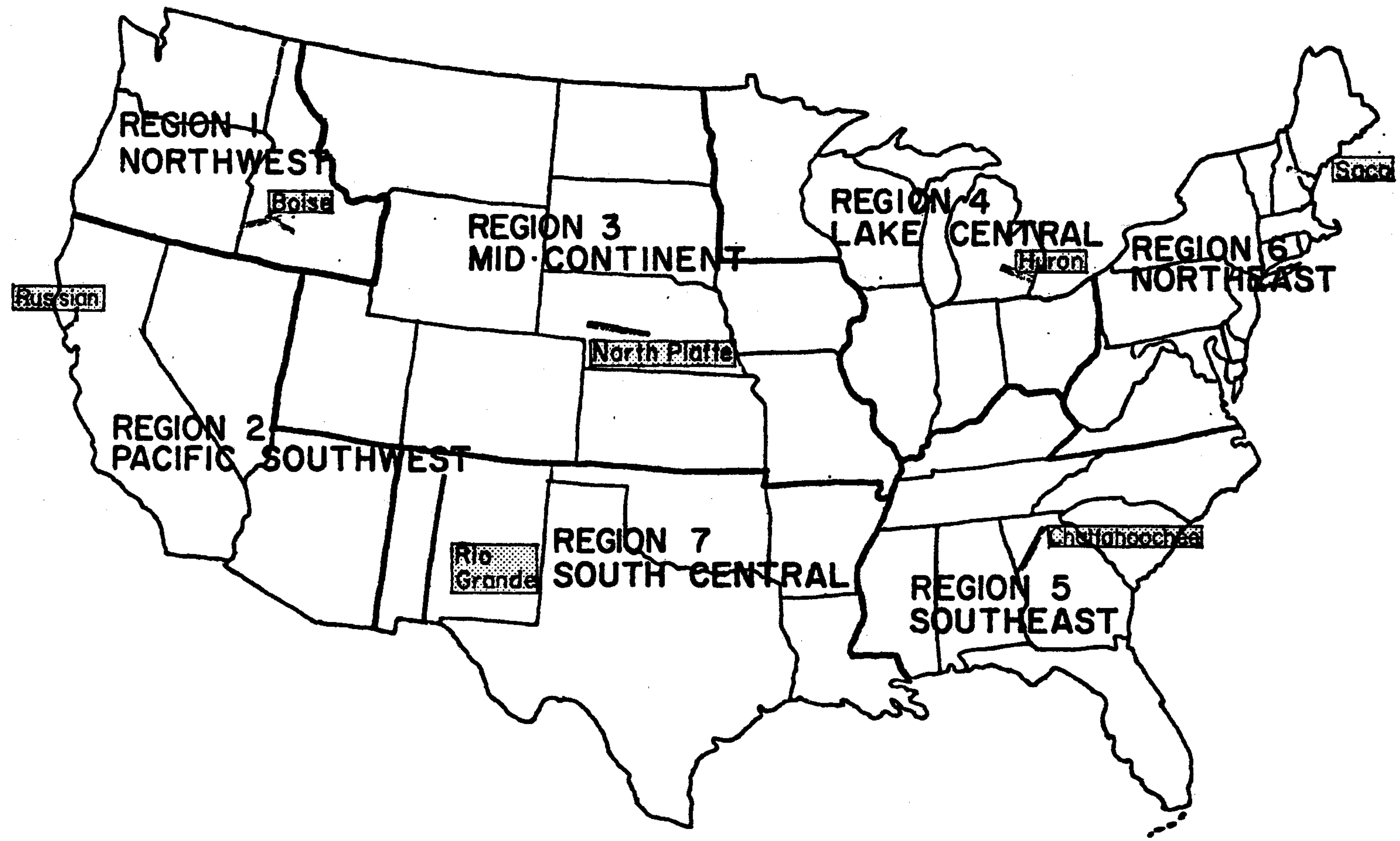
Wild or Scenic River Designation: While such designation was not a bar to selection, it was felt important not to have all test program rivers in this category.

Federal Power Commission Jurisdiction: Relicensing procedures of the Federal Power Commission offer an opportunity to modify future releases to support recreation.

Accessibility: Given limited budgets, easy access to the rivers to be studied was deemed desirable.

2.2 Selection

The seven rivers selected for field study provided a range of types which met the selection criteria. A total of 16 rivers was investigated for possible inclusion in the program. Geographic variability was assured by focussing the selection process on one river in each of the Bureau of Outdoor Recreation Regions (See Figure A-1).



RIVER STUDY LOCATIONS

Figure A-1

2.2.1 Chattahoochee River - Southwest Region

The Chattahoochee River between Buford Dam and Atlanta, Georgia offered a number of attractive characteristics for a study. It was, in fact, chosen as the pilot river, the first river to be studied.

There were a number of special considerations which made the Chattahoochee particularly attractive as a candidate for the pilot river study.

Time of Year: The logic of the program design and the desires of the sponsoring agency dictated a preliminary field study in 1975. The required "start-up" time precluded any field work during the summer. This indicated a southern river. The weather in October was sufficiently warm to permit efficient conduct of a field program near Atlanta.

Observation of Recreational Activities: Although activity on this part of the Chattahoochee is greater during the summer months, it was still possible to observe active recreation as late as mid-October.

Recreation Potential: Studies by the Atlanta Regional Commission and the Georgia Department of Natural Resources indicated that the full recreational potential of this part of the Chattahoochee was not being used.

Data Base: Access to a good data base on such key factors as flow and recreational use, as well as good mapping, was considered extremely important for the pilot river study. This was available for the Chattahoochee.

Flow Variation: Study of the hydrological data base indicated that it would be possible to observe the effects of wide variations in flow on the river's characteristics within a short period of time. Unannounced changes in release schedules proved to be a disadvantage, however.

Proximity to Regional BOR Office: It was felt that this would be a vital element in the first river study. The Southeast Regional Office of the Bureau of Outdoor Recreation is located in Atlanta. It was able to provide invaluable assistance in pre-trip planning, in effecting coordination with local public and private agencies, and by providing logistic support.

Considering all of these factors, both general and specific, the Chattahoochee was an obvious choice for the pilot river study.

2.2.2 Saco River - Northeast Region

The Saco rises as a white water stream in the White Mountains of New Hampshire and passes through Maine to the coast. Within a distance of 130 miles it undergoes transitions through all river types, from steep mountain rivulet to tidal estuary, through mostly rural areas. There is regulation of some reaches by dam. These are well downstream of the study reach. The river receives very heavy recreational use including white water canoeing, fishing, and water enhanced recreation such as picnicking, hiking, and camping. An intensive field study was planned on the upper reaches during the white water season. The Saco is not under consideration for designation as a wild or scenic river.

2.2.3 Rio Grande River - South Central Region

It was planned to study portions of the Rio Grande in New Mexico between Cochiti Dam north of Alburquerque and Isleta. Between these points the river passes through rural areas dedicated to agriculture, through Indian lands, and through a city. The river is regulated, and water is diverted for irrigation purposes. There are wide variations in flow (and in channel width and depth) on a seasonal basis, with lows occurring during the summer months. There is some canoeing and floating during the spring months, but recreational usage is not high at present. This is attributable to better quality canoeing and related opportunities in mountain streams as well as to poor aesthetic attributes of the river, especially during periods of low flow. Because of the low water temperatures, attributable to bottom flow from Cochiti Dam, there is a trout and bass fishery in the upper portions of the stretch studied, and in irrigation canals fed by the river. The fishery is said to be good in the latter.

2.2.4 Huron River - Lake Central Region

The Huron River rises to the northwest of Detroit, Michigan and passes through Livingston, Washtenaw, and Wayne Counties to enter Lake Erie south of the city. The stretch of interest is about 11 miles long, between Hudson Mills and Delhi Mills in Washtenaw County. The metropolitan area location and the presence of two river oriented parks on this part of the river contribute to heavy use. The area studied is mostly agricultural in nature. There are rapids in Delhi at the Delhi Metropark and at Hudson Mills; these represent an opportunity for canoeists when the water is high and an obstacle when it is not. The river is used for canoeing and some swimming. Water enhanced activities occur at the two parks. There is some opportunity for fishing (panfish) and for wildlife development, including some game as well as nongame animals. Regulation of the river is provided upstream by Portage Lake, the level of which is controlled to provide recreation on the lake. Currently there are no provisions for releases to maintain minimum stream flow, and this has been a matter of controversy in the past. Downstream recreational opportunities can be definitely adversely affected by low flow (impacts on fisheries, impossibility of passage of Delhi rapids, possible impacts on water quality).

2.2.5 North Platte River - Mid Continent Region

The North Platte is an excellent example of a Great Plains river, wide and flat with a braided channel. The reach chosen was that between Hershey Bridge and the diversion dam at North Platte, Nebraska. The river is controlled to provide water for irrigation so extensively that it sometimes nearly dries up in the summer. Riverine recreation is affected adversely by these extreme flow variations and by difficulty of access because of private property holdings along the banks. There is some float-boating and canoeing during spring high water, but participants often encounter fences across the bed which necessitates portage. A Nebraska statute enacted in 1967 does, however, allow persons "in the process of navigating or attempting to navigate with non-powered vessels in any stream or river in this state" to portage or otherwise transport their vessels around obstructions in the stream. During the summer months flows are highly variable; however, when downstream demands for irrigation water are heavy, the releases from the dam at Lake McConaughy allow the river to be used for boating. While Nebraska is primarily an "appropriation law" State, it does recognize certain attributes of "riparian" water law. In the case of the North Platte, both appropriation and riparian doctrines impact unfavorably in riverine recreation. There is some opportunity for hunting of small game and birds in wooded areas and wetlands along the river, although again private property rights tend to limit access. Though not in strong current use for recreation, the North Platte does offer opportunities that are curtailed because of legal and institutional considerations. This factor made it attractive for the purposes of this study.

2.2.6 Boise River - Northwest Region

The Boise River is a prime example of a small, regulated, western river which passes through an urban center and serves as a focus of recreation for metropolitan Boise, Idaho. The stretches of interest were Barber Dam to Boise and from Boise to Caldwell. Upstream, the Lucky Peak Dam, along with 2 other reservoirs, regulates water releases for irrigation and flood control. The river is used for fishing, swimming, tubing, and bankside activities such as hunting in the more rural areas and water-enhanced activities in adjacent urban parklands. Recreational use is highly dependent upon release from Lucky Peak Dam, which is in turn dependent upon needs for irrigation.

During periods of extreme low flows, water quality has deteriorated to the extent that it has been necessary to close the river to use for water contact recreation. There have been a number of studies on this part of the river by other agencies, providing a good ready-made data base against which field techniques and observations could be tested.

2.2.7 Russian River - Pacific Southwest Region

This river, regulated by Coyote Dam, flows through rural areas north of San Francisco. The reach of interest extends 94 miles from Ukiah, California,to the Pacific Ocean. It was planned to concentrate the field studies in the area from Cloverdale to Healdsburg. The upper river is widely used for recreation, including float trips and canoe trips extending over several days. North of Healdsburg there is a great deal of organized commercial recreation as well as public access for boating and swimming. One of the largest canoe rental operations in the entire State of California is maintained on this river with about a thousand craft available for hire during the summer recreation season. The river regulation combines upstream flood control with provision of water for diversion (irrigation). To meet the latter needs, the flow of the river has been augmented by diversion from a power dam on the Eel River, so that augmented flows now existant are considered better than the river's natural historic flows. The river is used for swimming as well as for streamside activities such as picnicking. Some preliminary studies of recreational potential had been carried out by the Southwest Regional Office of BOR.

3.0 TIMING OF FIELD STUDIES

Selection of dates for the seven river studies was influenced by a number of factors. The contract requirements made it necessary to complete the series by late summer of 1976. It was considered desirable to conduct the first, "pilot" river study as early as possible in the work, which dictated a date in the late summer or early autumn of 1975. It was also felt that it would be advantageous to schedule individual visits to coincide with the occurrence of flows which would permit active recreation on the river to be studied and which would also be suitable in terms of conducting field studies. This tended to rule out extreme cold weather conditions, for example, as well as periods of extremely high flow.

Since the river studies program was designed as an iterative process, the early portions of the schedule were arranged to allow time between studies which would afford an opportunity to digest results and modify methods and techniques before moving to the next river. However, as the work progressed and confidence in the approach grew, trips to more than one river were combined. This approach, which was adopted on the Huron-North Platte and Boise-Russian trips, made it possible to use manpower more efficiently and to conserve funds. The schedule for the series required minor adjustments to afford the best opportunity to observe the flow regime desired. (Even so, special circumstances resulted in observed flows that varied considerably from that which had been desired in two instances.) The actual schedule for the visits appears in Table A-2.

3.1 Chattahoochee River

Work on the contract started in the summer of 1975. As has already been noted, the ruling considerations in setting a date for the field work were a desire to conduct the pilot river study while weather still permitted but as late as possible in the season so that sufficient preliminary analysis could be performed. Because the Chattahoochee is a southern river, it permitted both field studies and observation of on-going recreation during the latter part of October. This timing of the pilot study permitted early evaluation and refinement of pre-field studies and of field techniques and methods. Post-trip analysis of the results and preliminary data gathering for the rest of the series took place during the winter months when field work was not practicable.

TABLE A-2

FLOW CONDITIONS DURING FIELD VISITS

River	Dates	AAF (Gage Loc.)	Flow Observed	%AAF
Chattahoochee River	10/21-10/25 1975	2270 (Buford Dam) 2880 (Atlanta)	510-7890 (Buford) 1160-3800 (Atlanta)	22-350% 40-131%
Saco River	4/22-4/26 1976	973 (Conway)	1810-3160	186%-325%
Rio Grande River	5/16-5/19 5/22,23, 1976	1043 (Albuquerque)	3400	326%
Huron River	6/24-6/27 1976	345 (near Dexter)	250-273	72%-79%
North Platte River	6/28-7/1 1976	661 (N. Platte)	2000	303%
Boise River	7/29-8/2 1976	1360 (at Boise)	950	70%
Russian River	8/5-8/8 1976	1024 (Cloverdale)	240	23%

3.2 Saco River

The initial list of candidate rivers included at least one white water stream from each of the BOR regions. It was felt that a wider variety of river types should be investigated in the course of developing and testing methods for determining minimum instream flows for recreation. At the same time, it was desired to include at least one white water in the series. The Saco was chosen for reasons suggested earlier. The reach studied, which lies in New Hampshire just above where the river enters into Maine, offers five or six weeks of white water flows in an average year. These flows are dependent upon spring runoff from melting of winter snow in the mountains. The timing of the trip was based on an analysis of historical hydrological data; this set the period in which the desired flows would be most apt to be encountered. Close contact with area outfitters and the local USGS office was maintained to determine the start of spring runoff conditions suitable for white water recreation. The actual flows observed were at or close to the minimums for a good white water experience.

3.3 Rio Grande

It was desired to observe the Rio Grande under flow conditions which preliminary analysis had suggested would meet the minimums for most tranquil water boating, sailing excluded. This appeared from the hydrological records to coincide with the tapering off of spring runoff conditions in the watershed. In spite of rather close coordination with USGS and BOR personnel in the Albuquerque area, the actual observed flow at the time of the visit was considerably in excess of that which had been hoped for. These flows were suitable for boating and boat or bank fishing, but they were inappropriate for wading or swimming. Even boating was found to be marginal at the observed flow; at lower flows the location and traversing of main channels would have been easier than under the high flows obtained during the field trip. Additionally, these heavy and unexpected flows precluded wading to accomplish cross-section transit measurements; all transects had to be run from bridges.

3.4 Huron River

Field studies on the Huron were intended to coincide with typical summer flow conditions. Historic streamflow data indicated steady, gradual decrease in flow during the summer. The late June dates were chosen to permit measurement of river conditions during a season of actual recreational usage. The flows seen were somewhat higher, on average, than had been planned for. An unpredictable storm added to runoff and stage during the latter part of the field work.

3.5 North Platte River

The trip to the North Platte was timed to coincide with flows expected to be suitable for canoeing and floating. The dates selected were based on data provided by the Missouri River Basin Commission Level B Study of the Platte River and information provided by personnel of the Nebraska Parks and Game Commission, as well as anlysis of historic flow records. Heavy rains in the area, coupled with unusual demands for irrigation water downstream, resulted in the observation of the river at flows considerably in excess of that which had been desired. In fact, the river was at the upper end of navigability by canoe, instead of near the minimum as had been desired. These high flow conditions created some problems in terms of conducting actual field work; fortunately, for this trip the study team was augmented by personnel from the Mid-Continent Regional Office of BOR. This additional manpower proved to be essential to the measurements at several transect locations.

3.6 Boise River

In terms of flow alone, the trip to the Boise could have taken place at almost any time after the end of spring runoff. The major recreational activity is tubing, and the necessary conditions are met once flows settle down. However, it was also desired to observe actual recreational use of the river by tubers. This is dictated more by air temperature than by flow. Late July and early August provided the requisite conditions of sufficient flow and warm temperatures. In this case, the predicted flow used to set the date for the trip correlated well with the actual observed flow.

3.7 Russian River

The Russian River is somewhat unusual in that the "normal" summer flow is higher than would be observed under natural conditions. This is attributable to transfer of water from the Eel River in an adjacent basin to provide minimum flows of approximately 250 cfs at Healdsburg throughout the summer months. There was some concern that these flows might not be available this year because of the lack of winter snow in the watershed and the spring drought which followed. However, the actual flows encountered were very close to those which had been anticipated from analysis of the hydrological records. An earlier visit would have afforded an opportunity to study limited white water conditions on a part of the river; however, the flows investigated were keyed to flat water canoeing, wading, swimming and fishing. Since the time requirements for this river were not critical, it was paired with the study of the Boise.

4.0 USE OF THE FIELD PROGRAM TO DEVELOP AND TEST METHODS

One of the prime objectives of the study approach was to develop methods which would not require large investments in field investigations. Emphasis was placed on the use of remote data to minimize time in the field. Emphasis was placed on methods which would not require large amounts of manpower. And emphasis was placed on methods which would not be dependent on a series of discrete flows obtained by releases from a dam under the control of the study team. The studies of the seven rivers described here were carried out to test a number of potential methods for achieving these ends.

The perfect method for relating instream flow to recreation potential would be one that could be carried out without any field investigation at all. This ideal was seen from the outset to be impossible to realize. The state-of-the-art simply does not permit one to predict exactly what conditions will be found in rivers at any given flow. Each river is unique and non-uniform in nature; still it seemed possible that like portions of rivers could be classified according to basic characteristics, even though flow regimes might be quite different. The hydrologic regimes of rivers also vary markedly; it was thought that analysis of hydrological data would give insight into conditions affecting recreation on a particular river. The tie between the river's physical characteristics and recreation potential is a function of what happens at particular places as the flow is increased. This suggested that potential recreation sites and stretches could be pre-selected on the basis of remote data. Field work could then confirm or deny the original estimate. Field observations and physical measurements, such as cross-section transects, would provide a basis for estimating the impact of a change in flow on recreation potential.

Thus, the basic method for evaluating a river was established at the outset. However, the details of that method underwent a great deal of modification as the result of experiments in the field. The method involves study of maps and aerial photographs to develop an understanding of the river by stretch and the preliminary location of sites and stretches to be studied in more detail. The method also requires a study of the river's hydrology, with special emphasis on the distribution of flows over the year. It calls for limited field investigations to provide hard physical data on river conditions at a given flow. Finally, after-the-fact analysis is necessary to provide insight into the effects on potential recreation of higher or lower flows than those studied in the field. In practical application of the method, follow-up field visits at other flows will probably almost always be required. But these should be limited in both number and scope.

4.1 Chattahoochee River

The pilot study of the Chattahoochee was the first test of the method outlined above. The study confirmed that the general thrust of the approach was correct. However, it also confirmed the need for a number of changes in detail.

Fairly extensive map studies were undertaken prior to entry into the field. The basic tool was the USGS quadrangle sheet, but road maps, regional planning maps, and Corps of Engineers Floodplain study maps were also useful. The analysis provided a good understanding of the gross characteristics of the river in the reach under study. However, later field reconnaissance revealed that many significant details at the micro-scale level were not easily found from map study. These included bottom exposure, location of minor rapids or ledges, immediate bank form, and possible beach and bar sites. On the basis of this finding, it was determined that aerial photographs should be examined on future river studies as a supplement to map analysis.

The classification system essayed on the Chattahoochee was that developed for the State of Washington by Wolf Bauer (See Figure A-2). It divides rivers into four types of zones. These are named the Boulder, Floodway, Pastoral, and Estuarine Zones. Each has a characteristic channel pattern and each is further defined by typical valley cross-section and by gradient. It was found that the system did not work well for the Chattahoochee. As a result, an alternative classification system derived from Culbertson *et al*. was adopted. This defines a river in terms of a number of descriptors which permit description of the channel in a consistent set of terms.

An alternative method developed for Illinois by Stall and Fok was also investigated. A variant of Horton's Stream Order designation system, this uses "proportional stream order" to develop relationships among flow, width, depth, and velocity. Attempts to apply this to the second study river were not successful, and the approach was dropped.

Extensive analysis of hydrological data was accomplished before the Chattahoochee was visited. This revealed that because of the influence of Buford and Morgan Falls Dams the annual variation in flow was remarkably low. The average peak monthly flow of April is less than twice the average low monthly flow of December. Flow duration analysis was also undertaken and showed that the 10% and 50% flows at Atlanta were but slightly in excess of those at Buford Dam. However, the 90% flow at Atlanta was about twice that at Buford.

Unfortunately, the flows on the Chattahoochee between Buford Dam and Atlanta are controlled primarily by releases for power generation. These releases are highly variable on an hour-to-hour basis. The flow below Morgan Falls varies during a

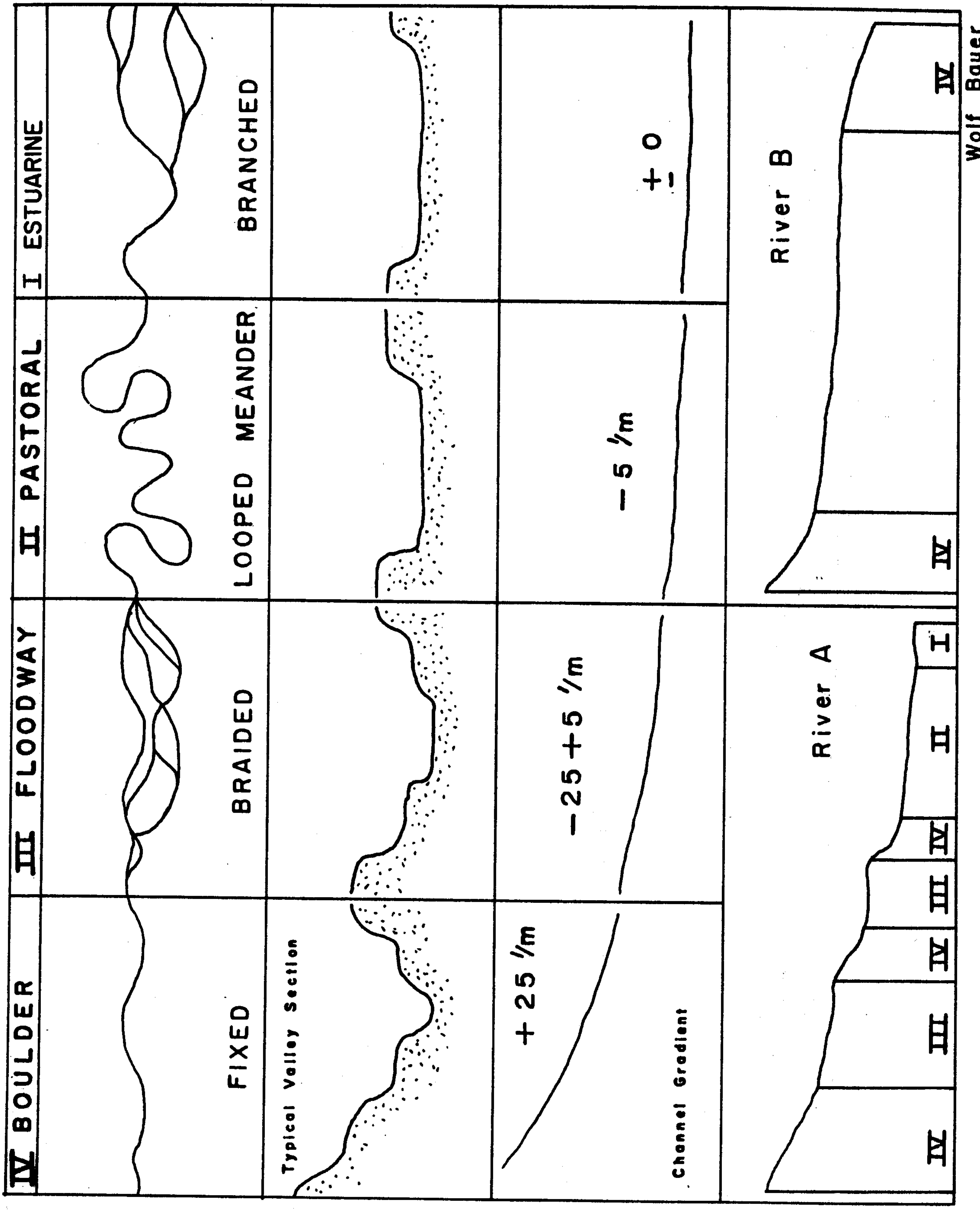

IV BOULDER
III FLOODWAY
II PASTORAL
I ESTUARINE
FIXED
BRAIDED
LOOPED MEANDER
BRANCHED
Typical Valley Section
+ 25 '/m
-25 +5 '/m
- 5 '/m
± 0
Channel Gradient
River A
River B
IV
III
IV
III
IV
II
I
Wolf Bauer

Figure A-2

typical day by a factor of from four to five. But at Buford Dam the releases vary from about 500 cfs to as much as 9000 cfs. These enormous differences are masked in the average data, even the average daily data. They were not properly understood at the time of the field visit.

Observations in the field were complicated by these flow variations. In the lower portion of the river, below Morgan Falls Dams, flows were modulated almost every hour in response to generating demands. A schedule of generating releases provided by Georgia Power was used to aid in interpretation of field data after the trip. In the case of Buford Dam, the field team had been provided with a planned release schedule and built much of the studies of the upper portions of the river around this schedule. However, unanticipated power demands led to a breach of the schedule. This impacted adversely on some planned studies. In subsequent river studies a fairly consistent flow over the field work period was sought.

On the basis of consultation with recreation experts in the Atlanta area, map studies, and the attempted application of the Bauer classification system, preliminary choices were made for detailed site investigations. Once in the area, a reconnaissance of the river was carried out. This involved a combination of site visits by automobile and passage of two stretches by canoe. The preliminary study sites were confirmed by this reconnaissance, but new ones were also discovered that had not been obvious before visiting the river. The combination of preliminary site selection with field reconnaissance verification was made a standard operation in the conduct of later studies.

The field team had planned to make a number of cross-section transects at selected sites. This was not done. It was discovered that the US Geological Survey was engaged in a detailed and precise re-survey of the river, taking cross-sections at half mile intervals. Since it was indicated that these would be available for analysis in the near future, the transect program was dropped. The sections did not become available as soon as we had hoped. Additionally, most of them did not happen to coincide with the sites of interest because of the arbitrary spacing criteria governing the USGS program. As a result of this experience, field teams did their own cross-section transects on future river studies.

Summary of the Chattahoochee Study

Map studies proved to be essential. The use of aerial photographs as an adjunct to maps was indicated and adopted for later studies.

The chosen classification system failed. Later studies considered the stream order system of Stall and Fok and the stream channel descriptor system of Culbertson et al. The latter was ultimately adopted.

Preliminary site selection on the basis of map studies and other data proved to be a viable concept, subject to field modification after reconnaissance. This combination was built into the latter program.

Analysis of basic hydrological records did not serve well on the Chattahoochee because of special local conditions which were not properly accounted for. Study of these records remained a part of the later program. However, efforts were made to work in places where the flow would either remain relatively constant or would be influenced more by natural events than by dam releases.

Direct measurements of cross-section transects, including velocities, was built into the later field studies program. Where possible these were taken by wading the river; when this was not feasible they were taken from bridges. The results of these measurements provide a means for tieing observed flow conditions to those at the nearest gage, for which accurate cross-sectional data are normally available.

4.2 Saco River

The method tested on the Saco River Study approached the problem primarily as an "in-office" technique and analyzed the physical characteristics for a particular stretch using previously calculated data from a nearby location. Ideally, with this method, physical parameters necessary for a particular recreational activity can be input into the proper mathematical relationship. From this the discharge necessary to produce these parameters can be computed.

Basic to this approach are the hydraulic geometry equations developed by Leopold and Maddock (1953). Initially hydraulic geometry equations were developed for the gage nearest to the reach under investigation (USGS Conway, NH, gage). This was accomplished by calculating the power functions which related published data on discharge with the width, depth, and velocity at that discharge.

After the power functions were calculated, flow duration data were related to discharge data. These equations had the general form: $\ln Q = a-bF$, where Q = discharge, F = frequency of occurence, and a and b were empirical constants evaluated for the range between $F = 0.10$ and $F = 0.90$. With these steps complete, discharge events at the Conway station were then described both in terms of width, depth, and velocity associated with a discharge event and the frequency of occurrence of such an event. The next step was to compare the gaged location with locations along the Saco for which such relationships have not been established.

Stall and Fok (1968) have synthesized several geomorphological techniques, useful in comparing drainage basins, with hydraulic geometry relationship developed for locations within the drainage basins. By relating hydraulic geometry to drainage area or stream order, they found it possible to discuss channel characteristics likely to occur in unmeasured sections, using relationships developed for gaged sections within the basin.

Following the procedure outlined by Stall and Fok (1968) several geomorphic parameters for the upper Saco River were calculated. These include: drainage area of the entire study reach, drainage area of each of the seven study stretches, and stream ordering for the drainage area contributing to the study reach. Linear regression equations were then used to relate discharge to proportional stream order, and then discharge to drainage area. Once discharge relationships had been determined, width, mean depth, and mean velocity could be related to drainage area through regression equations.

Using these equations and the drainage area at the downstream end of a study stretch, predictions as to the width, depth, and velocity likely to be encountered at different flows were made.

One of the main purposes of the field work on the Saco was to test these predictions by actual field measurements. This was accomplished by taking width, depth and velocity measurements at selected cross-section areas. In addition to these measurements, predictions of possible access sites were made and field verified.

Upon return from the field study, predicted data were compared with measured parameters. The agreement between the two data sets was poor. In all probability this was because the channel conditions at the gaging station were unlike those at many upstream study stretches. Another weak point of this method was the fact that velocities and depths were described in terms of an average measurement for the entire section. Many recreational activities cannot be evaluated accurately using mean data; on the other hand, it would be difficult to develop hydraulic geometry relationships for any form of data except mean depth or mean velocity.

As a result of studies performed in the field and in the office, minimum flows for white water activities on the upper Saco were defined. These were found to lie in the range of 200-300% AAF. These limits were then compared with measured discharge at the Conway gage station to evaluate the frequency of occurrence of such flows. Using the most comprehensive data available on flow duration, it was determined that minimum white water flows occur less than 9% of the time.

As a first approximation, or in situations where average values for flow parameters will suffice, hydraulic geometry relations serve as a useful tool. The applicability of a method such as this is limited, however, to gaged streams or to situations where enough similarities exist to compare streams from different basins. Accordingly, a different method was used in the succeeding field studies.

4.3 Rio Grande

A method which was considered on the Saco, but not in as much detail as the hydraulic geometry approach, was to use a percentage of AAF to predict conditions supporting different recreational activities. Tennant (1975) indicates that 10%, 30% and 60% AAF describe adequately conditions for fish survival, ranging from minimum to optimum. It has been suggested that such criteria may also apply to recreational activities.

Based on a preliminary analysis of recreational activities likely to occur on the Rio Grande at various discharges, an attempt was made to carry out field studies at a discharge slightly above the minimum necessary for most tranquil water boating activities on the Rio Grande. Conversations with personnel at the USGS office in Albuquerque indicated that the minimum flows were on the order of 150 to 200 percent for trips which did not require excessive portaging. Water quality problems in the Rio Grande through the Albuquerque area generally preclude activities such as wading and swimming, even though suitable physical flow conditions are found at different times of the year.

Even though close contact was maintained with the USGS personnel, higher flows were encountered than were originally hoped for. The flows examined were in excess of 200% AAF rather than the expected 100%. This raised two problems: first, wading measurements were not possible; second, wading, wading fishing, and swimming were also not possible. The conclusion was reached that on rivers such as the Rio Grande, where the main channel moves from one side of the river to the other and where suspended sediment concentrations are high enough to form bars and shoal areas which are not visible, optimum boating conditions require lower flows so that these hazards are exposed for boaters.

After initial stretch classification was made from USGS maps and aerial photography, gradient and sinuosity were calculated to see if any pre-study estimates of recreational potential were possible from this information. The ranges of gradients (1.8 - 6.6 feet/ mile) and of sinuosities (1.05 - 1.2) were not great enough to make any accurate predictions of on-site condtions, i.e., bank materials, suitable areas, etc., prior to visiting the river.

Access difficulties along most all sections from Cochiti Dam through Albuquerque permit only a limited suite of boating trips. As a rule, public access was possible only at bridge crossings and at several parks near bridge access areas. The distance between these access areas varied from 10 to 15 miles. With this limited access situation, boaters necessarily confined their travels to routes between bridges with the total length depending on drift velocity and the amount of portaging necessary.

This survey saw further refinement of the "Field Survey Form" (See Volume II, Figure 12) and its use as an integral part of the study. Particular emphasis was placed on an accurate determination of bank conditions. This enables prediction of the role of the banks at future flow levels in terms of access as a hindrance or an asset.

Rio Grande Findings and Their Impact

The format of the Field Survey Form was revised.

Because of access problems, it was not possible to accomplish verification of preliminary site selection. This was done by air.

Sites for activities concentrated about a specific site such as wading, swimming, and bank fishing could be identified from low-level aerial observation. Possible hindrances to boating and other activities of a longitudinal nature require detailed investigation.

It appeared that dependence upon some percentage of AAF as an indicator of recreational potential may not work for rivers where there are many diversions for irrigation.

The utility of using interpretation of aerial photos in the analysis of recreational potential appeared to be confirmed. This led to heavy emphasis on such interpretation in later river studies.

Based on experience on the Saco and Rio Grande, the conclusion was reached that the flows to be investigated be close to expected minimums for recreation rather than near optimum. It is difficult to visualize the impact of flows lower than those actually observed. At higher flows the range of options appears to center on boating.

Historical records provide only a rough guide to time visits to coincide with desired observation flows. Close contact with USGS personnel helps to improve timing. Even so, rainfall, unexpected releases, or other non-predictable events may result in missing the flow desired.

For broad rivers, with many shoal deposits, classification based on analysis of "normal" or lesser flows may not apply at higher flows when many essential differences in channel pattern are hidden.

The river stage prevented taking cross sections, save from bridges. There were accurate USGS cross-sections available, but these lacked velocity data since they had been carried out as part of a sediment transport study. There were also Bureau of Reclamation sections spaced at intervals of one mile. This arbitrary spacing reduced their usefulness in analysis of recreational potential. The method developed here calls for a limited number of cross-sections, taken at critical or representative points along the reach.

4.4 Huron River

The reach of the Huron River which was studied extended from Hudson Mills to Delhi Mills. On the Huron River the emphasis was on the pre-selection of study sites based on the examination of aerial photos, rather than USGS topographic quadrangle sheets. Although some difficulty was encountered in obtaining copies, they proved to be of more use than maps in locating physically limiting stretches.

Once again emphasis was put on evaluating recreational potential, prior to field studies, at flows in multiples of AAF; 10, 30, 60, 100, and 200%. A preliminary evaluation of recreational potential indicated that bank conditions and access would limit swimming and wading to areas where the natural bank conditions had been altered. Various types of tranquil water boating and fishing (wading, some bank) were selected as the recreational activities with the greatest potential. These predictions were also supported by studies of the Huron which indicated similar activities.

The field visit was scheduled to coincide with flows approximating 60% AAF. This flow level was chosen based on an analysis of historic records and by the desire to examine the river in the optimum-minimum range for boating. Flows actually encountered were in the range of 70-80% AAF.

Prior to the field study, discharge measurements were obtained for the USGS station nearest to the study reach (Dexter). Predictions of recreation potential at 10, 30, 60, 100, and 200% of AAF were also made. The data available for 10% and 30% AAF were at locations other than the gage station, and in several cases were 1000 feet downstream. Although it was possible to discuss potential at the gaging location itself, extension of the results over a complete range of flows was not possible because several channel sections were used.

When site selection was finalized on the Huron, several known access areas for boating and wading were chosen. These were in addition to sites selected as being representative of geomorphically similar stretches. Several sections were measured at physically constricted sections of the river, which in this case were rapids. Measurements were taken so that the basic channel and bank geometry was defined and could be used as a basis for examining width and depth conditions at higher discharges. It was generally not possible to make velocity measurements in the rapids.

In terms of refining physical criteria, no major changes in width, depth, and velocity requirements for various types of recreation were made.

The Huron Field Study resulted in the following modifications:

After limiting areas are identified, the activities that are likely to be affected at various flows are also identified.

Although stretches may be classified similarly on the basis of air photo examination, field survey is necessary to reduce the total number of possibly repetitive sections while preserving those which represent real differences.

Areas under the direct influence of man-made structures should be examined. However, where ponding occurs, normal streamflow relationships may not be strictly applicable.

4.5 North Platte

On the North Platte River, a reach between Hershey Bridge and North Platte was chosen for study. This area, because of limited access, was used primarily for boating and hunting. When determining the dates for the field study, historical flow records were used in conjunction with flow recommendations contained in the Platte River Basin Level B Study. Flows close to the minimum expected during the summer irrigation period were targeted because it had been shown through earlier studies that examining flows nearer to the minimum for an activity were of more use for a one-visit situation than those closer to optimum flows. It was expected that at these flows, canoeing, rafting, and kayaking would be the most likely activities, given access limitations to activities such as swimming, wading, and bank and wading fishing. As it turned out, actual flows encountered in the field were much higher, in the area of 300% AAF. At this level, optimum to maximum boating flows were encountered. Although the field trip dates had been based on information from a person close to the study area, heavy rains and irrigation demands downstream resulted in higher than expected flows.

Privately owned agricultural land on both sides of the river from Lake McConaughy to North Platte made land side access a legal and physical problem. Additionally, barbed wire ran parallel to or perpendicular to the river in most stretches. For these reasons, final site selection and field measurements had to be carried out by boat. The heavy flow conditions encountered on some restricted stretches required the use of cables and a boat for transect measurements. Excellent air photo coverage was available for use in classifying stretches of the study reach and for locating transect sites within these stretches. Sinuosity and gradient were calculated for the study stretch and for each of the reaches making up the stretch from USGS topographic quadrangle maps. Enlarged black line prints of the air photos encased in plastic proved to be invaluable in navigating the river and in locating positions in the field.

Most of the study stretches were of a braided nature (See Figure A-3). These were further classified into single and multiple bar and single and multiple island stretches. Transects were taken for each type to determine if any were more suitable for recreation than others. Multiple bar stretches were found to be generally wider than the other types, and thus shallower; such places are more apt to become physically limiting at reduced flow than the other types. Single bar and single and multiple island stretches generally have one channel which has sufficient depth for boating when other areas of a section may not.

The North Platte Field Studies may be summarized as follows:

The river classification scheme (Culbertson et al.) proved to be satisfactory in locating typical cross-sections on this, the first braided river to be examined.

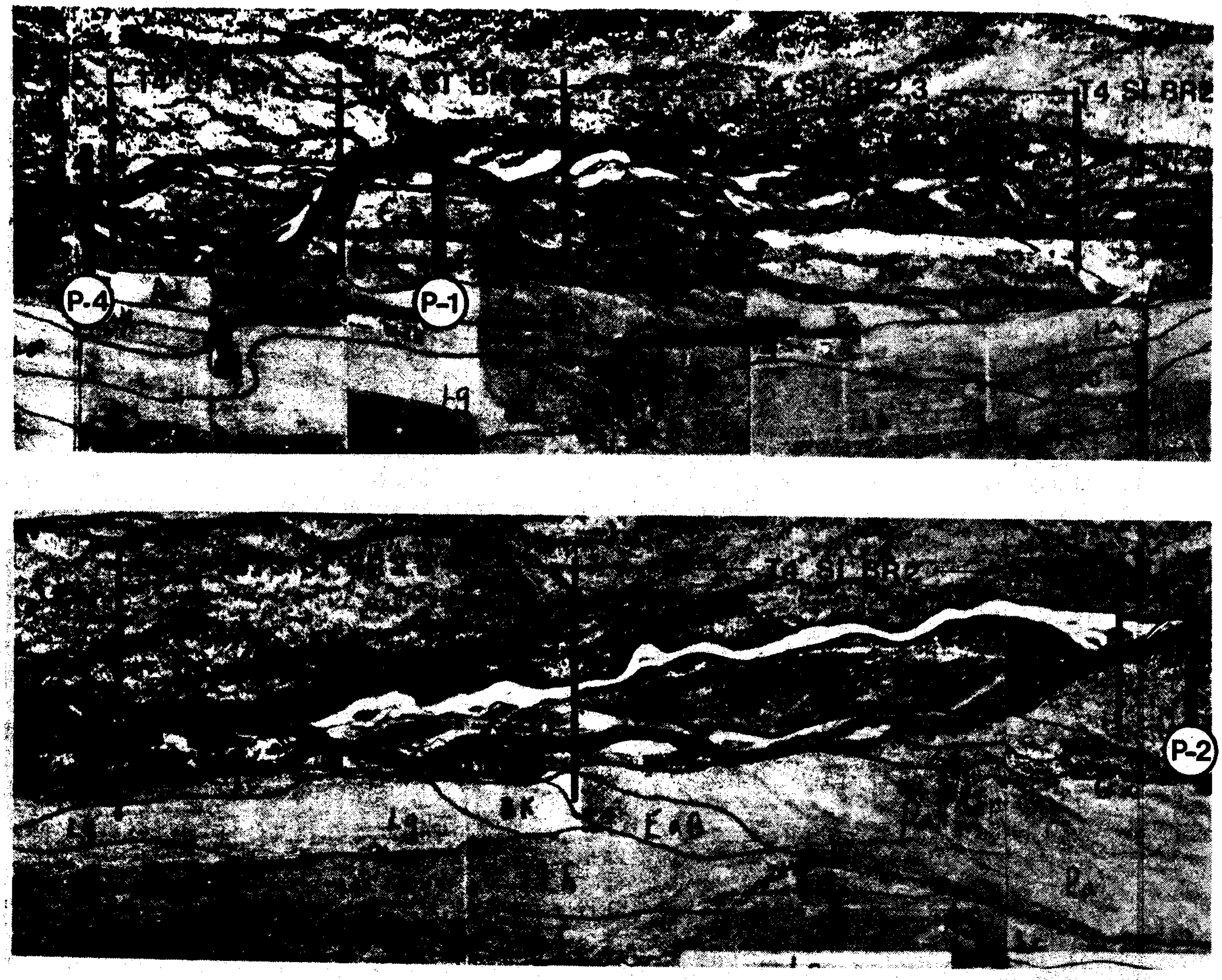
When working on rivers with few prominent landmarks, it is essential to have air photos as well as maps for field work.

Equipment taken into the field must include those items necessary to measure transects where wading is not possible: cables, anchor stakes, and a boat.

For visually estimating recreational potential, it is best to carry out field studies at lower flows than were encountered on the North Platte.

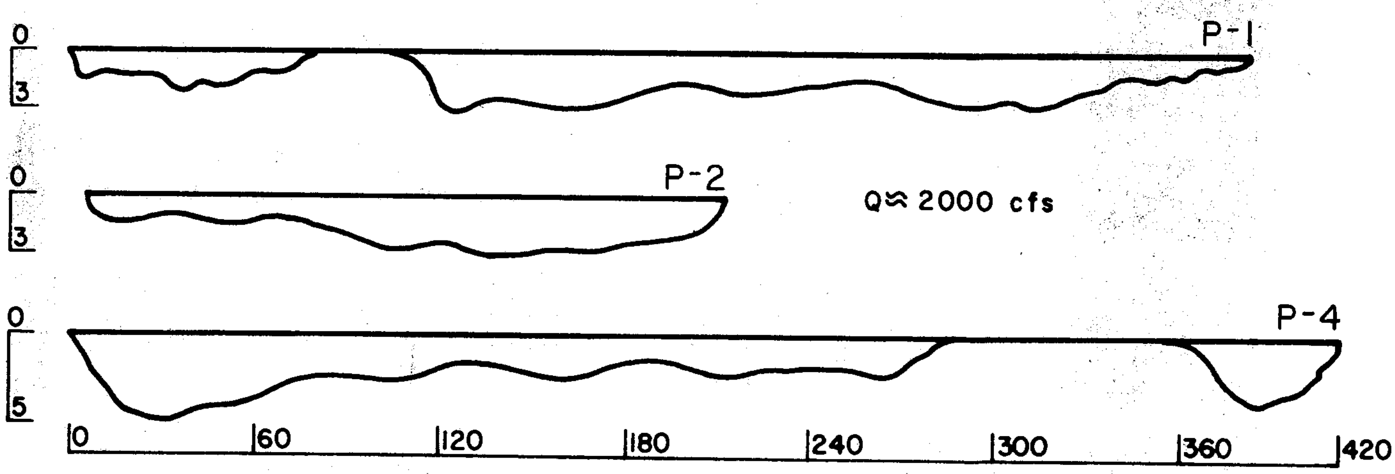
The data gathered at flows in excess of AAF are as useful in a quantitative sense as are data gathered at lower flows, although accurate channel geometry measurements are more difficult as flows increase.

The recommended number of people in a field party is best set at two for wadeable rivers and three for transects where cable or cable/boat crossings occur. It should be pointed out that while



MAP SCALE 1:28,800 (appx.)

CLASSIFICATION OF A SECTION OF THE NORTH PLATTE RIVER, EAST OF HERSHEY, NEBRASKA



SURVEYED CROSS-SECTIONS P-1,2,4, NORTH PLATTE RIVER, JULY 1976

VERT. EXAG. 6X
SCALES IN FEET

Figure A-3

an attempt is almost always made to visit a river at a flow less than AAF (wadeable conditions), provisions must be made to measure any flow encountered below bank-full conditions.

On braided reaches, areas of multiple bars should be included, generally, as potentially limiting stretches. From air photos, the extent of the stretches can be delineated. Field studies at a typical cross-section are then used to predict flows at which the areas become impassable.

4.6 Boise River

4.6.1 Background

Field studies on the Boise River were carried out in late July and early August, 1976. Two stretches of the river were studied: between Barber Dam and Boise and from below Boise to Caldwell (See Figure A-4). During the Boise River study, a large amount of data which had already been gathered on the Boise River was used to become more familiar with the river and to cross check the data generated during the field study.

Streamflow characteristics of the Boise River are greatly affected by regulation, diversions, and large withdrawals during the irrigation season. Four major reservoirs in the Boise River system are available to store natural streamflow and regulate the available supply. Two of the reservoirs (Arrowstock Reservoir and Lake Lowell) are operated primarily to fill irrigation needs. Anderson Ranch Reservoir is operated for power, flood control, and irrigation, while Lucky Peak Lake, closest to Boise, is operated to fill multiple needs, including flood control, summer recreation, and to a degree, winter fishery flows.

Abrupt changes in streamflow characteristics occur as a result of irrigation and flood control releases. During the irrigation season, from April 15 to October 15, demands result in high, well-sustained flows between Lucky Peak Dam and Boise. Irrigation withdrawals then reduce flows, which often become critically low downstream near Star and Notus.

In the non-irrigation season, the reverse holds true. Between Lucky Peak Dam and Boise, flows are often very low when the gates of the dam are closed, while downstream, below Star, groundwater discharge produces sizeable, well sustained flows.

Additionally, during the winter, when reservoir and snowpack measurements indicate surplus flows are likely to occur (in excess of the reservoir storage capacity), releases are made to provide for storage space for flood control.

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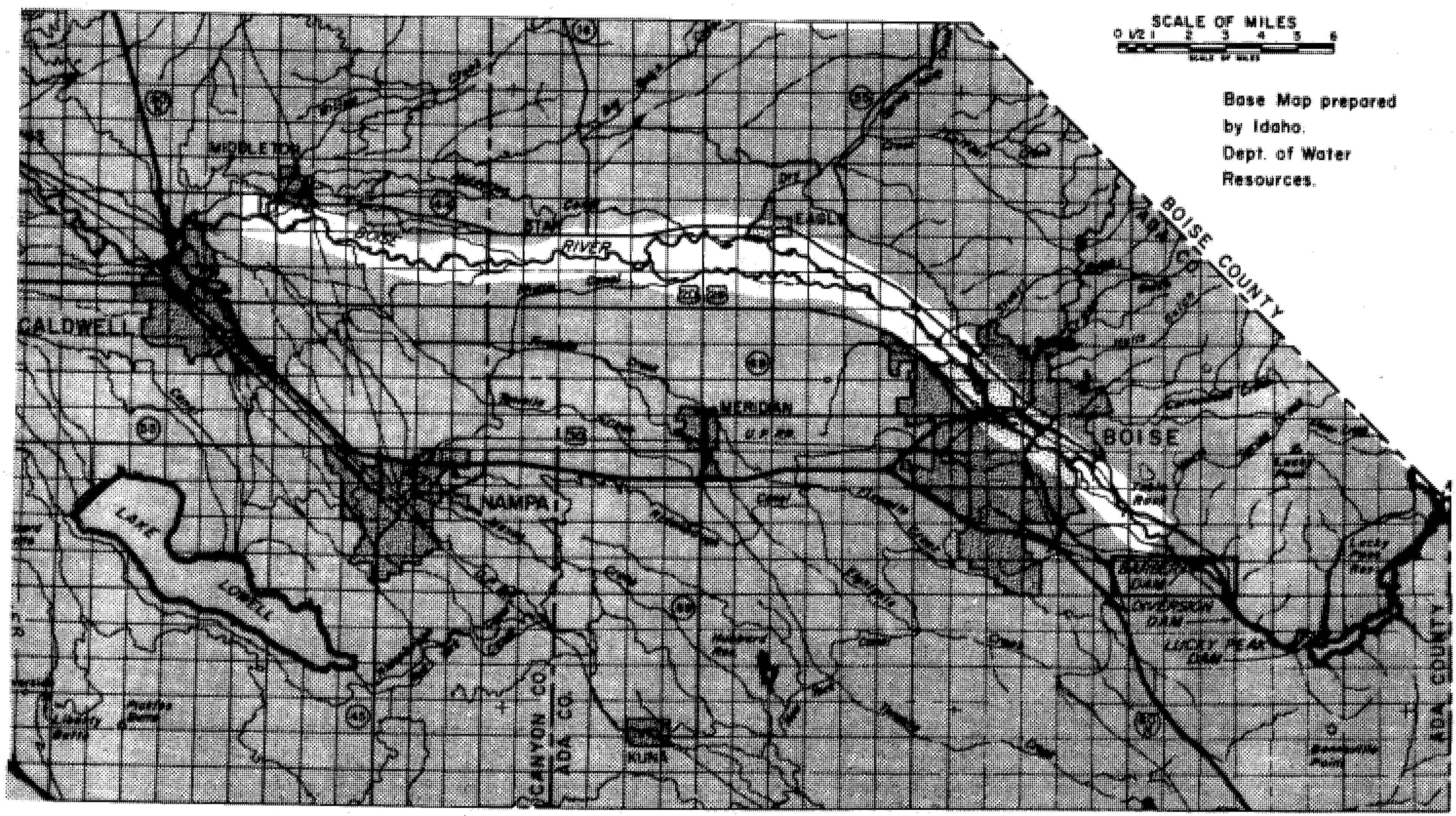


BOISE RIVER LOCATION

A-26

Figure A-4

It can be seen from the above discussions that in the upstream portion of the study area between Boise and Lucky Peak, flows are generally high during the irrigation season, a time when air and water temperatures are suitable for instream recreation. Activities which may be less dependent on temperature (hunting, some types of fishing), however, may be possible year-round, with proper flow conditions.

Flow duration curves for the period October 1st to March 31st and from April 1st to September 30th are included as Figures A-5 and A-6. The records for the Boise River near Boise are for the outfall of the Lucky Peak Dam while Boise River at Boise is the USGS gage near downtown Boise.

Additional background information was obtained from various members of the U.S. Fish and Wildlife Service, Ada Council of Governments, the Water Resources Division, U.S. Geological Survey, Bureau of Outdoor Recreation, U.S. Army Corps of Engineers, Walla Walla District, and from several publications on recreation in the Boise River.

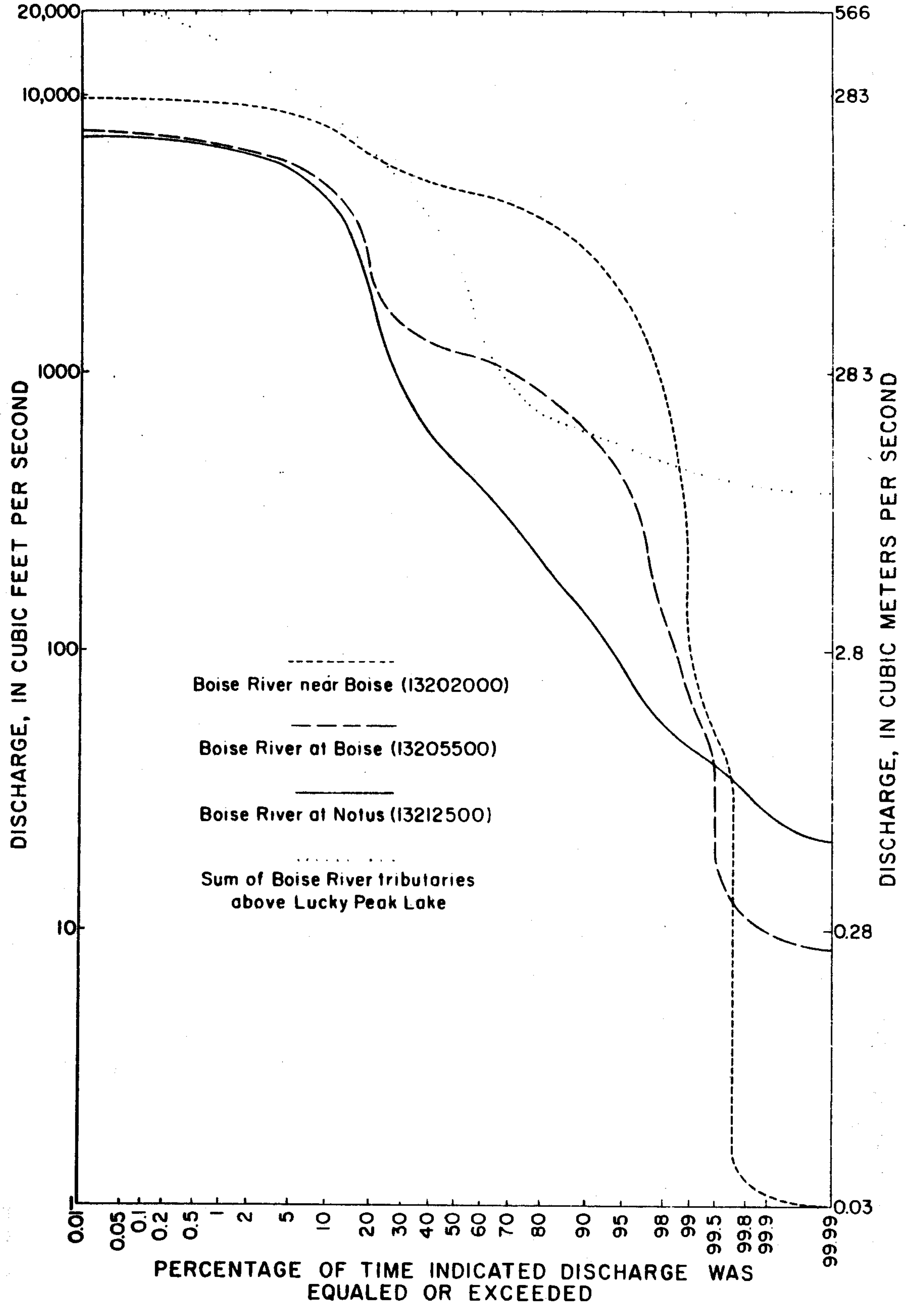
Cross-section data were obtained from the U.S. Fish and Wildlife Service, Division of River Basin Studies, Boise, Idaho. Much of this information was used in evaluating the recreational potential at different discharges of the Boise River.

4.6.2 Field Study on the Boise River

Field studies were conducted on the Boise River from July 29th to August 2, 1976. Flows which were measured were between 930 and 960 cfs in the vicinity of Boise and approximately 240 cfs near Middleton.

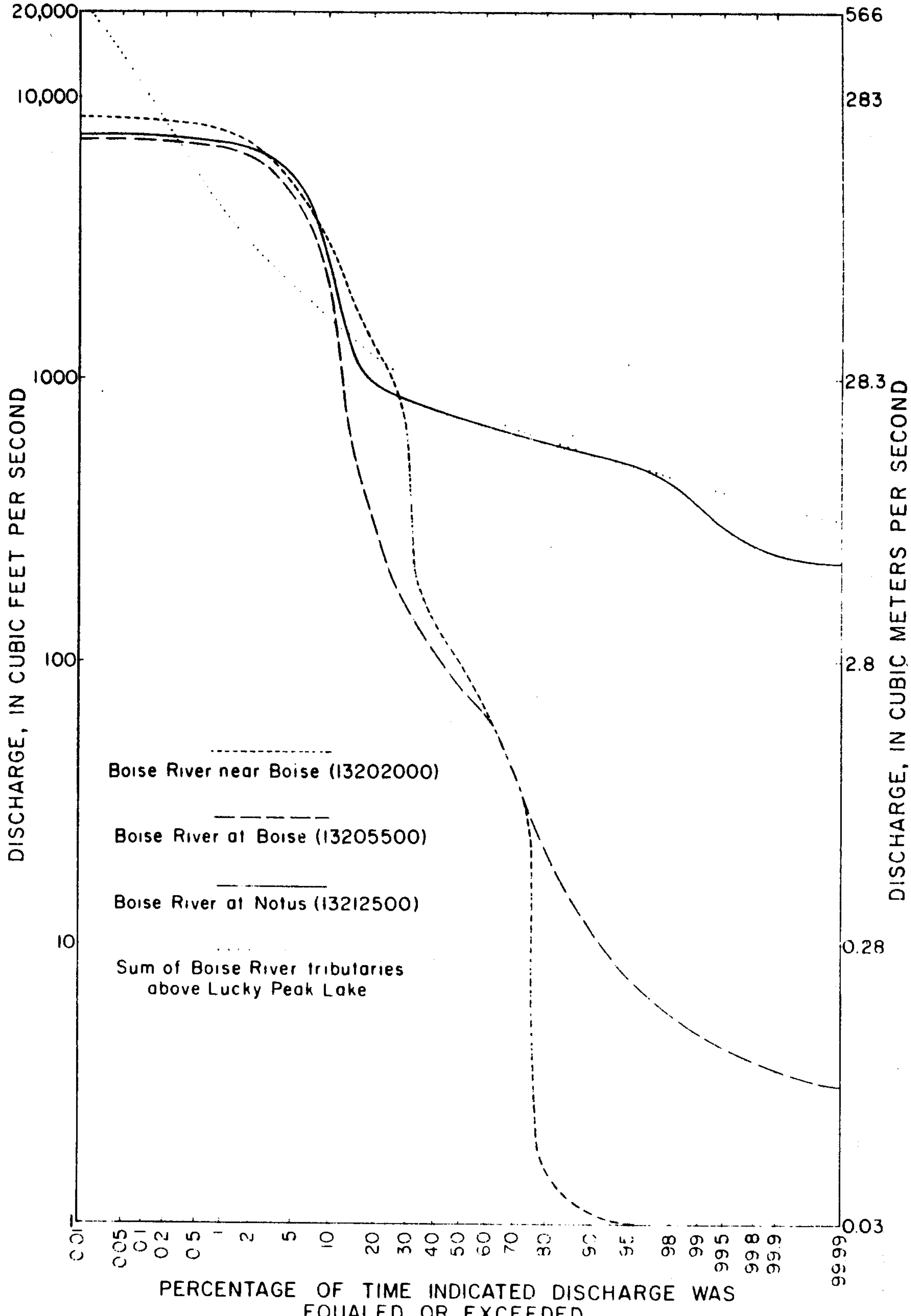
Large scale aerial photography, provided by the Ada Council of Governments, was used in classifying the river into reaches of similar characteristics. The classification scheme which was used was taken from Culbertson, Brice, and Young (See Section 2). Fifteen cross-sections were selected and later run during the course of the field studies. The locations of the cross-sections are indicated on Figure A-7. At four locations, data were available for flows higher and lower than those which were encountered in the field. These sections were: J-1, J-4, J-6, and the USGS gage station near the Capitol Boulevard Bridge. Sections J-4 and J-6 were located at the site of profiles LBR #1 and #3 which were part of a U.S. Fish and Wildlife Service study on the Boise River.

The remaining 11 cross-sections were located at sites which were typical of a reach of geomorphic similarity, were at major access or egress areas, or were at a restricted section (such as an area of rapids or a dam).



Flow Duration Curves: Boise River April 1-September 30
(USGS, 1974)

Figure A-5



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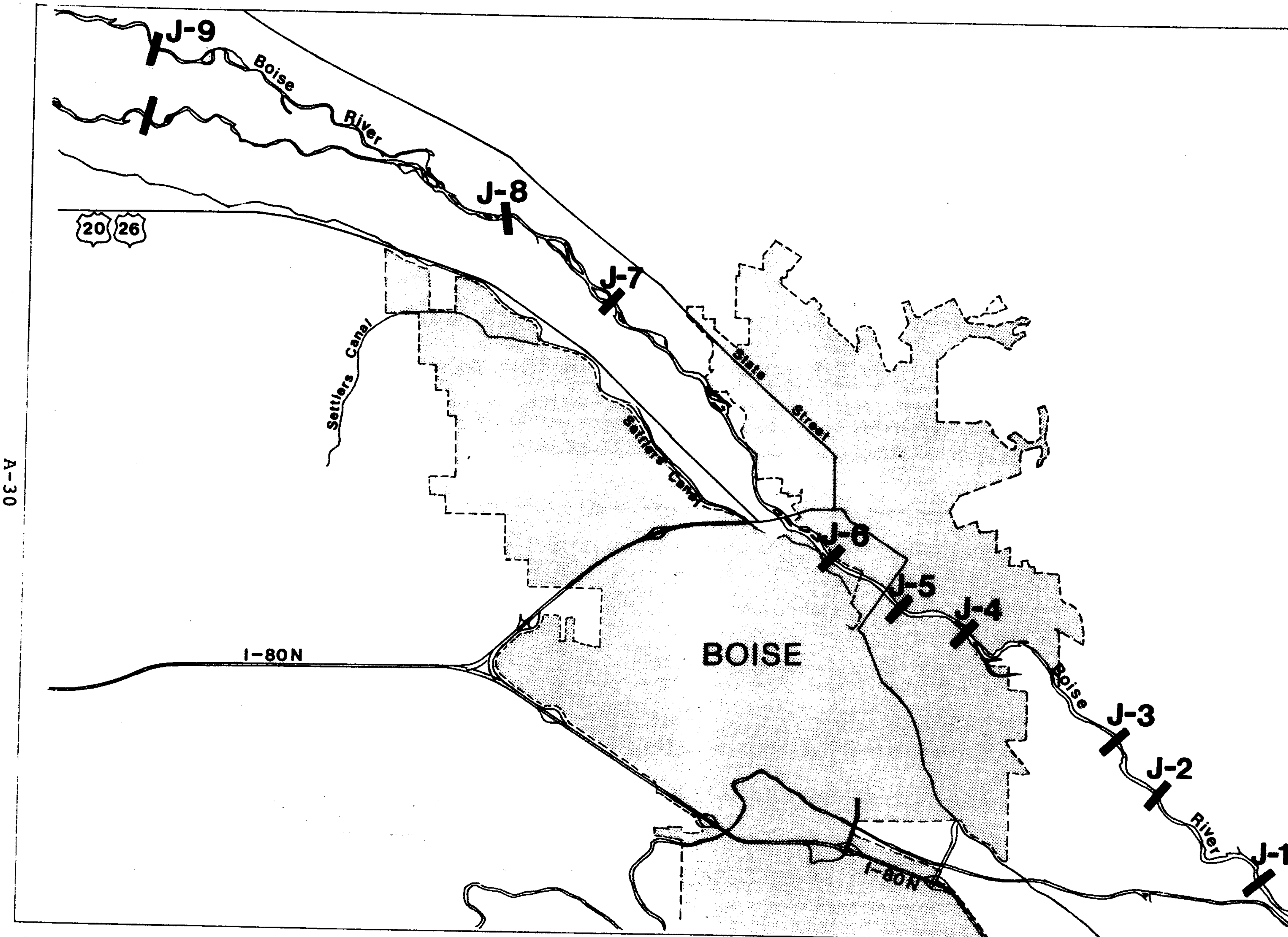
Flow Duration Curves: Boise River October 1 - May 31
(USGS, 1974)

Figure A-6



Cross-Section Locations: Boise River

Figure A-7

At each of the fifteen locations, complete cross-sectional data (including width, depth, velocity, and temperature) were obtained in the field. Width, depth, and velocity measurements were made by using standard techniques of the U.S Geological Survey.

Data obtained for all the sections which were surveyed in July and August, 1976, and those from other sources were examined to determine the suitability of various flows for different types of recreation. The recreational standards which were applied to the cross-sectional data are those presented in Section II of the main text.

Two levels of data analysis were possible for the sections surveyed on the Boise River. For the sections described earlier, where data were available for a number of discharges, predictions as to the minimum flow necessary for different types of recreation were possible.

For the remainder of the cross-sections, the only data which were available for a particular location were those obtained in the field study. An example is presented where data from one of these sections was extrapolated to higher and lower flow levels and minimum flows for different recreational activities were determined by using surveyed channel geometry and Manning's Equation.

4.6.3 Recreation Analysis - Known Stage-Discharge

Data from the four sections which were described initially were used to make plots of discharge (in cfs) versus usable width for a recreational activity. Usable width was determined by examining surveyed cross-sectional information and noting the width of the section which met the velocity, width, and depth requirements for a particular recreational activity.

Initially, this information was summarized in tabular form from which data were extracted and plotted. The data are shown in Table A-3.

Waterskiing and sailing are not practicable at any of the flows which were examined at the various cross-section locations.

After the data were tabulated and plotted, it was possible to evaluate minimum flows for different recreational activities on a reach-by-reach basis. Each of the following sections' geometry characterizes reaches of the river extending approximately one quarter mile upstream and downstream from the cross-section location. Each of the sections is briefly described below as to its suitability for different activities at the flows for which data were available. Results from these four representative sections were then used to characterize conditions between Barber Dam and Boise.

TABLE A-3

RECREATION ANALYSIS - BOISE RIVER

Discharge	Width Feet	Avg. Depth Feet	Avg. Velocity Feet/Sec.	WADING Usage Width Feet	%	SWIMMING Usage Width Feet	%	TUBING Usage Width Feet	%	FLATWATER CANOEING Usage Width Feet	%	ROWING Usage Width Feet	%	LOW-POWER BOATING Usage Width Feet	%
Diversion Dam and J-1															
75	90.2	1.84	.49	90	100%	0	0	0	0	71	95%	78	95%	42	46%
138	93.1	1.94	.66	93	100%	0	0	0	0	83.3	89%	73.5	79%	54	58%
149	93.1	2.07	.75	93	100%	0	0	0	0	83.4	89%	73.5	79%	54	58%
942	170	2.5	2.2	170	100%	75	44%	115	67	161	95%	161	95%	126	74%
LBR#1 and J-4															
75	160*	.34	.76	140	88%	0	0	0	0	0	0	0	0	0	0
82	192*	.37	1.7	140	73%	0	0	0	0	0	0	0	0	0	0
155	184*	.44	2.25	140	76%	0	0	0	0	50	27%	0	0	0	0
266	240*	.61	2.03	240	100%	0	0	0	0	130	54%	0	0	0	0
502	250*	.8	1.9	250	100%	0	0	100	40%	150	60%	100	40%	0	0
995	232	1.2	2.7	232	100%	0	0	134	57%	170	73%	150	65%	34	15%
Boise River at Boise															
158.2	127	.853	1.41	127	100%	0	0	25	20%	112	88%	45	35%	0	0
322.9	136	1.17	2.02	136	100%	0	0	105	77%	114	84%	104	76%	5	4%

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Recreation and Instream Flow. Volume 2. River Evaluation Manual

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Prepared for

Bureau of Outdoor Recreation, Washington, D C

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Vol. 2

River Evaluation Manual

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16. Abstracts

Very few provisions for the controlled releases of water from dams and other such water resources projects to increase instream flow specifically for water-based recreation exist in the United States. The few projects that provide such releases are discussed and analyzed. These projects are more common in the humid East; in the drier West such releases are mainly for contaminant dilution and support of fish and wildlife.

Such questions are dealt with as: how much flow is required for recreation, how justified are such flows compared to other needs, and what legal and institutional obstacles exist.

The conclusions of the document are: while instream flows for recreational purposes cannot be guaranteed in a specific case, a recreational planner can measure the amount of water required, its value, and the obstructions to be encountered.

An annotated bibliography is included.

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Water rights
Water law
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PREFACE

This document is Volume II of the report Recreation and Instream Flow Requirements, produced for the Bureau of Outdoor Recreation under BOR Contract 5-14-07-7. It represents a distillation of those findings and is intended to provide planners and other potential users with a practical means of applying them to a specific river evaluation problem. The emphasis is on physical relationships between discharge and the potential for recreation in the riverine environment.

The manual presents methods for using basic principles of hydrology to make predictions of the impact of changes in flow on the basic physical parameters affecting recreation. These methods combine theoretical calculations with field observations. The users of the manual will not become expert hydrologists, but they should be able to make judgments about recreational potential in a river at different levels of discharge.

Economic, legal, and institutional factors concerning instream flows are addressed in Volume I.

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1.0 INTRODUCTION

1.1 Background

The demand for water-based recreation has grown substantially in the past several decades. It has, in fact, grown faster than population. Generically, this has to do with the increase, since the turn of the century, in the amount of leisure time and disposable income available to individuals. Additionally, many water related activities, such as white water canoeing, have undergone growth of boom proportions. This growth has affected both lake and stream-based activities. There are, however, inherent differences between the two types of activities which must be recognized.

Lake activities may be viewed as activity oriented. That is to say that the activity may be successfully and pleasureably carried out on virtually any relatively large body of water. More to the point, lake environments can, and have been, provided by human works (dams). Thus, it is not a supply-limited resource in any immediate sense.

Stream-based activities, on the other hand, are resource oriented. The availability of the activity and its quality may depend on the particular stream in which it occurs. Additionally, free-flowing water is seldom created by human works; indeed the dam that creates a new lake almost always inundates a stretch of free-flowing stream. Thus, instream recreation depends upon a supply-limited, and shrinking, resource. To compound this difficulty, there is intense competition for the waters in a free-flowing stream.

The assessment of such a set of activities is necessary if they are to be preserved. In the past, water has been viewed as a consumable resource with little or no supply limit. This is no longer the case. The need now arises to treat instream water and instream recreation as a nonrenewable resource and to enter into the competition for what free-flowing water remains.

However, before trade-off analysis can begin, the range of possible activities must be determined. Different riverine recreational activities impose different physical requirements.

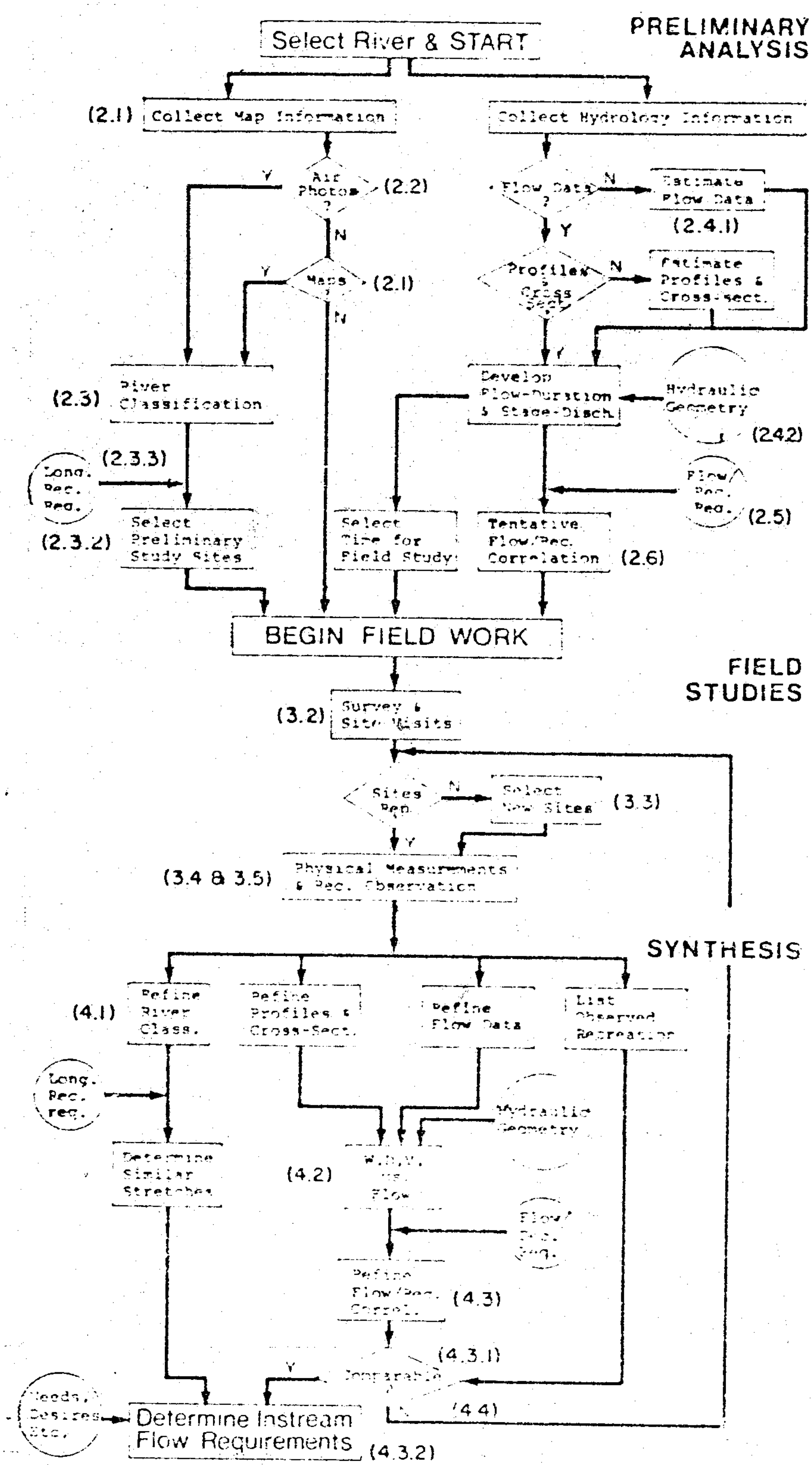
1.2 Scope of the Manual

This Manual serves as a practical guide to the evaluation of the physical relationships between recreational potential and flow level (discharge) on a river. While numerous factors impact on recreational potential, those most closely affected by variations in flow at a given place on a river are width, depth, and velocity. The method presented here concentrates upon relating changes in these parameters, whether observed or predicted, to recreational potential. Figure 1 is a flow chart of this procedure. The basic approach is synthetic in nature to the extent possible. That is, it relies upon preliminary analysis of data, on limited field studies, and on post-field analysis to yield predictions about conditions on the river, in relation to their effect on recreational opportunities. It does not require access to data on or observation of actual recreational experiences, though these can be helpful when they can be provided. It will probably in many cases require field measurements at more than a single flow, but it does not depend upon the availability of controlled releases from a dam or on measurements at a large number of discrete flows. Should an investigator feel, however, that controlled release experiments would be of value, Appendix A provides guidance on carrying them out. These approaches might be of particular use on remote, controlled streams where a second field visit is not feasible.

Section 2, Preliminary Analysis, describes the steps to be taken at the outset of the study of a specified river. This includes: the acquisition and use of maps and aerial photographs; the classification of the reaches of interest according to basic morphological form; the collection and analysis of hydrological data; the specification of criteria governing various types of flow-related riverine recreation; the correlation of the above data to permit tentative predictions as to discharge-recreation relationships on specific stretches or at specific sites on the river; and, finally, the applicability of available data on actual recreational usage of the area. The output of this entire process of preliminary analysis is the preliminary selection of sites for field study and the identification of the optimum expected flow under which to conduct the field study part of the effort.

Section 3, Field Studies, presents the tasks to be accomplished in conducting direct analysis of actual conditions on the river. Topics covered include: selection of dates for the visit, in relation to the previously identified desired flow; reconnaissance of the reach of interest to check stretch and site locations against those derived from map and photo studies; final selection of observation site; physical measurements; and observation of on-going recreation, if any. The field study process provides specific physical information on sites of interest at a given flow and provides the basis for later predictions as to changes in site conditions with variations in discharge.

Section 4, Synthesis, involves the development of predictions as to recreational potential as a function of discharge. The steps required to accomplish this include: analysis of data gathered during the field studies; correlation of the physical measurements and observations with hydrological data; development of rough predictions of changes in physical parameters such as width, depth, or velocity with a variation in flow; pre-



Flow Chart
RIVER STUDY PROCEDURE

Note: Bracketed Figures Refer to

diction of recreation potential at non-observed flow; and the checking of these predictions by a limited set of observations at flows different from that observed at the time of the primary field study. At the conclusion of this portion of the effort it should be possible to relate recreation potential to flow in the portions of the river that have been studied and, thus, to permit specification of flows for different recreational pursuits. This information, in conjunction with analysis of the recreational "market" or demand, of the available supply, and of the value associated with various recreational activities, will provide the basis for developing recommendations about the preservation or provision of instream flows for recreation.

1.3 Considerations for Planners and Policymakers

The following situations cover a broad range of possiblities. They share one common and important element, however. In each case, future recreational potential at some recommended flow may be more important than existing recreational activity on the river. This is as true for the non-regulated as for the regulated cases. While ultimate judgments and decisions must rest on a full evaluation of the social and economic benefits attributable to provision of flow-dependent and recreational opportunities, the initial determination of the requisite discharge depends upon an evaluation of the physical capacity of the river to support recreation and to meet the necessary flow related recreation criteria at specified flow.

1.3.1 Preservation

In some cases, the question may be one of preserving an existing natural flow. This would be important in considering the designation of a river under the provisions of the Wild and Scenic Rivers Act, for example. It could also be important in evaluating the long term impact of a proposed impoundment or large diversion which would radically affect natural flow conditions.

1.3.2 New or Proposed Designs

It may be possible to use a proposed new structure to provide instream recreational benefits greater than those found under existing conditions. This can be accomplished by releases to support recreation which would not be possible lacking regulation of the stream. The Duck River and Bear Creek projects of the Tennessee Valley Authority have such capabilities built in. The additional benefits from augmented instream flow (canoeing and fishery improvement, for example) serve the dual function of helping to justify the project economically and of mitigating unfavorable environmental effects of an impoundment.

1.3.3 Retention and Timed Release

Recreational oportunities on a stream may be enhanced by temporary retention and timed release of water from flood control structures. This is sometimes done on flood control dams which were initially designed to operate in a pass-through mode, with retention only to prevent imminent flood hazard. Modified scheduling of retention and release at such installations can provide an extended white water season and can improve fish habitat and, thereby, fishing opportunity.

1.3.4 Recapture

Even where existing flows are highly regulated and discharges governed by other needs, such as power generation and irrigation, it may be possible to recapture some flow for recreational purposes. This could take the form of acquisition of storage rights behind an irrigation dam as has been done by the Idaho Fish and Game Department at Lucky Peak Dam on the Boise River. It might take the form of acquisition of water rights by State agencies through the appropriation process to maintain instream values. A start was made in this direction by the State of Idaho at Malad Canyon where a flow was "appropriated", not for the normal diversion and consumptive use, but to maintain the aesthetic qualities of a river inside a state park. It could take the form of an alteration of generating schedules and resultant discharges at power dams. Licensing or relicensing of power projects operated under Federal Power Commission regulations may afford an opportunity to insure that impacts on instream recreation below the structure be provided for in release requirements.

2.0 PRELIMINARY ANALYSIS

The objective of the preliminary analysis phase of river evaluation is to gather as much information as possible prior to engaging in field work. The purpose is to develop an understanding of the river's morphology and hydrology and to relate these to recreational potential. This permits the tentative pre-selection of specific stretches and sites to be studied. It permits conduct of the field investigation with a maximum of efficiency. And it provides a data base which will be useful in the synthesis phase which follows the field experiments and which ultimately leads to development of firm estimates of recreational potential at specific levels of discharge.

The basic tools employed are maps, aerial photographs, published hydrological data and, when available, data on existing recreational use of the river. Maps and aerial photographs assist in the early identification of areas of obvious recreational potential. Examples would be rapids suitable for white water canoeing or rafting and areas of numerous point bars and mid-channel bars which may be suitable for boating access, wading, or camping. Close examination of aerial photos often permits discovery of physical limiting factors such as dams, waterfalls, large boulders, fallen trees, or other obstructions and hazards.

Maps and aerial photographs are also useful for classification of the river into stretches according to channel morphology. Morphologically similar reaches will tend to exhibit the same general reactions to variations in discharge and will tend to afford similar recreational opportunities at appropriate levels of flow. Thus, the use of these aids permits developing a rough estimate of the kinds of recreation that may be possible and the places where they may occur. Based on such judgments it is possible to accomplish preliminary site selection for the field work taking into account both the nature of the river and the kinds of recreation potential that may be anticipated.

It is also of great importance to develop a good understanding of the physical parameters which describe a stream's regimen and make possible some predictions as to future conditions as flow is varied. This requires consideration of width, depth, velocity, volume (w x d x v), composition of bottom materials, and channel morphology. Collection and analysis of hydrological data permit application of principles defining generic relationships between the hydrology and geomorpholgy of the river. Such relationships provide a basis for development of preliminary, rough predictions of river conditions and associated recreational potential under different levels of discharge. When published data are lacking or insufficient, there are other techniques which can be employed to develop this kind of information.

Although there are broad areas of overlap, different recreational activities impose their own sets of physical requirements on the river. The most important of these for the purposes of river evaluation are limiting requirements (minima or maxima) with respect to width, depth, and velocity. Correlation of these requirements with hydrological and morphological data provides the basis for estimation of the range of possible recreational activities on the river at various levels of discharge.

When there is available a body of information on existing use of the river, such data can be helpful in evaluating the potential under known conditions of flow. Such information is not essential to the evaluation process, but it does provide benchmarks against which predictions can be checked. Analysis of such data may also permit formation of tentative judgments as to the impact on current recreational use of an increase or decrease of flow at specific times of the year.

2.1 Map Studies

There are many types of map resources which are of use in instream flow studies: topographic maps (various scales), geologic maps (surficial and bedrock), state and local highway maps, recreation maps (canoeing, hiking, boat and fishing access areas, parks, etc.), soils maps, U.S. Forest Service Maps, Bureau of Land Management Maps, Flood Prone Area Maps (USGS, SCS), and maps indicating locations of irrigation ditches, drains, and diversions.

Depending on the extent of mapping in areas through which the study river flows, USGS 7 1/2 -minute or 15-minute quadrangle sheets may be available. These should be obtained for the complete reach under study, and upstream or downstream far enough to encompass any significant flow control devices.

2.1.1 Topographic Maps

The USGS topographic maps are useful for determining drainage area, stream gradient, and general physical characteristics of the stream and its floodplain. The drainage area of a stream or river is the horizontal projection of the drainage basin to the most downstream point interest.

The initial step in drainage area calculations is to outline the drainage basin. This is done by carefully noting drainage divides (often topographic highs or ridgelines). A river's drainage basin includes all the surrounding area that drains toward it and supplies it with water. The drainage divides should be extended or contracted until all points within the divides satisfy this condition.

Once the drainage basin has been drawn, the drainage area is taken by measuring the area of a horizontal projection of the drainage basin using a planimeter, grid squares or other techniques. The area is commonly expressed in square miles. However, when using drainage area to aid in calculating a figure such as annual flow, it is expressed in square feet.

After the drainage basin has been outlined, streams contained within the basin should be indicated. This will result in a drainage net or network being established for a particular basin. Considerable research has been carried out by workers on relating drainage network geometry to various geographical and hydrologic factors.

In very general terms the following drainage patterns indicate different types of bedrock influence (See Figure 2):

Dendritic patterns (tree-like shape)-These are quite common and often reflect a fairly uniform resistance to erosion and a lack of any structural control.

Trellis patterns (systems of sub-parallel to parallel streams) -Patterns such as this generally reflect bedrock control, such as folding. Fault control may also result in this pattern.

Rectangular patterns (streams and tributaries show right angle bends)-These are often developed in areas of fault or joint controlled features.

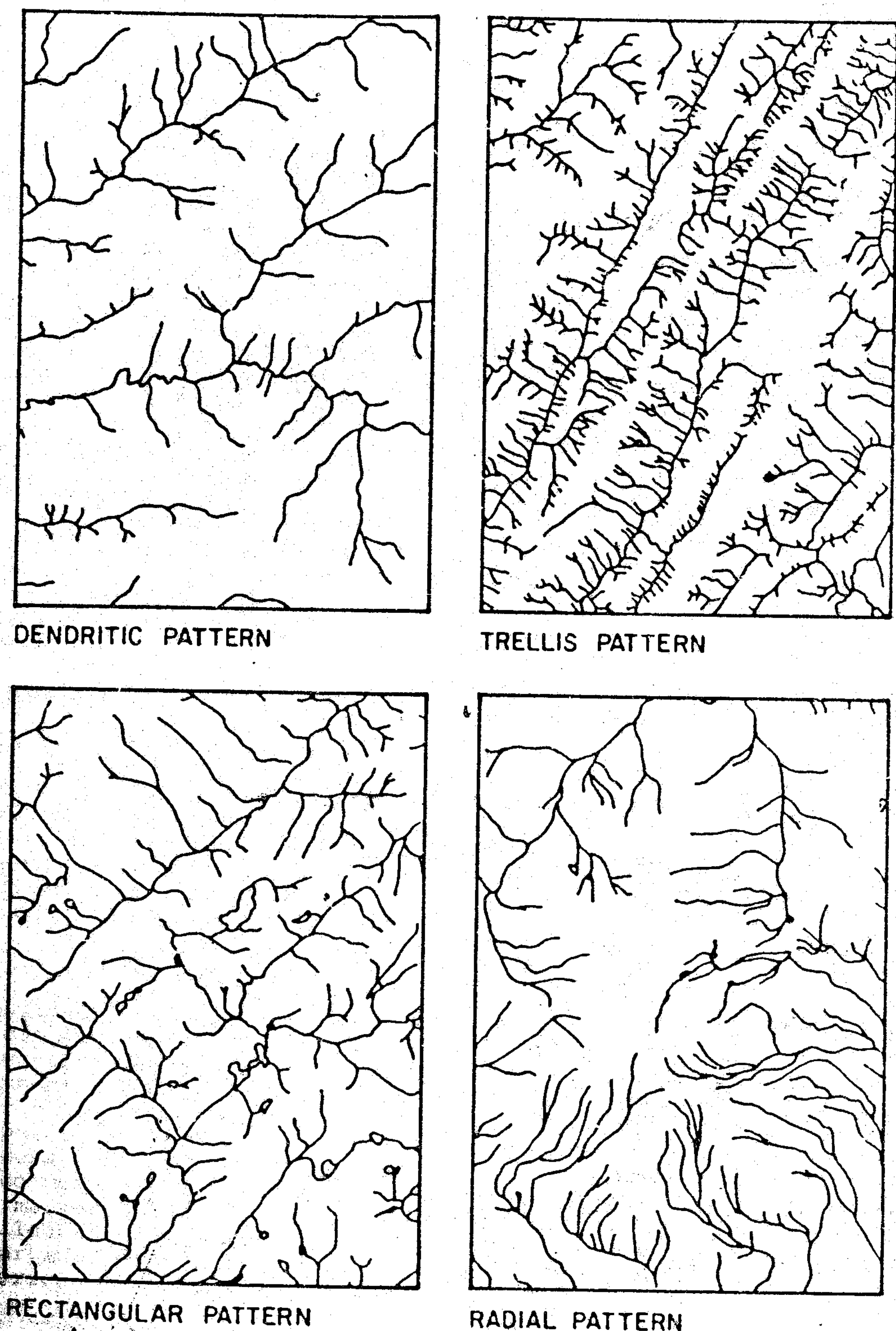
Radial patterns-These patterns have streams which diverge from a central elevated tract. They commonly develop on domes, volcanic cones and other isolated conical hills.

These patterns are general in nature. However, when comparing drainage basins, these generalizations may indicate first level similarities or dissimilarities between basins which can be further explored using aerial photography and stream classification.

River gradient approximations can also be made from USGS quadrangle maps. Briefly, this is done as follows:

1. Delineating the stretch of interest,
2. Noting the elevations at the upstream and downstream ends of the stretch,
3. Measuring the map distance between these two points along the river's path,
4. Setting up the ratio, elevation difference/river distance (usually presented as feet/mile).

The result (Step 4) is the average gradient along a given stretch of river.



TYPES OF DRAINAGE PATTERNS
AFTER THORNBURY, 1969

Figure 2

Of more significance is maximum gradient which consists of measurements taken where the greatest elevation change takes place over the shortest horizontal distance. The advantage of determining maximum gradient is apparent when it is realized that a gradient of, for example, 20 feet per mile may consist of two ten foot waterfalls in one river and on another river may be an "even" gradient with no large steps.

In a situation where hydrologic information is not sufficient on a particular river, gradient calculations for that river may be used as one method by which this river is compared to another for which more complete hydrologic records exist (by means of gaging). If the gradient and other parameters compare closely enough, it may be possible to use data from the gaged river to extend or predict hydrologic data for the ungaged river.

2.1.2 Geologic Quadrangle Maps

When comparing gaged rivers to ungaged rivers, the geologic features of the two areas must be considered. Geologic characteristics such as jointing, fracturing, intensity of weathering, etc., should be compared when rivers are to be compared. Information about these properties is contained on surficial and bedrock geologic maps. The interpretation of these maps and their possible effects on river patterns should be done by a trained geologist, as many of the above-mentioned properties may not be obvious to the untrained eye.

2.1.3 Highway Maps

State and local highway maps are of use in determining potential and existing access areas. These maps may indicate ownership patterns, especially in terms of publicly owned areas. In areas where topographic mapping has not been done recently, the roads and other features on maps such as these will prove useful in planning field studies.

2.1.4 Recreation Maps

Published recreation maps will help to establish types of recreation which are currently taking place, and, depending on the publication, may indicate user numbers, parking spaces, boat launching facility capacities, etc. Private outfitters' guides for rafting, canoeing, and kayaking generally describe the most popular river routes during the recreation season and include access information, travel times, and, in many cases, recommended flows either in cfs or related to a gaging station or marker. If no other information of this nature has been collected by the party investigating a particular river, a good starting point for contacts and guidebook information is the American Canoe Association, Denver, Colorado.

2.1.5 Miscellaneous Maps

There are a number of other maps which may be available from different state and Federal agencies which would prove to be useful. These would include SCS Flood Prone Area Maps and Soils Maps, US Forest Service Maps, Bureau of Land Management maps and so on. Use of these maps in a particular area is dependent on their availability and applicability to a particular study reach.

Like many other tools used in instream flow investigations, maps have limitations which must be recognized. In all probability the course of a river or stream drawn on a map represents a flow condition which may not correspond with flow conditions shown on other maps. The configurations present on the map may be dated, and items, like newly built access roads or dams, may not be included.

The map studies, however, give the investigator the following tools for instream flow studies:

1. The drainage area of the stretch being studied,

2. The general channel pattern of the stream and its tributaries,

3. The average stream gradient and areas of maximum gradient,

4. Information on possible points of access,

5. Preliminary information on the most popular forms of recreation in the stream, if recreation maps are found.

These preliminary data can be considerably refined by study of aerial photographs.

2.2 Aerial Photography

Aerial photographic analysis is perhaps the most efficient method of determining river morphological patterns, classifying those patterns, and using this classification to make preliminary predictions as to a river's recreational potential. After the initial steps, much of the same data can be used to locate specific study sites and transects along the river.

There are many types of remote imagery available for use in evaluating recreation potential along a river's length. In terms of ease of use and accessibility to the user, standard black and white stereo air photos offer adequate coverage.

Aerial photography and other remote sensing is available from many sources. The office of Biological Services, U.S. Fish and Wildlife Service, has in print an atlas of existing high altitude coverage, available for library use only.

Additionally, a comprehensive catalog of most all aerial photos is to be published by the USGS, National Cartographic Information Center.

Many of the photographs indexed in these publications are from the following Federal and state agencies:

Federal

Dept. of Agriculture
- Soil Conservation Service
- Forest Service
- Agricultural Soil Stabilization Service

Dept. of the Army
- Corps of Engineers

Dept. of the Interior
- Bureau of Reclamation
- Fish and Wildlife Service
- Bureau of Outdoor Recreation
- Geological Survey
- EROS Data Facility/S. Dakota

State

- State Transportation or Highway Departments
- Departments of Natural Resources and Environmental Conservation
- State Geological Surveys
- Universities and Colleges

Private

- Private firms located within the region
- Universities and Colleges

This list represents a starting point for locating the air photos.

When looking for air photos the following types may be of particular use.

1. Relatively low level vertical photography (scale 1"=1320', 1"=600')

2. Stereo coverage is best for vegetation analysis, height determinations and a detailed topographic analysis.

3. Non-stereo coverage is sufficient for river classification.

4. When available, photos taken at less than bank full conditions on the river are most useful.

5. Ideally, photo coverage at different flows should be available. The approximate flow (cfs or %AAF - see Table 1) can be obtained from comparing the flight date on the photos with discharge records for that date from the nearest gaging station.

6. Low-level obliques are useful for general overviews, access determination, and bank condition surveys. These may be taken by the investigators themselves.

Other types of remote sensing such as LANDSAT, Skylab, and IR coverage are generally available from the EROS Data Center, Sioux Falls, SD. This type of photography is more expensive than standard black and white aerial photography, but coverage does exist for virtually all areas and at different times of the year. The usefulness of these types of imagery is that frequent flights are made, so that photos should be available for many flow levels.

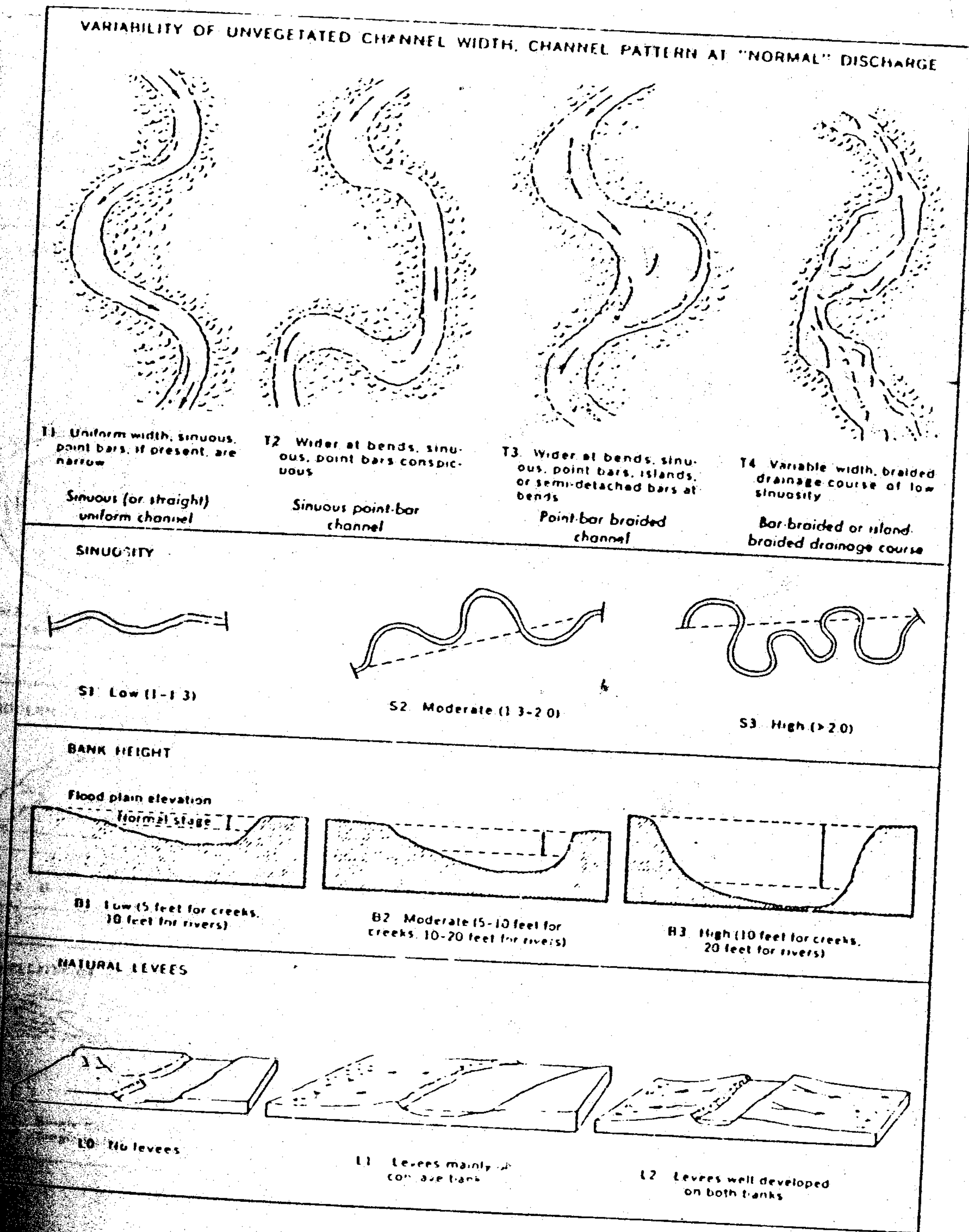
A study prepared for the Bureau of Outdoor Recreation (Contract 4-14-07-03) on the "Recreational Analysis of River Basins - Remote Sensing Applications" contains techniques for using color-enhanced LANDSAT-1 imagery for land use classification and an analysis of the effects of development on the Russian River. The usefulness of LANDSAT imagery is that it is available for a particular area over a wide range of flow conditions.

2.3 Classification and Preliminary Site Selection

2.3.1 The Classification System

Once the proper air photos and maps have been obtained, stretches of the river exhibiting similar channel patterns may be classified. The classification which is used (Culbertson *et al.*, 1967) is based on channel patterns and variability of width at near normal discharge. In practice, classification is carried out for the stage represented on the best available photos. Only extremely high or extremely low flows will affect the classification.

When this classification system is used, a channel is initially placed in one or another of four channel pattern types, as show in the first section of Figure 3. These types are:



(CULBERTSON et al., 1967)

Stream Channel Characteristics

Figure 3

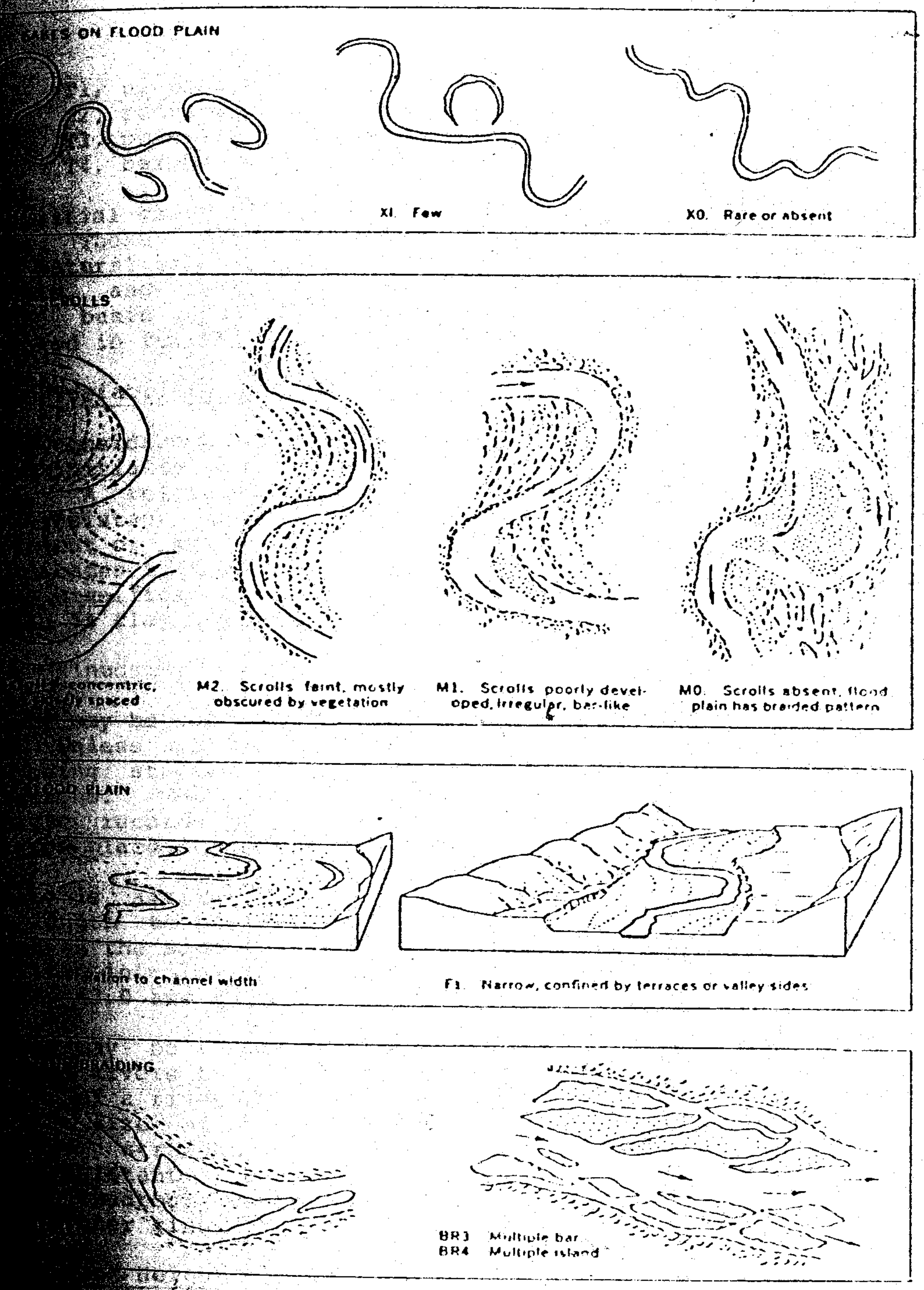

ON FLOOD PLAIN
X1. Few
X0. Rare or absent
M2. Scrolls faint, mostly obscured by vegetation
M1. Scrolls poorly developed, irregular, bar-like
M0. Scrolls absent, flood plain has braided pattern
F1. Narrow, confined by terraces or valley sides
BR3 Multiple bar
BR4 Multiple island

Figure 3

T1, sinuous or straight uniform channel
T2, sinuous point-bar channel
T3, point-bar braided channel
T4, bar-braided or island-braided drainage course

These initial categories are supplemented by other channel descriptors. These include: width variation, sinuosity, bank height, natural levees, oxbow lakes, meander scrolls, modern floodplain, and complexity of braiding. In the following sections basic channel patterns are discussed and are illustrated in further sections of Figure 3.

2.3.1.1 Variability of Width

Width is considered as "unvegetated channel width". This is determined initially from aerial photography and is later field checked. A relatively uniform channel width often indicates erosion-resistant banks, which may result from suitably high clay content or may be due to a thick vegetation cover. Recent work indicates that bank materials which have greater than 5% clay are significantly more resistant to erosion than those with less than 5% clay (Knighton, 1974).

2.3.1.2 Sinuosity

Sinuosity may be calculated from map work or from aerial photography. Unless air photo mosaics are available for the river reach being studied, topographic maps are best for sinuosity calculations. The date of mapping should be compared with hydrologic records to determine if any extreme discharge events have taken place subsequent to mapping.

Sinuosity is airline calculated by setting up a ratio of the river length to the distance. Both distances are commonly measured in the same units. The sinuosity classes in Figure 3 are divided into low (1.0 - 1.3), moderate (1.3 - 2.0), and high sinuosity (2.0 and above).

Sinuosity may be used in general terms to compare segments of individual rivers to one another or river to another river. The sinuosity of a river is the end result of the interplay of gradient, size of bed-load material, and stream energy. Generally, straight stream courses indicate areas of erosion-resistant banks, whether caused by cohesive bank materials, bedrock controlled banks, or vegetatively stabilized banks. Higher sinuosity often indicates a shallow, wide stream.

2.3.1.3 Bank Height

This is calculated by measuring the distance between the water surface at normal stage and the surface of the modern flood plain. This distance can be estimated by comparison with objects of known height (cars, houses, etc.), or determined relatively accurately by using stereo air photo coverage of the banks and a parallax bar. The modern flood plain is the lowest flat surface along the river, and can generally be identified on aerial photos by features such as scrolls, oxbow lakes, meander scars, etc. High banks suggest either that the river is actively degrading or that flood flows which overlap the banks are relatively infrequent. Low bank height often indicates frequent flooding, or lack of sediment cohesiveness due to a paucity of clay in the sediments or a lack of bank vegetation.

2.3.1.4 Natural Levees

These are often best identified on cross-sections which have been surveyed across the flood plain, although moderately well developed levees may be identified from air photos. The significance of the presence of natural levees is that they suggest that a lateral migration of the channel is not likely, unless flow events occur which overtop or breach the levees.

2.3.1.5 Oxbow Lakes and Meander Scrolls

The shapes of these morphologic features are included in the classification figure. The presence of features such as these indicate lateral migration of the channel. High flows, at or near bank-full conditions are usually responsible for scroll formation so that areas with large numbers of scrolls may be expected to experience frequent at or near bank-full conditions.

2.3.1.6 Braiding

Bars or islands that divide the flow in a channel are the most important elements of the braided pattern. Variations in the size, the number, and the distribution of these gives rise to many diverse kinds of braiding, of which two major kinds are illustrated in Figure 3. The point-bar braided channel is braided mostly at bends, and most of the islands or bars have apparently originated from point-bar deposits; it is transitional between a braided and an unbraided channel. Where bars or islands are more numerous or more consistently distributed, the term "braided drainage course" is appropriate. According to its degree of complexity, the braiding of a drainage course can be described as single-bar (or island) or multiple-bar (or island) braiding. The term single implies that the braiding at a typical cross-section is due to a single bar (or island) rather than to two or more bars (or islands). Vegetal cover distinguishes an island from a bar, and islands are likely to be more permanent than bars. As a river course becomes more braided, it is very likely to become wider and less sinuous, especially if the braiding is due to the growth of channel bars or islands. However, a low sinuostiy of the drainage course is not necessarily accompanied by a low sinuosity of the individual channels (sometimes called anabranches) between islands and bars. The channels of glacial outwash braiding are characteristically sinuous, and this sinuosity may be a morphologic indication of aggradation (Culbertson et al.).

In the area of interest on a stream, these variables are each determined for various points along the reach. These may then be tabulated versus position on the stream to provide an indication of stretches of similar characteristics and points at which characteristics change. These points mark the beginnings and ends of stretches which can be considered to be similar for purposes of study. Additionally, the use of this classification system will provide consistency among studies carried out by various investigators and in different parts of the country.

2.3.2 Preliminary Site Selection

A thorough examination of air photos and various types of maps on which classification variables are plotted will enable the planner to make preliminary site selections for later field studies. These selections should be indicated on the maps and on photos which are to be taken into the field. If doubts arise as to the suitability of a particular site, or to whether or not one site investigation rather than two would suffice, these issues should be checked in the field rather than in the office.

There are at least two approaches to site selection which, dependent upon existing information, should be considered. One approach is to assume that most or all types of recreation are possible, if not at similar flows then at different flows, and to evaluate each stretch and the river as a whole,for all types of recreation.

This approach eliminates those recreation activities which would not be suitable at any flow conditions but considers all other types whether or not they actually occur on a specific river.

Another approach is to evaluate the sites suitable for existing recreation or a limited number of types of recreation. This leads to somewhat of a biased result, skewed obviously in favor of existing recreation and types which for one reason or another are considered more likely to occur.

The method which is used in this manual requires that equal consideration be given all recreation types in the preliminary stages.

When considering preliminary sites for instream flow investigations, classification of channel patterns will have identified areas of gross morphologic similarity. Since an entire river cannot be investigated in detail, it becomes necessary to choose sections of a river or stream which when studied in greater detail will produce information that can be applied to other portions of a similarly classified stretch. The utility of a cross-section, then, depends on how representative it is of an entire stretch and how well recreation potential can be studied by using this one particular site.

From careful examination of air photos, it is possible to make a useful preliminary site selection. For each stretch of river which is classified differently, a study section should be identified which has the following characteristics:

Width -

> The width of the section should be within ± 10% of the median width of the stretch. This is intended primarily to eliminate constricted areas for which discharge-depth relations are not typical of the stretch as a whole.

Bank -

> Bank conditions should be similar to conditions present throughout the stretch in terms of bank height and vegetation.

Obstructions -

> The section should be free of man-made and natural obstructions which may cause eddies or backwater effects.

Wading area -

> If possible, the section should be chosen where the river or stream appears to be wadeable.

Meanders -

> On meandering rivers, asymmetrical velocity and depth measurements will be found on the outside of the meanders. Sections should be chosen to avoid these areas.

In essence, the above conditions have been outlined to encourage a uniformity of site selection from a geomorphological point of view. Based on known conditions necessary for various types of recreation, it is also possible to delineate sites along a river likely to support different types of recreational activity. Therefore, if based on information gathered previously, a recreation activity such as canoeing is identified as being likely to occur, then features critical to the success of canoeing can be looked for. The following section contains basic information on recreational activities and parameters affecting their success which can be ascertained from air photo investigation. These features may preclude a recreational activity by their presence or may help identify areas suitable for the activity.

2.3.3 Recreational Parametric Requirements

2.3.3.1 Fishing

a. Advice of fisheries personnel should be input with respect to species present, necessary survival flows, and favored fishing areas.

b. Sufficient cover for various species may be observed on air photos.

c. Where survival requirements for a particular species indicate, pool/riffle ratio may be important.

2.3.3.2 Non-tranquil Boating

a. Serious hazards such as dams should be noted.

b. Portage routes and access/take out areas can be located.

c. The advice of an expert white water canoeist/kayaker should be sought out.

d. Arighi and Arighi (1974) have shown that gradient information can be used for preliminary classification of whitewater boating (See section 2.5.2).

2.3.3.3 Tranquil Water Boating

a. Channel width in excess of 1 1/2 times the boat length (approximately 25 feet).

b. Wide, shallow areas which could, at low flows, interrupt trips should be noted.

c. Hazards, including dams, fallen trees, and flood control devices should be identified.

d. Maximum length of trip possible. This implies the location of obvious limiting structures or stretches and determining the distance between such features.

e. For sailing and power boating (water skiing), surface areas free of obstructions generally in excess of 150 acres. Smaller power boats and sailboats may require a minimum 50 acres. Critical depths must be field determined.

2.3.3.4 Wading

a. Areas should be away from major rapids and falls.

b. Excessively high vertical banks (>5 feet) should be avoided.

c. Vegetation along the banks should not be so thick as to rule out easy access.

d. Point bar and island areas are often good locations.

e. Pool areas should be located.

f. Man-made hazards in the stream and along the banks are to be avoided.

2.3.3.5 Swimming

a. Pool and backwater areas.

b. Bank conditions similar to those for wading.

c. Point bars on meandering rivers may be especially good sites, as can natural impoundments.

2.3.3.6 Tubing

a. Riffle areas present and partially covered with water are favorable.

b. If the stream meanders, the outsides of bends should be free of overhanging debris or erosion control devices.

c. If there are natural diversions or dams they may be high enough or built in such a way as to preclude passage. In this case, areas for portaging around the structure should exist or be possible.

The combination of the morphologically based classification of the river reach with these generic recreational parameters assists in sharpening the preliminary site selection process. The locations of cross-section transects will reflect both the stretch classification and the expected use. Thus, for a stretch expected to provide good flat water boating, the section might be taken at or near a major put in point, whether existing or potential. Where a very limited area on a stretch may provide specialized recreational potential such as wading, swimming, or running a short rapids, a transect would be taken. Where two very similar stretches are separated by one which is quite different in nature and recreation potential, study of the middle stretch and either the upper or lower similar stretches bounding it may suffice.

2.4 Hydrology and Hydraulic Geometry

There are many ways of summarizing hydrologic data, both for gaged and ungaged rivers. Definitions of the most commonly used terms are presented in Table 1.

Average Annual Flow (AAF) has advantages for instream flow studies which many of the other measures do not. On ungaged rivers, AAF is more easily calculated than any other measure. In areas of moderate rainfall (10-40 inches per year) it is possible to calculate AAF to within 90% of its actual value (Riggs, 1969). AAF can be found for gaged rivers in the USGS Water Resources Data for the state in which the gage is located.

Many fishery workers have expressed flow in percentage AAF when discussing the flow requirements for spawning, rearing, and flushing flows. One of the better known methods which utilizes AAF is the "Montana Method" (Tennant, 1975).

In terms of frequency of occurrence, a discharge equal to AAF is likely to occur approximately 25% of the time. When computing AAF, all flows occurring within a period of time are considered including spring runoff flows which will raise the average flow, but in themselves occur infrequently.

Median flow is the flow which occurs 50% of the time. It is more likely to be encountered in the field than is the AAF.

2.4.1 Hydrology

As a first step in studying the hydrology of a section of a river it is useful to outline the stretches which are of interest on a topographic map (See Section 2.1). The map should be of such a scale that most of the tributaries can be outlined and the drainage area to the farthest downstream point of the stretch under consideration can be mapped.

TABLE 1

COMMONLY USED HYDROLOGIC TERMS

Average Daily Flow (ADF)	The mean flow over a particular 24-hour period and is most often expressed in cubic feet per second (cfs).
Annual Mean Flow (AMF)	The arithmetic mean of average daily flows over a period of one water year. It should be always modified by the year for which it is calculated.
Average Annual Flow (AAF)	The mean of a number of annual mean flows. The USGS does not report average annual flow for stations having fewer than five years of record. As a general rule, AAF will be observed in a stream with a frequency of occurrence of about 25%.
Median Flow	That flow for which, over a given time interval, there are an equal number of greater and lesser flows observed. This is the 50% flow on a frequency diagram.
Low Flow	The lowest discharge ever recorded at a particular station over a given time span. Low flow data is often presented in low-flow frequency curves which show the magnitude and frequency of minimum flows for a period of given length (after Fraser, 1975).
High Flow	The highest discharge ever recorded at a particular station over a given time span. It is expressed in similar terms to those used for low flows.

TABLE 1 (Continued)

Flow Duration Curve	A curve which expresses the relationship of flow (in cfs), arranged in order of increasing magnitude along the ordinate, and time, often expressed in days, along the abscissa. Daily duration data published by the USGS show the distribution of daily discharges for each water year ending September 30. Discharges are indicated in class ranges, ranked in increasing order of magnitude. The percentage of time is also reported during the period of record that the lowest discharge in each class was either equalled or exceeded.
Cubic Feet Per Square Mile (CFSM)	This is computed for a particular station by dividing the discharge (in cfs) for a period of time (month or year) by the drainage area at the station (measured in square miles). The USGS computes monthly and yearly CFSM data for many of their gaging stations. CFSM may also be computed for ungaged basins by first computing the average annual flow at a point on the stream and then dividing this figure by the drainage area, in square miles, for the same point.

Man-made structures including dams, diversion structures, canals, and sewage outfalls should be identified. It is important to recognize the effects structures such as these have on the hydrology of a river.

2.4.1.1 Gaged Streams

The nearest gaging station should be located and marked on the maps. If the gage is located in a section where irrigation or other large offstream use takes place, it is essential to determine whether or not the gage records reflect diversions and return flow or merely diversions, with return flows entering below the gage site. In this case, the gage data would under predict flows downstream of the return point.

For many reaches, there are published flow charts indicating diversions and points of return on to which gage station locations may be placed. Figure 4 is an example from the Boise River, Idaho.

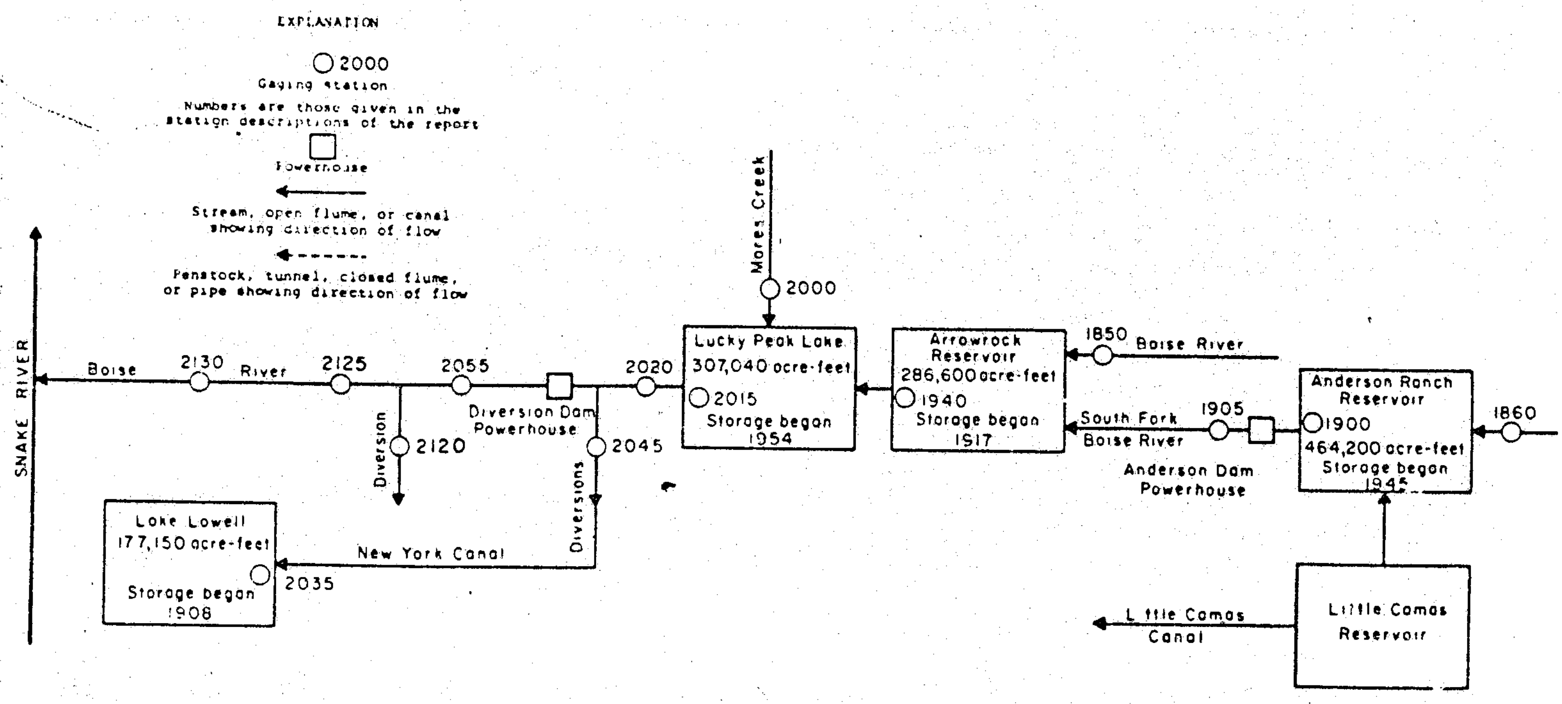
Assuming that a gage station does exist, the USGS or comparable state agency publishes its records in several formats which are of use in the initial stages of an instream flow study. This information should be ordered early in instream flow studies. Some of the records are described below.

1. Rating Curves, prepared periodically by the USGS, indicate the discharge associated with a particular stage, or gage height. They are useful in field work because they enable the field party to verify discharge at a particular time and, thus, to compare the accuracy of measurements with those published by the Geological Survey.

2. Water Resources Data is a document published yearly by the USGS for each state. It contains the daily mean discharge measurements at a particular gaging station for one water year, withdrawals for irrigation, reservoir storage, and other useful statistics.

3. Duration Tables of Daily Discharge have been prepared for many USGS gaging stations. These tables show the distribution of daily mean discharges for each water year ending September 30. Discharges are shown in class ranges, which are ranked in increasing order of magnitude. From these summaries, flow-duration curves, such as that shown on Figure 5, can be plotted on logarithmic probability paper; this type of paper tends to linearize the the curve and provides easier analysis.

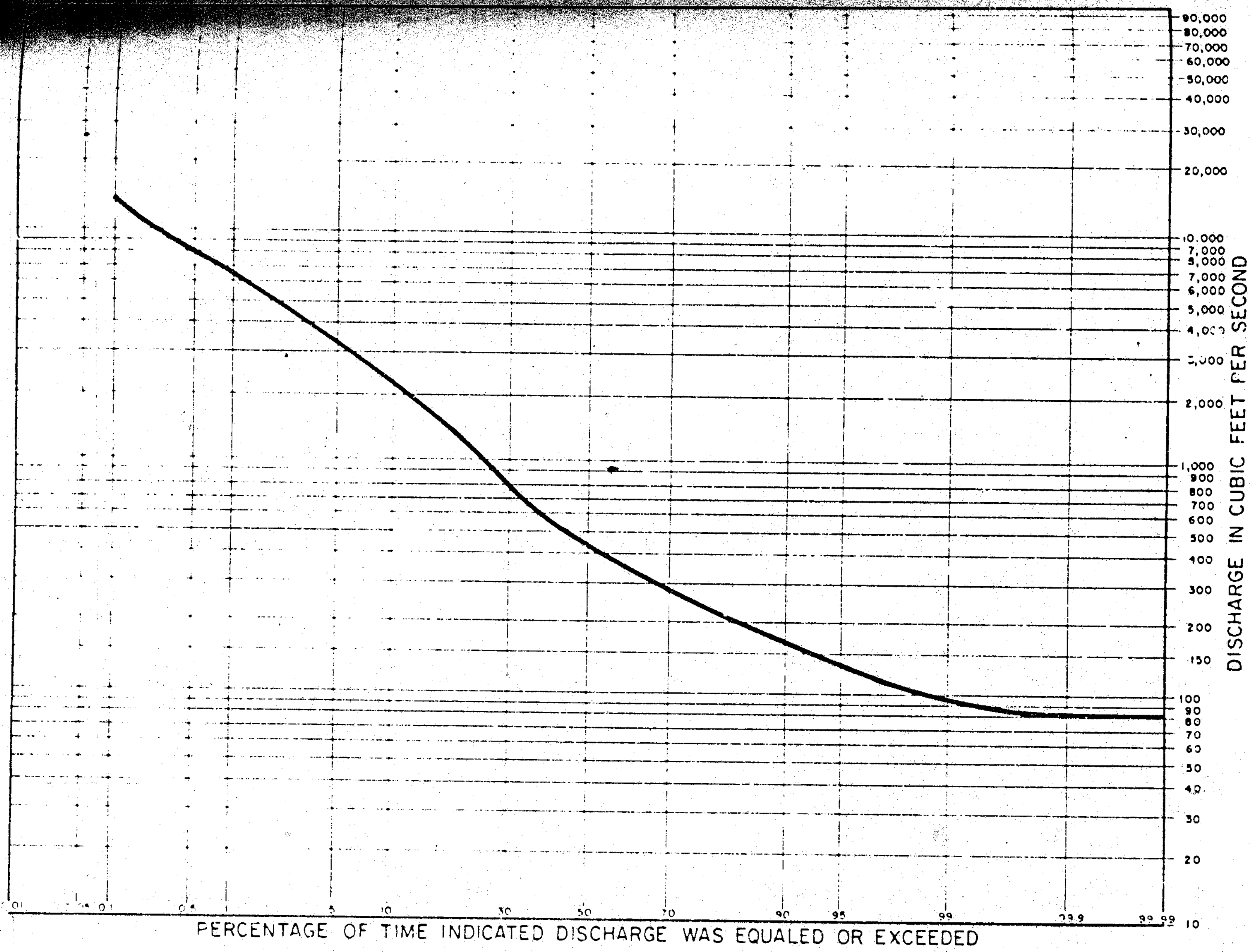
4. Discharge Measurement Notes (USGS 9-275) are available from local USGS offices for each day on which a cross-sectional measurement was taken at or near a gaging station. The notes contain detailed width, depth, and velocity measurements, as well as air and water temperatures.



SCHEMATIC DIAGRAM SHOWING GAGING STATIONS IN BOISE RIVER BASIN

(WATER RESOURCES DATA FOR IDAHO, 1974)

FIGURE 4



FLOW DURATION CURVE: SACO RIVER, CONWAY, N.H.

Figure 5

These notes are summarized yearly on USGS form 9-207, Discharge Measurement Summary Sheet. In terms of the most efficient use of both the instream flow investigator's time and the USGS's time it is best to examine the yearly summary chart and to pick out measurements representing a range of discharges and then request copies of individual discharge measurement notes. As a starting point, it would be useful to obtain individual measurements for various multiples of AAF such as 10, 20, 30, 50, 60, 80, 100, 200 and 300 percent AAF. It should be pointed out that measurements do not always exist for these exact multiples, but generally measurements within 10% do exist. A prime reason for examining the individual discharge measurement notes is to examine the range of depths and velocities present at the gage at a particular discharge measurement.

2.4.1.2 Limitations

Before examining other sources of hydrologic data, the limitations of the above mentioned data should be considered. A problem when relying on gage data to make predictions is determining how representative the gage data are for the stretch under consideration.

This problem can be overcome generally by a discussion with the USGS office responsible for making measurements at that location. In addition to the issue of how representative the gage data are, several other questions need to be resolved or kept in mind if the data are to be used. Are all of the measurements taken at the same spot or, for example, do high discharge measurements represent cable measurements, while lower discharges represent wading measurements, near to, but not exactly at the location of the higher discharge measurements? Backwater and ice effects must be considered. Usually, an indication is made on the measurement notes if such a situation was present at the time of measurement.

The period of record for gage data may affect their utility. Summary information may overlap periods of time during which changes are not carefully noted. Again most of these problems can be resolved by explaining to the USGS personnel what the data are to be used for and asking what limitations must be taken into account.

An integral part of stream gaging records is the effect of various water development projects on the natural stream regimen. Although summary stream data published by the USGS normally take these projects into account, it is useful to obtain an individual breakdown of such projects and their contribution to the overall picture. Other factors which should be taken into account are hydroelectric dams, flood control structures, irrigation demands (withdrawal and return flows), and water demands for reservoir recreation behind hydroelectric and flood control dams. Flow charts summarizing this information should be prepared so that consideration of various portions of the whole project are viewed in the proper perspective. In many instances portions of the above mentioned hydrologic data are summarized in reports put out by a variety of local, state, and federal agencies. The USGS has published reports on stream flow conditions present on many rivers. Flood Plain Studies by Housing and Urban Development (HUD) and the Soil Conservation Service (SCS) often contain cross-section information as well as hydrologic summaries. Bridge site reports prepared for highway agencies contain cross-section information for sites under consideration for bridge crossings.

2.4.1.3 Ungaged Streams

When a river or stream, which is under consideration, has not been gaged or the gage data which does exist is not for a long enough period of time (10 to 15 years), it becomes necessary to estimate flow records based on streams of a similar character (Riggs, 1973).

There are several techniques for estimating average annual flow based on drainage area calculatons and annual precipitation and runoff data. Initially the drainage area for the stretch of river under consideration is outlined on a map of suitable scale and the area computed in square miles or feet. From USGS Hydrologic Atlas maps of average annual runoff, the isopleth nearest to the downstream end of the reach under study is determined. This value in inches may be converted to feet, multiplied by the drainage area in square feet and divided by the number of seconds in a year to arrive at an average annual flow in cubic feet per second.

In the absence of complete runoff data, data from gaging stations, located within the same basin, can be used to estimate the yearly runoff for an ungaged area. This is estimated from the following formula (note: this formula is for the northeastern states, in other regions the proper formula may be found in the Hydrologic Investigation Atlas which has been prepared for that area.):

$$R_u = (R_g + 20)\,\frac{(R_u avg + 20)}{(R_g avg + 20)} - 20$$

in which R_u = yearly runoff for any one year of an ungaged area
R_g = runoff for the same year measured at a gaging station.
$R_u avg$ and $R_g avg$ = the average annual runoff for the respective areas as determined from published runoff maps. (e.g., U.S. Department of Interior, Hydrologic Investigations Atlas HA7)

All of the above runoff measurements are in inches, which should be converted to feet. Similar techniques to this have been discussed by Riggs (1969) and Osborn (1974). This technique has proved to be most accurate in humid regions.

Additional information on estimating annual flows, flood flows, and low flows is contained in Stalnaker and Arnette (1976) pp. 20-25 and is recommended to those interested in further discussion of alternate techniques.

Rantz (1964) has developed a regression equation method for use on gaged, recently gaged, and ungaged streams. His method for ungaged streams requires actual discharge measurements on the ungaged stream which are then compared to the nearest comparable gage for which long-term records exist.

2.4.1.4 Cross-Sectional Information

Channel cross-sections at varying flows are available in many cases. These are available in two basic forms, plotted and unplotted.

There are many potential sources of cross-sectional data, including these federal agencies:

- U.S. Geological Survey
- Soil Conservation Service
- Bureau of Reclamation
- Bureau of Land Management
- U.S. Army Corps of Engineers
- U.S. Fish and Wildlife Service
- U.S. Forest Service

On the state and local level, cross-sections may often be obtained from highway or transportation departments, fish and game commissions, etc. If cross-sections do exist for a particular river, their location is generally known by individuals from one or more of these agencies.

Due to the large number of cross-section measurements taken annually, only a small portion are plotted by the agency responsible for their measurements. If an agency has its data analyzed and displayed using computers and/or computer-driven plotters, then the majority of the cross-sections will be drawn up and should be available for use by other investigators.

If the water surface has not been drawn on the cross-section, it may be done where the sections have been measured at or near gaging stations. In other cases, the water level will be indicated in the survey party's field notes.

In the case where the data have not been plotted, they can be plotted by the instream flow investigator. When available, water surface elevations should be added to the cross-section.

When many cross-sections at varying flows are available, the investigator must decide which of these to use. Some general rules which should be followed are:

1. When viewed in the overall context of river classification, is a cross-section representative of a given channel reach? If cross-sections are chosen randomly, they may not be representative of a given reach or may not be taken at a point useful for recreation studies;

2. Sections which extend far enough away from the water's edge to allow computer modelling of higher flows are preferable to those which do not,

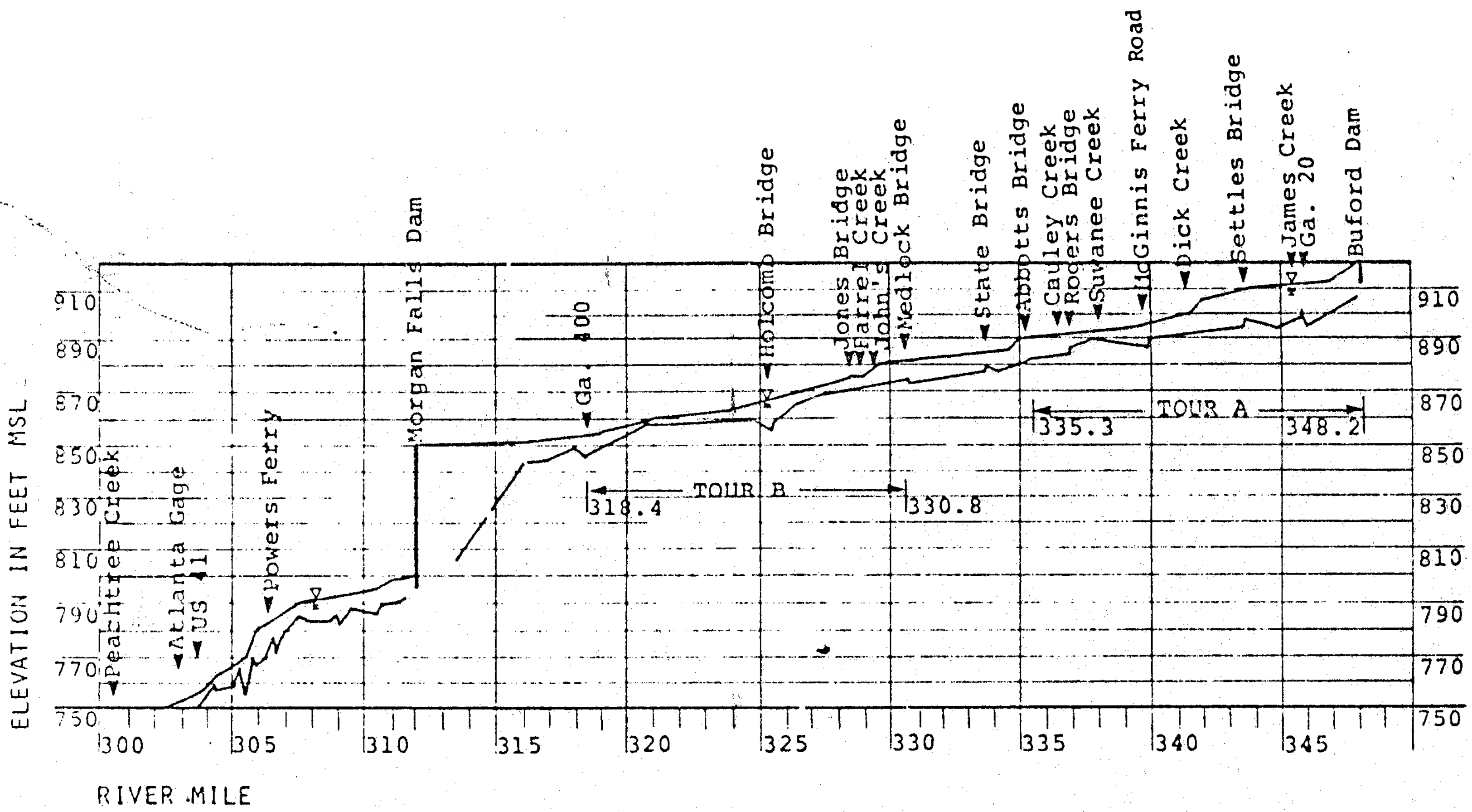
3. When varying known flows are available, flows below bankfull stage are of more use than overbank or flood profiles,

4. Sections which reflect the latest level of water development projects should be chosen.

2.4.1.5 Longitudinal Profile Information

Longitudinal profile information is available for many rivers from the agencies listed in Section 2.4.1.4. In the absence of published data, these profiles may be prepared from USGS topographic maps which cover the river stretches being studied. An example profile is shown in Figure 6. After profile information has been prepared, stream gradients may be calculated.

Profile and gradient information are useful to the investigator on both gaged and ungaged streams. On gaged streams, slope (or gradient) data are necessary to accurately characterize one stretch or reach versus another stretch or reach. Additionally, when Manning's Equation is used to calculate discharge at a particular cross-section, slope is a necessary parameter of the equation.



LONGITUDINAL PROFILE CHATTAHOOCHEE RIVER: ATLANTA TO BUFORD DAM

Figure 6

Where an ungaged stream is being investigated, slope/gradient data are useful when determining which, if any, nearby gaged streams can be used to estimate channel and geomorphological properties for the ungaged stream.

2.4.2 Hydraulic Geometry

After the hydrologic data mentioned in previous sections has been gathered, it must be organized and presented in such a way that it enables the user both to get a grasp of existing hydrologic information and to utilize this in predicting recreational potential at varying sites.

One commonly used method of describing flows at a given section is to consider the hydraulic geometry at that section.

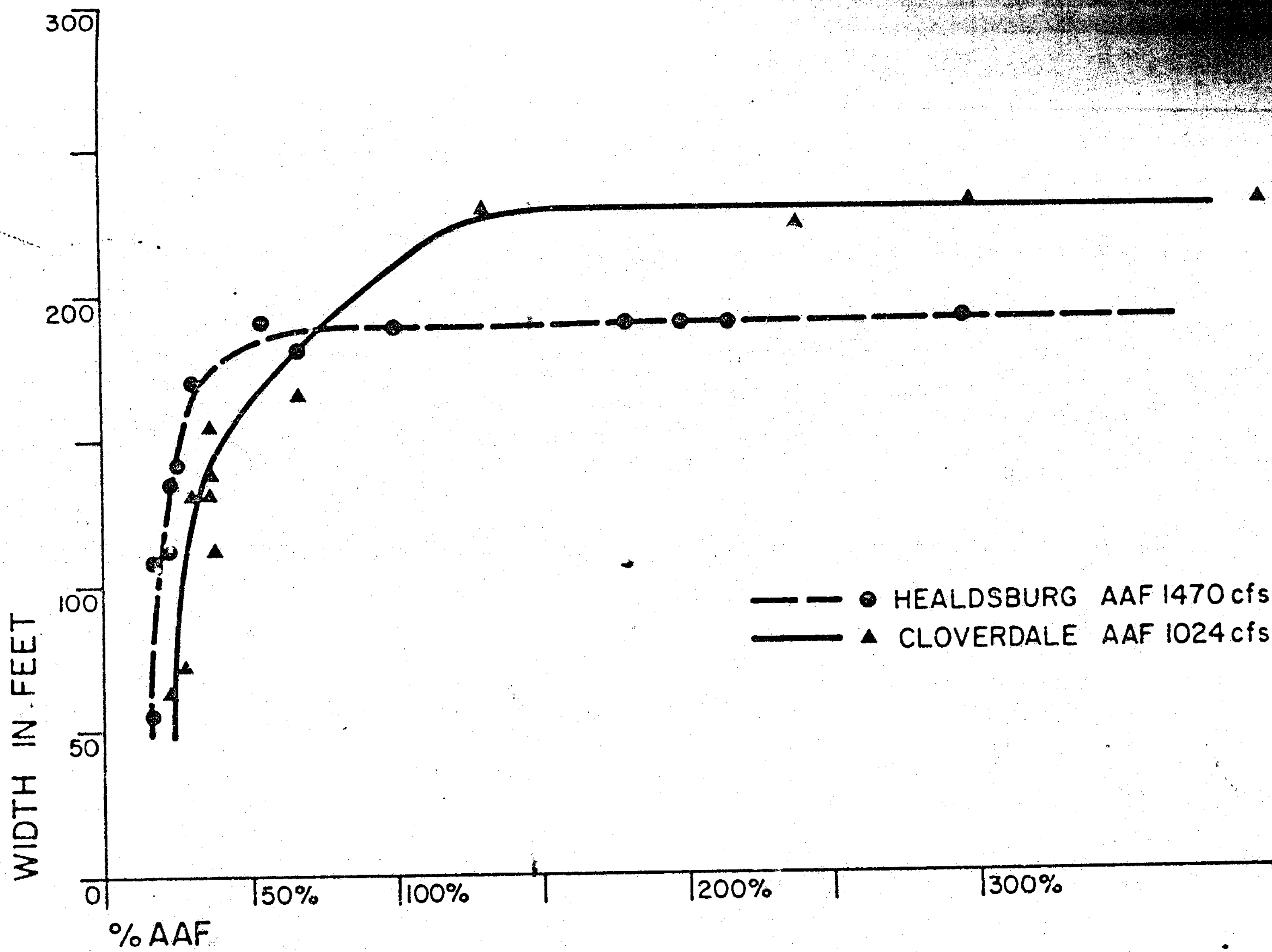
Hydraulic Geometry is the description, at a cross-section of a river channel, of the graphical relationships among hydraulic characteristics (width, depth, velocity, channel slope, roughness, and bed particle size) which help to determine the natural shape of a channel.

Information on the hydraulic geometry of streams or rivers is available by plotting the relationships between discharge and w, d, and v. When this information exists or is calculable, it provides general relationships which may be of use to the planner.

Graphs, such as those on Figure 7, in which values of various channel characteristics are plotted against discharge at a given river cross-section are termed at-a-station curves. This differentiates them from similar graphs describing how the parameters change downstream as discharge increases by successive contributions of tributaries.

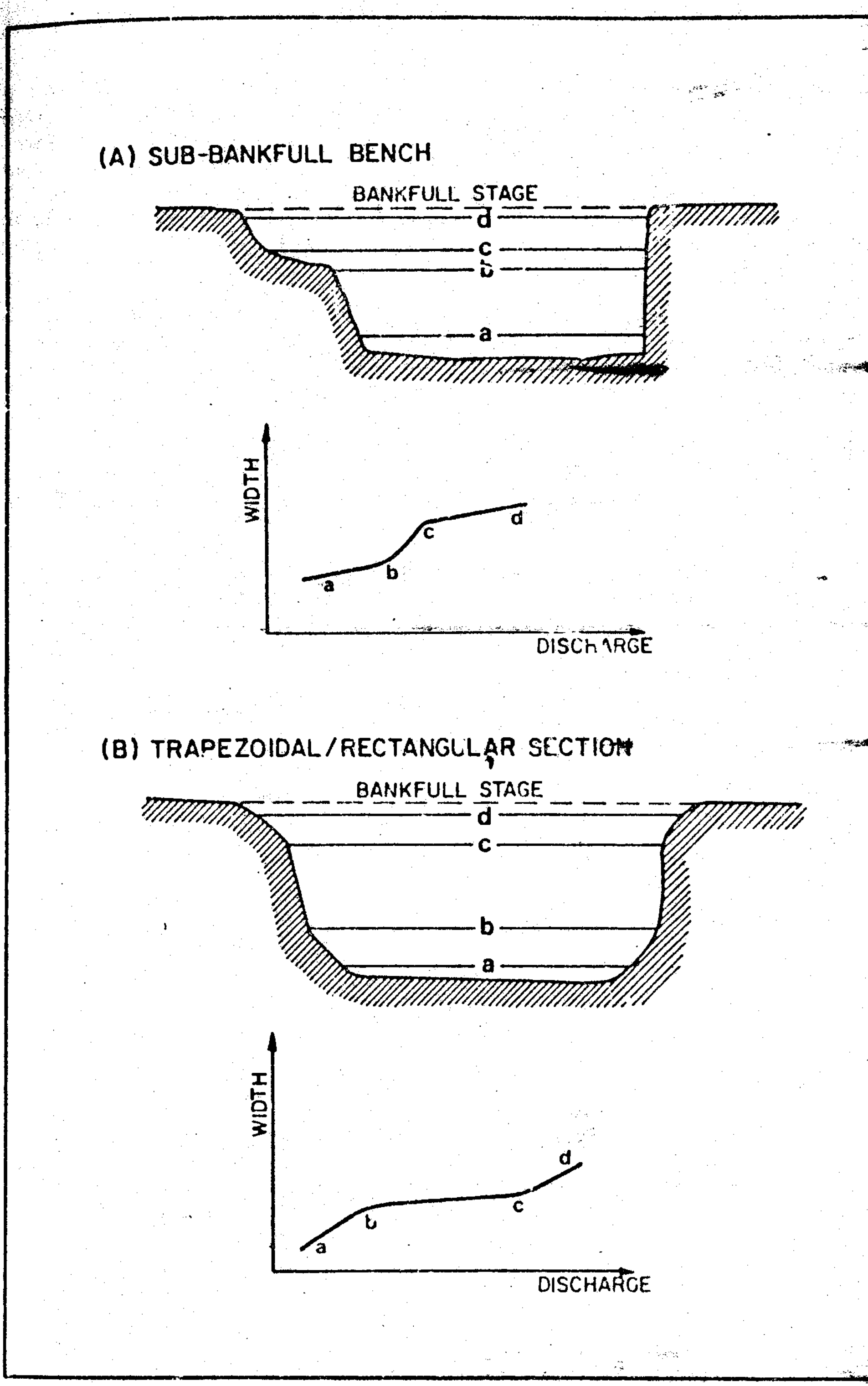
The data presented on these graphs may also be expressed mathematically as power functions, which basically state that as discharge increases, width, depth, and velocity increase exponentially.

Some authors (e.g., Richards, 1974) question the use of fitting the data to power function relationships when in many natural channels the variables either exhibit relationships not described by a single power function but by several power functions (Figure 8), dependent on flows, or not by a power function at all. The fact that in many natural channels these variables are not independent of flow levels raises doubts about the universal use of such techniques. Additionally, much of the data are based on gage station information, the limitations of



RUSSIAN RIVER, CALIFORNIA

Figure 7



HYPOTHETICAL CROSS-SECTION FORMS AND ASSOCIATED WIDTH DISCHARGE CURVES

(K.S. RICHARDS, 1976)

Figure 8

which have been discussed earlier, both in terms of representativeness of the data and the fact that mean depth and mean velocity are used. The physical parameters defining the limits of recreational activities often cannot be accurately described in terms of mean values; they are more accurately reflected by considering the range of depths or velocities present at varying flows.

When examining hydrologic data for use in predicting recreational potential, graphical representation of discharge versus w, d, and v is preferable to fitting power function equations to the data. As mentioned above, an even better approach is to analyze the changes in depth and velocity ranges with changing discharge.

2.4.3 Data Presentation

In preparation for predicting the types of recreation that might be possible on the study stream, the following arrangement of hydrologic data is recommended.

When gage information exists

1. Calculation of the AAF, yearly and monthly.
2. Flow-duration curves, on which AAF and percentages of AAF such as 10, 30, 60, 100, 200, 300 have been indicated.
3. Width vs. discharge, mean velocity vs. discharge, mean depth vs. discharge (discharge-axis units in CFS and %AAF).
4. Cross-section information for indicated flows, with water surface levels indicated, when available.
5. Rating curves at gages (primarily for field work).
6. Longitudinal profiles.
7. Ranges of velocity and depth at increasing discharges in tabular or graphical form for selected AAF values.
8. Schedules of dam releases, irrigation withdrawals (preferably on a flow chart).

When limited hydrologic data are available

1. Calculation of AAF yearly (and where precipitation records exist, monthly values of AAF).

2. Determination of hydrology of nearby basins or channels with similar geology, gradient, bedload, and precipitation.

3. Estimated hydrology of the study stream based on similar gaged basins.

2.5 Flow-Related Requirements for Recreation

The requirements for various forms of riverine recreation can be couched in many terms. Often, in the recreation literature, criteria are of the general type, specifying those qualities of a stream or river that lead to a high quality experience. Little attention has focused on the physical needs of a particular activity or on the conditions within a stream which will meet those needs. Additionally, many studies are based almost solely on observed activities and user interviews to determine the quality and worth of the resource. This has obvious drawbacks in dealing with cases where natural recreation potential has not been realized or where a proposed project (such as a planned structure) may so change conditions that future activities are not accurately predicted by existing use surveys. In these cases, a clear, physical description of those conditions necessary to support different activities is required.

The purpose here is to provide an accurate and concise description of those conditions in a stream which will support an activity, those which are optimal for the activity, and those which preclude the activity. The main descriptors will be width, depth, and velocity since these are the main characteristics of a stream which changes in response to changing flow. A summary of these requirements is presented in Table 2. Of secondary importance will be those auxiliary conditions which influence the desirability of the activity, such as sand bottoms for swimming; those which might eliminate a physically possible activity, such as a low-flow die-off of fish; and those which might influence the potential market for an activity, such as the presence of a competing, higher quality resource in the immediate area.

TABLE 2

Summary of Instream Flow Requirements for Recreation

	ACTIVITY	MINIMUM CONDITION	MAXIMUM CONDITION	OPTIMUM CONDITION	COMMENTS
FISHING	Wading	W = -- D = -- V = --	W = -- D = 4 ft V = 2.5 ft/sec	W = -- D = <4 ft V = <2.5 ft/sec	All conditions should be checked against fish survival flow.
	Boating-Canoeing	W = 25 ft D = 6 in V = --	W = -- D = -- V = 10 ft/sec	W = >25 ft D = 2-5 ft V = <5 ft/sec	
	Boating-Low Power	W = 25 ft D = 1 ft V = --	W = -- D = -- V = 10 ft/sec	W = >25 ft D = 2-5 ft V = <5 ft/sec	
	Bank	W = -- D = -- V = --	W = D = Flood V =	W = based D = on fish V = catchability	
WATER BOATING	Rafts & Drift Boats	W = 50 ft D = 1 ft V = 5 ft/sec (Class I)	W = -- D = -- V = 15 ft/sec (Class V & VI)	W = >100 ft D = 2-5 ft V = 10 ft/sec (Class II,III,IV,V)	In all cases, check against International Classification.
	Canoes & Kayaks	W = 25 ft D = 3-6 in V = 5 ft/sec (Class I)	W = -- D = -- V = 15 ft/sec (Class IV & V)	W = >75 ft D = 2-3 ft V = 10 ft/sec (Class II,III,IV)	
TRANQUIL WATER BOATING	Canoeing	W = 25 ft D = 6 in V = --	W = -- D = -- V = 5 ft/sec	W = >75 ft D = 2-5 ft V = <1.5 ft/sec	
	Rowing	W = 25 ft D = 1 ft V = --	W = -- D = -- V = 5 ft/sec	W = >75 ft D = 2-5 ft V = <1.5 ft/sec	
	Sailing	W = 100 ft D = 2 ft V = --	W = -- D = -- V = 1.5 ft/sec	W = >200 ft D = ~5 ft V = ~0 ft/sec	
	Low Power	W = 25 ft D = 2 ft V = --	W = -- D = -- V = 10 ft/sec	W = >100 ft D = ~5 ft V = <5 ft/sec	
	High Power	W = 100 ft D = 5 ft V = --	W = -- D = -- V = 15 ft/sec	W = >300 ft D = 10 ft V = <5 ft/sec	
WATER CONTACT	Swimming	W = 25 ft D = 3 ft V = --	W = -- D = -- V = 3 ft/sec	W = >100 ft D = 5 ft V = <1.0 ft/sec	Water temp - max 50-100°F Visibility - Opt=Depth Bacteria max 1000[illegible]
	Wading	W = -- D = -- V = --	W = -- D = 4 ft V = 2.5 ft/sec	W = -- D = 1-4 ft V = 2-5 ft/sec	Max D x V = 10 Opt D x V = 2-5 + above
	Tubing	W = 25 ft D = 1 ft V = 1 ft/sec	W = -- D = -- V = 10 ft/sec	W = >75 ft D = 2-5 ft V = 5 ft/sec	Same as Swimming
	Water-Skiing	W = 200 ft D = 5 ft V = --	W = -- D = -- V = 3.5 ft/sec	W = >500 ft D = 10 ft V = <2.5 ft/sec	Same as Swimming

2.5.1 Fishing

Fishing depends upon, first, the survival of desirable species of fish, and second, the ability of fishermen to pursue and capture them. The first requirement has been studied extensively by fisheries departments throughout the nation. It is usually specified in terms of a requisite minimum percentage of Average Annual Flow to support spawning, hatching, rearing, and passage at appropriate times of the year. The second is the proper focus of instream flow criteria for recreation.

Three forms of recreational fishing occur in rivers and stream: wading, boat fishing, and bank fishing. Flow criteria for these are most directly set by the flows governing the form of pursuit.

2.5.1.1 Wading Fishing

Minimum Conditions -

> There are none; wading can be engaged in so long as there is water in the stream. Flow is not required. There is a de facto lower limit, however, in the survival flow for the species of interest. Fisheries data indicates that, for coldwater fish, this is about 10% of the average annual flow of the stream. Warmwater game fish may survive long periods of very low flow.

Maximum Conditions -

> For a normal-sized, adult fisherman in chest waders, depth = 4 feet, velocity = 2.5 feet per second. At any lesser depth, the product of depth (ft.) and velocity (ft/sec) should be less than 10. Where the bottom is uneven, rocky, or slippery, the maximum conditions are shifted downward.

Optimum Conditions -

> These are determined by the catchability of the species being pursued. The ability of the fisherman to pursue the fish is assured by any flow yielding less than maximum depths and velocities.

2.5.1.2 Boat Fishing

Flow criteria governing fishing from a boat amount to a subset of the tranquil water non-power and power boating requirements. It is assumed that fishing occurs from a canoe or similar shallow draft craft and that power boats are the small fishing boat, equipped with a motor of 15 horsepower or less.

The following criteria govern fishing from small non-powered and low-powered fishing craft.

Minimum Conditions -

Depth = 6 inches for canoes, 2 feet for small power boats. There is no lower limit for velocity. Width can be as narrow as 1 times the length of the craft being used, or, more realistically 25 feet. (In narrower streams, wading or bank fishing would be preferred to boat fishing.)

Maximum Conditions -

Velocity = 10 feet per second. There are no width and depth maxima for boating in pursuit of fish. Velocity maxima should be for short distances only.

Optimum Conditions -

Depth = 2 to 5 feet. Velocity less than 5 feet per second. Width greater than 25 feet.

2.5.1.3 Bank Fishing

Bank fishing, to a high degree, is independent of stream flow. The activity is possible, although perhaps non-productive, at no flow and can be carried out at any flow that does not over-top or make inaccessible the banks of the stream. Optimal bank fishing flow depends upon the catchability of the fish being sought. In the sense of maximizing the chance of capturing a fish, it is the lowest flow that will sustain the population. This low level of flow minimizes the mobility of the fish. Such a condition, however, cannot be recommended since it would quickly lead to destruction of the fisheries resource.

2.5.2 Non-Tranquil Water Boating

There are four common forms of white water craft, each with its own advantages, disadvantages, and criteria for use. Perhaps the most common is the open canoe, usually from 15 to 17 feet in length, which is used by both serious and casual white water boaters. Kayaks are among the most popular craft for the veteran white water boater. On larger rivers, or with larger parties, wooden or aluminum drift boats and rafts are the crafts of choice.

The exact conditions of gradient and flow that yield white water vary from stream to stream, but a good rule of thumb is that white water streams have a gradient in excess of 10 feet per mile and a flow in excess of 500 cubic feet per second. These conditions will provide Class I white water on the International River Classification scale. This scale recognizes six grades of white water. These may be subjectively described as follows.

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

Class II - Easy. Rapids of medium difficulty with clear, wide passages.

Class III - Medium. Waves are numerous, high, and irregular. Passages are clear but narrow and require expertise in maneuvering. A spraydeck on open boats is useful.

Class IV - Difficult. Long rapids with powerful waves and many obstacles are present. Passages are difficult to see and powerful, precise maneuvering is required. A spraydeck is essential on open boats.

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.

Class VI - Extraordinarily Difficult. The difficulties of Class V carried to the extreme of navigability.

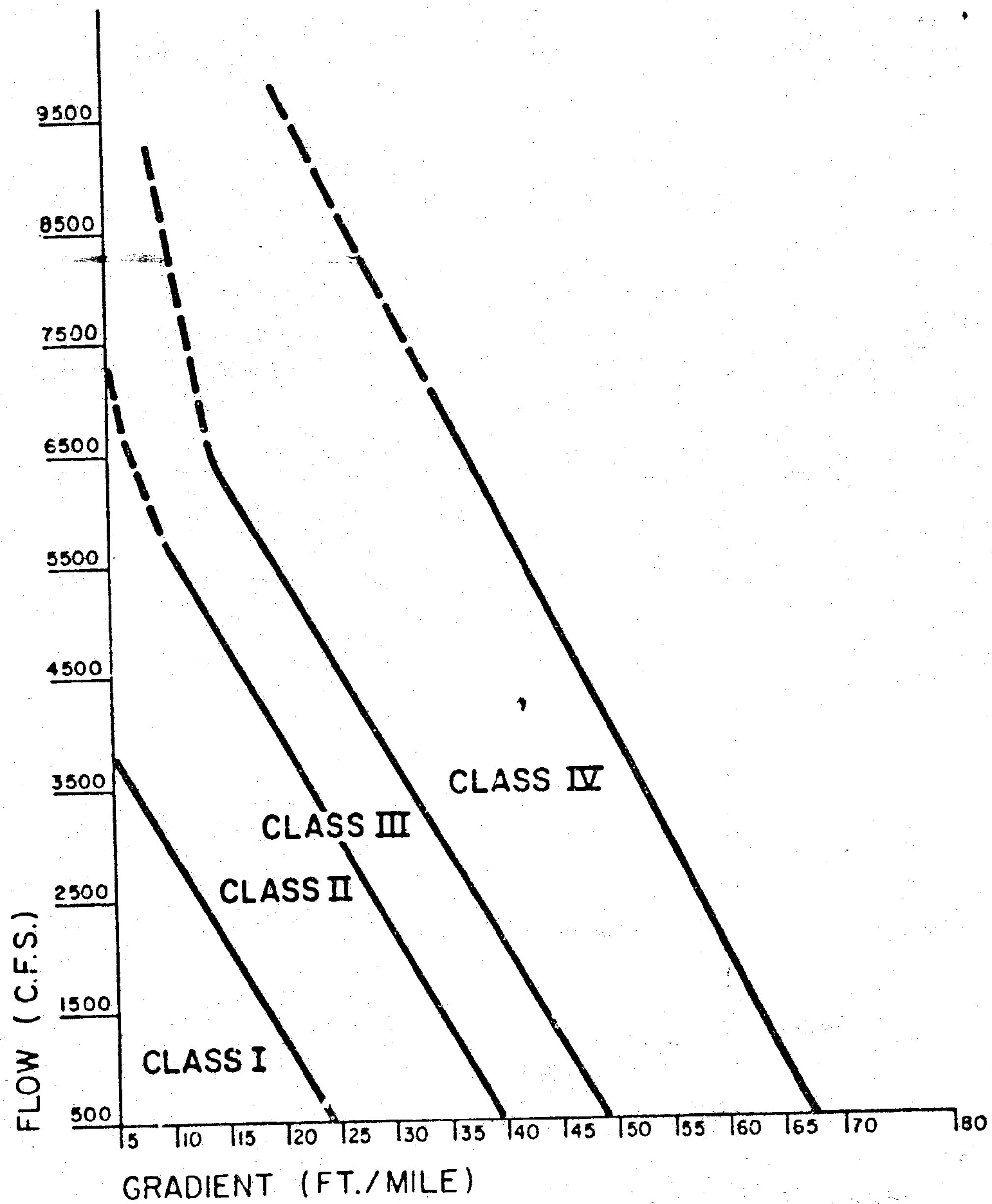
For recreational white water boating, only Classes I through IV are of interest. The Class of a stretch of a river can be estimated roughly from information on gradient and flow. The graph in Figure 9 applies to stretches of uniform gradient quite well. It does not predict the class of short, steep stretches.

More precise and less subjective Class determinations can be made if the river can be field inspected. A chart (Table 3) can be used for this purpose. The stretch of interest is scored in all 11 categories and the scores summed. The total score indicates the International Classification of the stretch.

In addition to providing water of a suitable International Class, a stream must meet other requirements in order to provide a high quality white water experience. These are best described in terms of obstructions and time of travel.

Obstructions must be viewed as detractions from the white water experience. Portaging around a dam is not what is sought by most white water boaters. Thus, careful map, air photo, and field inspection will be needed to find possible obstructions to boating and to determine if there is sufficient warning of these obstructions to insure against boater injury and suitable portaging areas to allow passage. This must be dealt with on a river-by-river basis, but in general, the more obstructions the less desirable the water for white water boating.

Time of travel has two influences. First, it may determine the gear and supplies required for a river trip and, second, it may



ESTIMATING RIVER DIFFICULTY
(Assumes Fairly Even Gradient)

AFTER ARIGHI AND ARIGHI, 1974

Figure 9

Table 3

River Rating Scale

Factors Related to Difficulty of Negotiating and Safety

Points	0	1	2	3	4	5	6
Bends	few, very gradual	many gradual	few, sharp, blind				
Length, ft.	less than 100	100–700	700–5,000	over 5,000			
Gradient, ft./mi.	less than 5	5–15, even slope	15–40, ledges or steep drops	over 40, steep drops, small falls			
Obstacles (trees, rocks)*	none	few; passage straight and obvious	some; courses easily recognized	maneuvering, courses not obvious	intricate maneuvering; course hard to recognize	course tortuous; frequent scouting needed	very tortuous; always scout from shore
Waves	few inches avoidable	low (up to 1 ft.) regular, avoidable	low to med. (up to 3 ft.) regular, avoidable	med. to large (up to 5 ft.) mostly regular, avoidable	large: irregular, avoidable; or med. to large: unavoidable	large irregular, unavoidable	very large (over 5 ft.) irregular, unavoidable
Turbulence	none	minor eddies	med. eddies	strong eddies, cross currents	very strong eddies, strong cross currents, holes	large-scale eddies and cross currents, some boils	
Resting or rescue spots	almost everywhere			good one below every danger spot			almost none
Water speed, mi./hr. ft./sec.	less than 3 less than 5	3–6 5–9	6–10 9–15	over 10 over 15 or flood			
River width	narrow (75 ft. or less)	wide	narrow	wide			
River depth	shallow (less than 3 ft.)	shallow	deep	deep			
Water temp., °F.	over 65	55–65	45–55	less than 45			
Accessibility	road along river	one hour or less "out"	one hour to one day "out"	more than one day "out"			
Total points Difficulty rating		0–7 I	8–14 II	15–21 III	22–28 IV	29–35 V	36–40 VI
Approximate skill required		practiced beginner	intermediate	experienced	highly skilled several years with organized groups	team of experts	

*Prepared by Guidebook Committee, American Whitewater Affiliation.

select for or against some forms of boating. The kayaker, for instance, may enjoy running and re-running a short, intense section of a stream with still water above and below. This might not be possible for a group in a drift boat, which is difficult to move upstream and heavy to portage. Thus, short sections of water may be ideal for "practice" and longer runs, of some hours or even days, may be more suitable for float trips or white water expeditions. Garren (1976) has provided some rules of thumb for determining the time of travel for various craft in various river situations. He notes that, if a kayak is assigned a drift time of 1.0, a canoe will require 1.1 times as long to traverse the same distance, a drift boat will require 1.3 times as long, and a rubber raft will require 1.6 times as long. These general drift times, much like the class derived from the Arighi and Arighi chart, can be greatly refined by the hydrologic studies.

Regardless of the approach taken to classification, upper and lower limits on river characteristics can be specified for the two groups of craft type, based on their characteristics.

2.5.2.1 Canoes and Kayaks

The criteria for white water boating in canoes and kayaks are as follows. Note that these are very general and, particularly for the optimum conditions, can only be accurately assessed at streamside or on the water.

Minimum Conditions -

> Width = 25 feet, Depth = 3 to 6 inches, Velocity = 5 feet per second. Conditions should yield Class I (and perhaps some Class II) water in the stream.

Maximum Conditions -

> No firm width and depth maxima can be established. Velocities in excess of 15 feet per second will preclude all but the most skilled and dedicated boaters. Conditions should yield Class IV or V waters over much of the stretch of interest.

Optimum Conditions -

> Width = 75 to 100 feet, Depth = 2 to 3 feet, Velocity = 10 feet per second. Conditions should yield Class II and III waters in the stretch of interest (some Class IV might be desirable for kayakers.) The optimum conditions will

require field checking, unless flow-related Classifications for the stream are available from reliable guidebooks or organizations.

2.5.2.2 Rafts and Drift Boats

Maximum and optimum conditions are very similar to those presented for canoes and kayaks, except that these boats can sustain Class V waters more readily than can the smaller craft. Numerical maxima are as before, but these conditions can yield a higher Class water in the stream without eliminating the activity.

Minimum Conditions -

Width = 50 feet, Depth = 1 foot, Velocity = 5 feet per second. Class I or II waters should prevail.

Maximum Conditions -

No firm width or depth maxima can be established. Velocities greater than 15 feet per second may be limiting. River conditions yielding Class V and VI waters over the stretch of interest will eliminate the activity.

Optimum Conditions -

Width = 100+ feet, Depth = 2 to 5 feet, Velocity = 10 feet per second. Conditions in the stream should yield Class II to IV waters in the stretch of interest. Some Class V will add to the enjoyment of skilled boaters, but may prove dangerous in the event of capsize.

2.5.3 Tranquil Water Boating

Five separate kinds of activity must be considered in tranquil water boating: canoeing, rowing, sailing, low power boating, and high power boating.

2.5.3.1 Canoeing

Minimum Conditions -

Width = 25 feet, Depth = 3 to 6 inches, Velocity = 0 feet per second.

Maximum Conditions -

There are no depth or width maxima. Velocities over 5 feet per second change the activity from tranquil water boating to low level white water.

Optimum Conditions -

Width greater than 75 feet, Depth = 2 to 5 feet, velocity less than 1.5 feet per second.

2.5.3.2 Rowing

Minimum Conditions -

Width = 25 feet, Depth = 1 foot, Velocity = 0 feet per second.

Maximum Conditions -

No width or depth maxima can be established. Velocities should be less than 5 feet per second.

Optimum Conditions -

Width greater than 75 feet, Depth = 2 to 5 feet, Velocity less than 1.5 feet per second.

2.5.3.3 Sailing

Minimum Conditions -

Width = 100 feet, Depth = 2 feet, Velocity = 0 feet per second.

Maximum Conditions -

There are no maximum widths or depths for sailing. Velocities should not exceed 1.5 feet per second as a rule.

Optimum Conditions -

Width greater than 200 feet, Depth = 5 feet, Velocity near 0 feet per second.

2.5.3.4 Low-Power Boating

Small power boats (less than 15 feet and less than 50 horsepower) can be operated in streams if the following conditions are met.

Minimum Conditions -

Width = 25 feet, Depth = 2 feet, Velocity = 0 feet per second.

Maximum Conditions -

There are no maximum widths or depths. Velocity less than 10 feet per second is required.

Optimum Conditions -

Width greater than 100 feet, Depth = 5 feet, Velocity less than 5 feet per second.

2.5.3.5 High-Power Boating

High-power boats (greater than 15 feet in length and greater than 50 horsepower) are far more restricted in their operation on streams than the other classes of tranquil water boats. In fact, this type of boat is most often found on a lake or reservoir, rather than on a stream.

Minimum Conditions -

Width = 100 feet, Depth = 5 feet, Velocity = 0 feet per second.

Maximum Conditions -

There are no width and depth maxima. Velocity sho .d be less than 15 feet per second.

Optimum Conditions -

Width greater than 300 feet, Depth = 10 feet. Velocity less than 5 feet per second.

2.5.4 Water Contact Recreation

Four activities are considered under this general category; swimming, wading, tubing, and water skiing. All share the characteristic of deliberate contact with or emersion in the water without protective clothing. This places some generic limits on the activities, based on temperature and water quality. Temperatures below 50°F or above 100°F will eliminate most water contact activities. Visibility should ideally extend to the bottom of the stream for both swimmer safety and for rescue. Total coliform bacteria counts should be below 1000 MPN (most probable number) per 100 ml of water to meet public health standards. Other than these general criteria, eacn water contact activity has its own unique set of physical limits.

2.5.4.1 Swimming

Swimming will be considered here as the advanced form, rather than the splash and wade form, treated as wading below.

Minimum Conditions -

Width = 25 feet, Depth = 3 feet, Velocity = 0 feet per second.

Maximum Conditions -

There are no width or depth maxima. Velocities should be less than 5 feet per second.

Optimum Conditions -

Width greater than 100 feet, Depth = 5 feet (10 feet if diving is part of the activity), Velocity less than 1 foot per second. Sand bottom and gently sloping beach.

2.5.4.2 Wading

Figure 10 presents limit curves for wading by age-body build class. In all cases, good bottom conditions are assumed. The upper curve relates primarily to fishermen. The second curve may apply to either fishing or water contact wading. The lower two curves are most pertinent to the latter activity.

The central portions of curves A, B, C, and D represent depth-velocity products of 10, 9, 5 and 2 respectively. As noted on the legend, they are keyed to large adults, normal adults and teens, sub-teens, and pre-schoolers.

With the caveats on body size and swimming ability in mind, the following general criteria will serve for wading activity by average sized adults and teens.

Minimum Conditions -

Width does not affect wading, nor is there any minimum depth in the exact sense. Velocity may be zero.

Maximum Conditions -

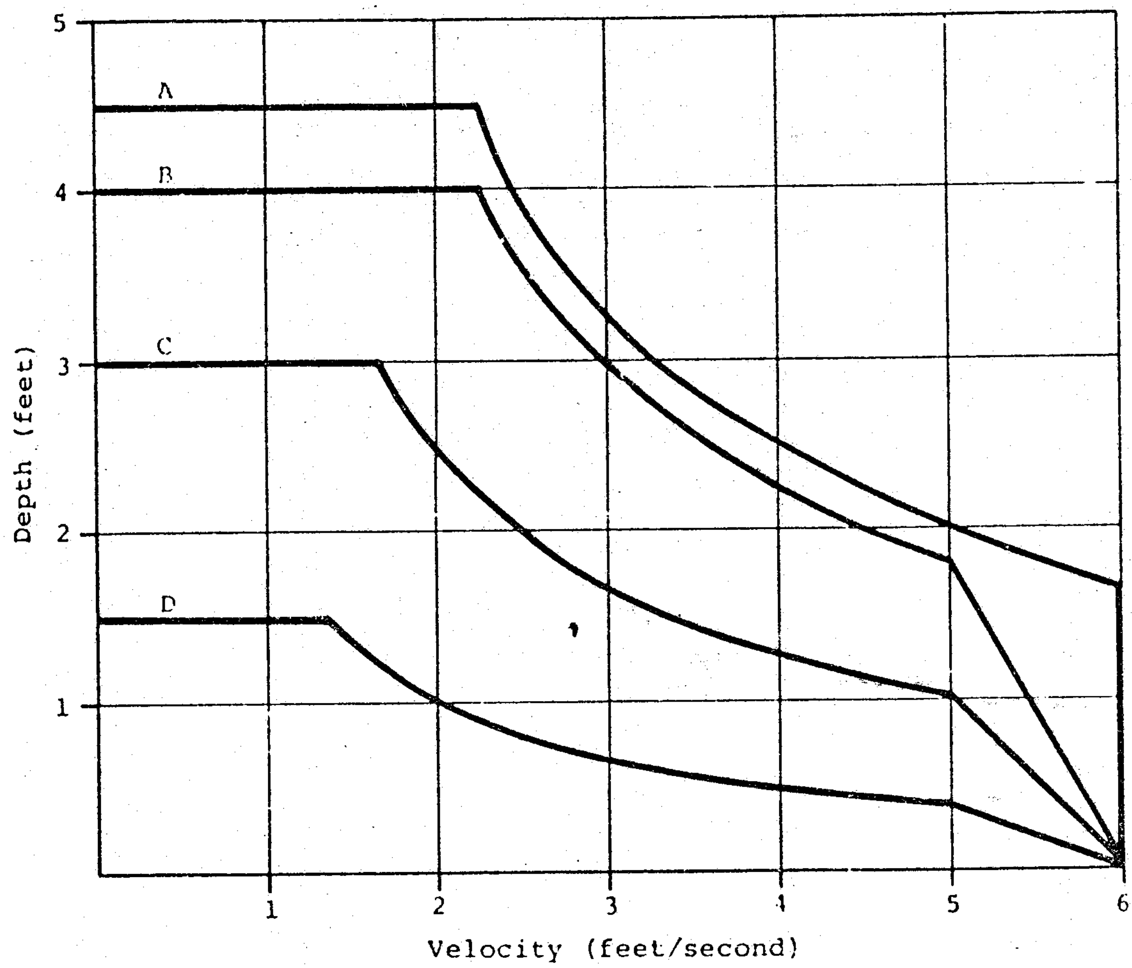
Width does not affect the activity. Depth should be less than 4 feet, and the product of depth and velocity less than 9.

Optimum Conditions -

Width is not of importance. Depth = 1 to 4 feet, Velocity times depth less than 5, unless pre-schoolers are involved, then V x D should be 2 or less.

2.5.4.3 Tubing

Tubing, floating down a river on an innertube, is a sport of rapidly growing popularity. It has several forms, from a lazy, swim-suited float down a slow-moving, warm river, to a specialized form of white water boating. Lower limits would be those which met the temperature and chemical requirements of swimming.



A. Tall, heavy adults (> 6')
B. Average adult, teen (≃ 5-6')
C. Sub-teen children (≃ 4-5')
D. Pre-school children (≃ 2-3')

DEPTH-VELOCITY LIMITS FOR WADING SAFETY

After Hendrickson & Doonan
(Modification of Figure 22)

Figure 10

Minimum Conditions -

Width = 25 feet, Depth = 1 foot, Velocity = 2 feet per second.

Maximum Conditions -

There are no maximum widths or depths. Velocity should be less than 10 feet per second.

Optimum Conditions -

Width = 75 feet, Depth = 2 to 5 feet, Velocity = 2 to 5 feet per second.

2.5.4.4 Water Skiing

Water skiing requires the temperature and water quality conditions of swimming combined with the physical requirements of large power boats. There must also be an extra margin of width to allow for turning the boat with the skier attached at sufficient speed to keep the skier at the water surface. As in the case of large power boating, small rivers are but poor substitutes for lakes and reservoirs for this activity.

Minimum Conditions -

Width = 200 feet, Depth = 5 feet, Velocity = 0 feet per second.

Maximum Conditions -

There are no width and depth maxima. Velocity must be less than 3.5 feet per second.

Optimum Conditions -

Width greater than 500 feet, Depth = 10 feet, Velocity less than 2.5 feet per second.

2.5.5 Wetland-Related and Water Enhanced Activities

This is by far the largest suite of activities considered under one general heading. Wetland-related activities include water-fowl hunting, bird watching, wildlife photography, and botanizing (the collection of plant specimens). Water-enhanced activities are all of those that take place out of the water, but which may be made more satisfying by the presence of water. The prime forms would be hiking, camping, picnicking, and sight-seeing along a river. Unlike the other groups considered above, these activities are not clearly related to the instantaneous level of flow, although flow level may be, in some senses, important or even crucial.

The only method for dealing with these effects is a radical departure from the criteria approach used for all of the in-the-water activities. Careful map study and limited field reconnaissance will allow the identification of wetland resources along and near the stream of interest and of the possibility of adverse effects from flow variation.

Water-enhanced activities are also not amenable to simple criteria setting. The aesthetic attraction of water operates at all flows from a trickle to a torrent. Even dry stream beds may be favored hiking places, both for ease of passage and for the water-carved forms sometimes seen.

Thus, these two groups of activities are not included in the criteria system developed above for the on-the-water activities. The recreation planner must be sensitive to these uses, but only the terrestrial ecologist and the aesthetic analyst can make meaningful determination of the influence of absolute flow or flow regime on these resources in specific situations.

2.6 Tentative Flow-Recreation Correlation

A preliminary estimate of the possibility, extent, and quality of available recreation resources on the study stream can be made by comparing the hydraulic geometry information developed in Section 2.4 with the recreation requirements presented in Section 2.5 The planner should assemble the following data elements.

1. Study area map with stretch classifications marked
2. Typical cross-sections for the stretches of interest
3. Stage-discharge, stage-width, and stage-velocity curves for those typical cross sections,
4. Annual and monthly average flow data for the stretches, with maxima and minima, if available,
5. The tabulated width, depth, and velocity criteria for recreation activities (from Section 2.5).

2.6.1 Hydraulic Geometry Correlations

A first level correlation is made in three steps. First, the AAF, monthly average flow, and monthly minimum and maximum flows are tabulated. These are compared to the stage-discharge, stage-width, and stage-velocity curves to determine the average annual width, depth, and velocity; the average monthly width, depth, and velocity; the maximum monthly width, depth, and velocity; and the minimum monthly width, depth and velocity. Finally, these are compared to the recreation criteria to determine possible recreation activities. Of particular importance at this level will be comparison to minimum and maximum recreation criteria. This yields a multiplicity of lists of possible recreation activities under different flow conditions, by month.

Another approach to this first level correlation can be made by simply noting the range of flows with a reasonable chance of occurrence. Several points within this range can then be selected and widths, depths, and velocities determined for these. Then, at each of the selected flows, a list of possible recreation activities can be prepared. This format has a useful side benefit. If the lists are compared in order of increasing flow, several observations can be made.

First, there will be a limited suite of activities available at very low flows. These might include swimming, wading, canoeing (flat water), rowing, and bank fishing in many streams. Second, at some level of flow above this minimum, a larger number of activities will become available. Depth and velocity increases might make possible tubing, sailing, and low power boating without eliminating any of the previous suite of activities. At some flow above this value, tradeoffs will occur. Some activities will be added and others will be deleted. For example, in many streams, the flow necessary to permit high power boating might violate depth and velocity maxima for swimming or wading. At a somewhat higher flow still, entire suites of activities will be replaced by others. The clearest example of this is the 5 foot per second velocity. When this level is reached, the non-power tranquil water boating activities will generally be replaced by the non-tranquil water boating activities and all of the water contact activities except tubing may be lost. At even higher flows, velocities in excess of 10 feet per second will limit low-power boats and tubing, leaving only the white water boaters and bank fishermen. Finally, velocities over 15 feet per second may eliminate even the white water boaters.

2.6.2 Map Correlations

The second level of recreation correlation is solely map dependent. Even though the analysis at typical cross-sections may show that a large number of activities are possible in terms of width, depth, and velocity, many activities are also governed by longitudinal considerations. This is where the earlier classification and air-photo interpretation comes into play.

Let us suppose that a stretch is found to be suitable for any of the various boating activities. This stretch should then be checked on the maps. If it is very short, its desirability for boating activities will be seriously reduced. For example, a short stretch of flat water bounded by two major rapids may not be suitable for tranquil water boating activities. On the other hand, a longer stretch, including both of the rapids and the quiet stretch may make a very desirable tubing area or non-tranquil water boating area.

2.6.3 Auxiliary Requirements

Site-specific considerations come into play in dealing with the water contact activities. For most of these, a sandy bottom and some beach area is preferable to a muddy or gravelly bottom and "fall-in" banks. If these latter conditions are found, the activity may not be practical, even though it is technically feasible.

Guidance in these types of auxiliary considerations is given in Section 2.4, where site-specific and reach specific requirements are determined from air photos, and in Section 2.5, where auxiliary conditions for the various suites of activities are discussed.

The final result of this task will be a listing of possible recreation activities at various flow levels, amended to reflect longitudinal and site-specific requirements.

2.7 Use of Available Recreation Data

Often there will be available to the planner reports, studies, user surveys, or like information on the numbers of people engaging in specific recreational activities at sites or along stretches of the river to be evaluated. Where such information is available, especially when ~~it is keyed to~~ specific dates, the usage can be correlated to hydrological records. This will permit at least a rough estimate of recreation potential, at specific places, at specific flows. Since such data rarely include much information of an hydrological nature, they rarely will provide much insight on specific river conditions such as width, depth, or velocity. That recreation is taking place implies that these parameters are within acceptable limits, but often little more.

2.7.1 White Water User Data

One possible exception to this general rule relates to boating, especially on white water. In some instances recreational information is available tieing recreationists' evaluation of their experience to flow, using home made staff gages or painted gage marks on bridge abutments or piers. On many rivers it is possible to relate such observational information to measured stream-flows at nearby USGS gages.

In the northeastern United States, the Appalachian Mountain Club (A.M.C.) maintains "A.M.C. River Folder Data" on many of the rivers and streams of the region. At the conclusion of each A.M.C. trip the trip leader is responsible for filling out one of these reports. Reports for the Saco River over the last 10 years were analyzed and compared to recorded daily average flows at the Conway USGS station. In Table 4, these are converted to a percentage of the Average Annual Flow and were compared with trip leaders' evaluations to arrive at a minimum flow acceptable for canoeing and kayaking. The level of acceptability is a combination of factors such as water depths over critical rocks, spacing of hazardous rocks at varying flow levels, and influences of bank hazards such as fallen trees. It can be seen that among different leaders there is not an exact point below which flows are considered to be too low. This reflects personal experience, the level of skill of those on the trip, and the fact that over the ten years of record changes in the river channel have taken place which require more or less water to negotiate than in previous years. For the Saco the minimum necessary for canoeing lies between 2.3 and 2.7 times AAF.

This kind of flow-specific information can be of great value, especially for white water activities which offer limited opportunities for direct observation. Additionally, of all instream recreational activities, white water conditions are most difficult to predict on the basis of synthetic data. While there are some general guidelines for classification which have been discussed above, each white water river is to a considerable degree unique.

2.7.2 Other Data

For other riverine recreational pursuits data on existing usage may help to identify places and flows which should be considered in conduct of the field studies program. As a rule, however, such information, while useful, will not be essential. It does provide a convenient check on preliminary predictions based on pure analysis of data.

TABLE 4

SACO RIVER COMPARISONS

USGS Conway Gage Reading (CFS)	% Average Annual Flow (AAF = 917 CFS)	Comments (AMC Trip Leader's Forms)
723	79	family 'float', considerable walking
771	84	near lower limit of usability
1610	176	too low for white water
1660	181	
1700	185	just runnable
2100	229	"optimum minimum" white water
2400	264	(too low at iron bridge)
2430	265	class II low
2580	281	
3810	415	
3900	425	not high, but enough
4380	478	water strong, few rocks
4990	544	water high, rocks covered
5410	590	high
5750	627	
5870	640	high
6280	685	
7210	786	
13200	1439	just a float trip

3.0 FIELD STUDIES

Preliminary analysis only begins the river evaluation process. Field visits are necessary to test preliminary hypotheses. Several important steps are required for the field studies aspect of river evaluation.

3.1 Timing

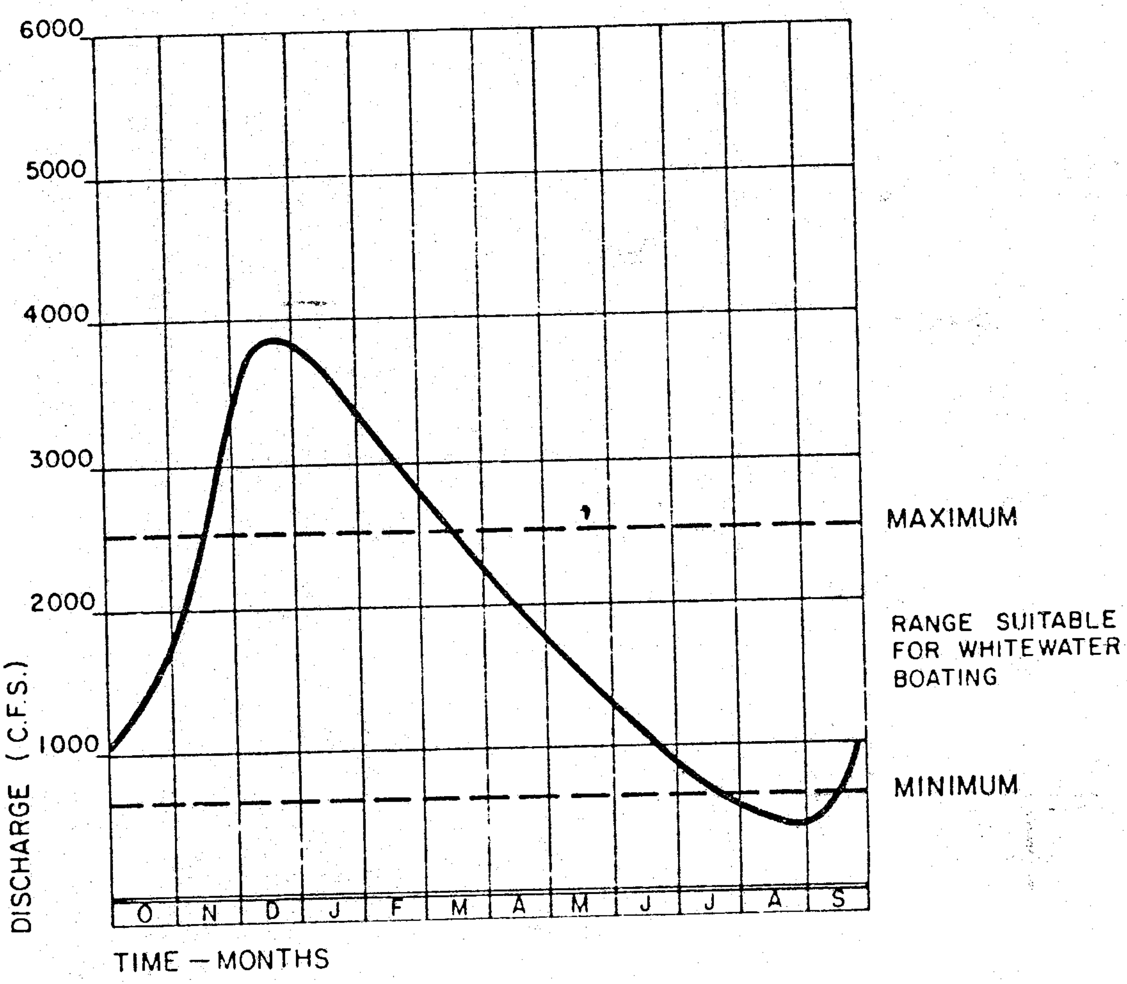
Timing of the field work is an important consideration. This should generally be chosen to provide a flow on the river which is considered to be at or below optimum for the kinds of recreational activity which appear from preliminary analysis to be of prime interest.

Where winters are severe it is desirable to avoid periods of very low temperature. River flow may be affected by ice at such times. Perhaps more to the point, conduct of field work on rivers is uncomfortable and may be hazardous when both air and water temperatures are low. In addition, all other things being equal, it is desirable to select times for the field visit which are appropriate to recreational usage in terms of weather.

Where a river is actively in use for recreation, the best choice of date for the trip may lie in the active recreation season. This affords an opportunity to combine theoretical studies of relationships between flow and recreation with actual observation of on-going activity. However, it will not always be possible to observe the flow of chief interest at such times. Ultimately, the timing of the trip should be governed by the expectation of finding a discharge close to that identified as more or less optimum for some dominant recreational use or some set of recreational uses. Often such flows will not coincide with the peak recreation season. This is especially true for many regulated rivers where flows during the summer months reflect irrigation requirements rather than the needs of recreation.

3.1.1 Identification of Dates for Flow of Interest

In the case of white water rivers, outfitters and canoeing organizations are usually very knowledgeable about the relationship between recreation potential and river stage. Canoeing guides frequently publish such information in written descriptions, tables, or graphs for specific rivers. Figure 11 illustrates this kind of presentation. When it is desired to study a river which is regularly used by white water enthusiasts the best course is to establish and maintain contact with the experts on the state of the water. This usually will provide sufficient information to permit scheduling a trip to the area about a week in advance and still obtain a flow in the range of interest.



SUITABLE FLOWS BY SEASON

(AFTER GARREN, 1976)

Figure 11

For many other kinds of recreation, however, the field visits may or may not coincide with peak recreational use, for various reasons. This being so, the period of expected flow at the desired level should govern selection of field dates. The objective should be to look for a flow on the low side of the expected optimum for the activity or activities expected to be of greatest importance as a result of the preliminary analysis phase of the work. In general, the lower the stage of the river, the easier it is to conduct the measurement program, especially in the case of running cross-sections.

3.1.2 Flow Data Analysis

During the course of an average year, most rivers, even most regulated rivers, exhibit rather wide ranges of average daily flow. The difference from high to low flow may cover several orders of magnitude. Moreover, save for the rare event, discharge patterns tend to be more or less consistent on a seasonal basis from year to year. Thus, if one chose the proper dates one might be able to examine any flow from, say, 200 to 30,000 cfs on a given river in the course of a year.

In the case of the natural stream which is adequately gaged there are usually available long term records of average flow by day, by month, and by year. These data can be plotted to reveal seasonal patterns. Usually, monthly averages will be sufficient for this purpose. However, in some cases where seasonal variation trends are sharp, it may be desirable to plot the pattern of daily averages for that season.

Most regulated streams will not exhibit ranges in flow as wide as those on a natural river. However, such streams are almost always gaged, which makes it possible to obtain and plot the patterns of flow distribution.

If the stream is ungaged, it is possible to approximate the discharge by calculating run-off from the watershed on the basis of meterological records of precipitation. The data can be plotted to some degree of accuracy in terms of seasonal or monthly averages. However, this method is usually not amenable to the determination of average daily flow, except perhaps on very small watersheds.

The analysis of flow data should permit identification of the best likely period in which to conduct the field trip within a matter of a few weeks, unless the year is atypical. The final selection of field trip dates should be made after consultation with USGS personnel or others who visit the reach of interest and are aware of the river stage and its relation to discharge. Where such information is lacking completely, it may be necessary to compare weather patterns (temperature and precipitation) with the norms for the average year and try to pick a period which should provide something approaching the desired flow under average conditions, modified if necessary to account for deviations from the norm in the weather.

3.1.3 Potential Conflicts with Active Recreation

An important consideration on some rivers may be the avoidance of certain recreation periods. An example of this would be the weekend of a white water race. Under these circumstances, cross-section measurements might range from impolitic to impossible. Basically, any event or condition which draws an unusual number of users to a river makes the actual field work difficult. One method of avoiding such conflicts and taking advantage of the circumstance is to plan the field effort for the week days just before the preclusive event or condition and to remain for the weekend to observe the activity and interview the participants.

3.2 Reconnaissance

Once in the field, the general reach of concern having been determined, a reconnaissance survey is the first step. Where the reach is long or access difficult, this is sometimes best accomplished from the air. Windscreen observations from an automobile provide a fairly rapid means for covering a reach of reasonable length if access is good. In some cases, actual transit of the river by canoe or other water craft may be desirable. The purpose of the reconnaissance is to develop a better "feel" for the river than can be obtained from simple analysis of maps, photos, and hydrological data. It permits the final selection of specific reaches and sites to be examined in detail.

3.2.1 Aerial Survey

In cases where the study reach is very long or where roadway access is difficult, aerial survey offers a large information return for little time investment. Aerial survey is best carried out by helicopter or in small, top-winged, low-speed aircraft. This allows slow, low flying and provides for unobstructed photography. Air reconnaissance gives the survey team an opportunity to see the entire reach in a short period of time, to take oblique aerial photographs, and to examine the reach for obstacles and opportunities which might have been missed in the map and aerial photo studies prior to field trip. This can be particularly useful in finding access routes to remote rivers. The routes may often take the form of small dirt roads or logging roads not visible on maps or high altitude air photos.

3.2.2 Windscreen Survey

An alternate to or supplement to air reconnaissance is a windscreen survey where roadway access to the river is good. This has the advantage of not requiring an aircraft, but it will seldom allow a view of all of the study reach. The intent is the same as aerial survey - to find obstacles and opportunities overlooked in remote studies. Additionally, site visits can be made part of the windscreen survey when preliminary sites are readily accessible from roads. A limited amount of bank side hiking can extend the coverage of a windscreen tour considerably.

3.2.3 On-the-Water Survey

If time will allow, an on-the-water survey can be a useful adjunct to an air or windscreen survey and may be required on rivers with little or no roadway access. In this case, on-the-water survey will be the most feasible method of visiting the preliminary study sites to gather information for final site selection. On truly inaccessible streams, it may be necessary to perform physical measurements on too many rather than too few of the preliminary sites to avoid the necessity of repeating the trip. In any event, the on-the-water survey is the most complete and accurate form of survey, since all of the photo stretch classifications can be field verified and amended, if required, before detailed studies are undertaken. The craft of choice for this task is usually an open canoe, either with or without a small outboard motor. Such a craft can negotiate very shallow water and, well handled, can be used in moderate (Class II or II-1/2) white water.

3.2.4 Initial Site Visits

Regardless of the method of reconnaissance chosen, visits to all preliminary study sites must be made. At each site, a field data sheet (see 3.4) can be used to record estimated and measured physical characteristics of selected sites and to record photos of the rejected sites. It is also possible that the preliminary reconnaissance will have revealed some sites of strong potential for study which were not discovered in the pre-field map and air photo studies. These should also be visited so that the final site selection will yield the most representative and useful set of field study sites.

3.3 Site Selection

3.3.1 Recreational Criteria Affecting Site Selection

Some categories of sites at which detailed measurements and observations are to be taken should be pre-selected prior to start of the field study. These might include sites which are representative of similarly classified stretches and sites which are expected to provide unusually suitable conditions for one or more recreation activities. Further subdivision of potential sites is often necessary to ensure adequate documentation of flow conditions along a river reach.

Instream recreational activities can be categorized generally as those centered about a suitable site and those requiring longitudinal suitability. In the one case, minimum flow requirements must be met at the specific location; in the other, minimum flows must prevail throughout the stretch. It is not always possible to identify all areas along a stretch which may present physically limiting factors from remote data alone; however, using a combination of air photos and field checking should make it possible to locate at least the critical areas. These would include such features as: dams, falls and rapids, very wide sections where depths are uniformly below the average for the rest of the stretch, and areas where extensive instream vegetation may interfere with passage. Failure to locate such areas, and to take account of the limiting conditions they present, may lead to error in recommendations based on remote information alone.

Complete width, depth, and velocity measurements at such areas may not always be feasible. For example, in a large riffle area with an average depth of less than six to eight inches it is easy to measure width and depth. But it is extremely difficult to take accurate velocity measurements because of the shallow water. For such a site, discharge information may be imputed by comparison with a site more amenable to measurement in the vicinity, either downstream or upstream.

3.3.2 Physical Site Criteria

The preselection process should have narrowed the areas to be considered for final site selection. However, field checking is often essential to complete the site selection process. Some conditions may not be found if remote data are relied on solely.

For activities, such as most non-tranquil water boating, where minimum depths are extremely critical, the location of physically limiting areas must be accomplished in the field.

When small dams or diversions have been emplaced since the most recent aerial photography, these must be identified either through a field check or through communication with people having knowledge of local conditions.

If no aerial photography is available, sites selected on the basis of map study alone must be verified by field investigation as a rule.

If extraordinary runoff events have occurred since the most recent aerial photographs were taken, major channel shifting may have occurred. While such changes may not require reclassification of the stretch, it may be necessary to shift field study sites to new locations at some distance from places identified during the preselection process.

When two sites appear on the basis of remote data to be similar in terms of classification it is wise to field check them to determine whether or not both must be studied. While no two sites are exactly alike, if the two are sufficiently similar that it appears that recreational activities will be affected in essentially the same manner by changes in flow, then a single site may be chosen for detailed study. If doubt exists, however, both sites may be studied.

Alternative sites may be required if access is difficult or land ownership is unclear. However, when a particular site is deemed necessary for a complete analysis, permission to enter should be obtained prior to departure for the field.

3.3.3 Number of Field Sites Required

The number of sites to be investigated may be influenced by many factors. These include the length and heterogeneity of the river reach, the difficulty of running sections because of river conditions, problems of access, the season of the year, available manpower, and budget. Because there are so many variables, it is not possible to stipulate precisely the number of sites which should be studied in detail.

If one assumes that about a week (5-7 days) is available for field work on a river reach, some rough estimates of the work can be made. If access is possible from roads or by hiking from a road, reconnaissance should take no more than a day for most investigations. If access must be by water, reconnaissance and field surveys are combined. Two people can run a cross-section on a wadeable river 300 feet wide in no more than 1.5 to 2 hours; this time includes completion of the field analysis form and establishing photo points. However, access time must be added. If one assumes no equipment failures, moderate to easy access, and depth and current conditions amenable to wading, a crew can study five sites per day.

If a river is essentially homogeneous in channel pattern, a small number of sites will provide adequate coverage of stretches of interest. However, consider a reach which is classified as 80% braided and 20% straight. This does not imply a like distribution of field investigation sites. If many of the braided stretches are quite similar in nature, it may not be necessary to sample each of them. On the other hand, if the straight stretches offer a number of potentially limiting or hazardous areas, they may require intensive sampling. As a rule, however, the number of sites will tend to be larger in those stretches representing the greater length of the total reach; but the site distribution will not necessarily follow the relative length distributions exactly.

Finally, it should be noted that the number of sites to be studied varies with the purposes of the river investigation as well as with the river conditions and other factors considered above. In some cases a "rough cut" may be all that is required; in others, a rather precise determination of flows may be called for. The latter will entail a much more extensive field program than will the former case. Accordingly, the number of sites to be studied must be determined by the study team after due account is taken of all the variables which must be considered.

3.4 Physical Measurements

When study sites have been definitely established, a suite of physical measurements are taken, including the development of cross-sections and velocity profiles. Along with measurements of width, depth, and velocity, observations of special conditions affecting recreation potential should be recorded. Liberal use of a camera provides a permanent record which can be of invaluable assistance later in analysis of field data. When a tour of the river is chosen as the means for conducting the reconnaissance, the measurements may be taken at appropriate places during the tour.

3.4.1 Equipment

The following items are necessary to carry out field measurements on wadeable streams or rivers. In the case of rivers which are not wadeable, provisions to carry out measurements from boats, bridges, or cableways must be made.

1. Data Forms:
   a. Field Survey Forms,
   b. Cross-section tabulation forms (on Field Survey Form).

2. Maps - preferably mounted on cardboard strips.

3. Air Photos - black line prints of originals joined together and mounted on cardboard, with a plastic or acetate overlay case.

4. Current meter (Gurley #622 or equivalent) with measuring rod.

5. Measuring tapes (steel).

6. Thermometers.

7. Line levels, attached to 30-40 feet of line.

8. Bound flow records including rating curves, flow duration tables, and summaries of gage data.

9. Stop watch.

10. Optional - Brunton Compass (for stake alignment).

If the sag-tape method of channel cross-section measurement is to be used, the following additional equipment will be necessary.

1. Two stake fasteners.

2. A small spring scale and tape clamp.

3. Data forms set up to record required data for the computer program to be used.

3.4.2 Physical Measurements Procedure

The procedures presented here represent a distillation of standard USGS stream gaging techniques, fisheries methods such as the Oregon method, and methods used when data input for computer simulation is necessary.

Width

1. Measured using a tape from water/bank intercept.

2. Where possible, a continuous width measurement should be taken.

3. If necessary to make more than one measurement, stakes aligned by compass should be used to keep the width line straight.

4. Measurement should be perpendicular to flow.

5. If the sag-tape method is used:

   a. The tape is stretched between stakes on either bank,

b. Tension must be put on the tape of at least 5 lbs., plus one pound for each 10 feet of transect length.

c. The computer program then requires the weight of the tape in lbs/ft, length of tape, and the tension applied.

Depth

1. Depth measurements are taken along the width of the transect line.

2. Measurements should be taken such that no measurement represents more than 10% of the discharge.

3. Measurements should be recorded in feet and tenths.

4. Significant bottom changes between fixed interval points should be noted and measured.

5. Depth measurements for the sag-tape method are taken at the same interval but are from the tape to the channel bottom, not from the water surface to the channel bottom.

6. At each depth measurement, an approximate bottom sediment description should be noted. Use the Unified Soil Classification (Figure 12). When possible, gravel sizes should be approximated, e.g., 60% 2-3 inch gravel.

Velocity

1. Taken at positions where depth measurements were made.

2. When the total depth is:

   a. Between 0.3 and 2.5 feet measurement taken at 0.6 of total depth measured from the surface down.

   b. Depth in excess of 2.5 feet, measurements at 0.2 and 0.8 of the total depth measured from the surface down.

3. Where conditions exist for which there are no available gaging records on a stream or river, the above outlined approaches must be used to obtain an accurate discharge measurement. However, in situations where considerable velocity-stage data are available, or extremely difficult field conditions are encountered, or serious time and budget limitations exist, single point measurements (0.6 depth) spaced at

Primary divisions			Group symbol	Secondary divisions
Coarse grained soils. (More than half of material is larger than No. 200 sieve size.)	Gravels. (More than half of the coarse fraction is larger than No. 4 sieve size.)	Clean gravels. (Less than 5% of material smaller than No. 200 sieve size.)	GW	Well graded gravels, gravel-sand mixtures, little or no fines.
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.
	...do.......	Gravels with fines. (More than 12% of material smaller than No. 200 sieve size.)[1]	GM	Silty gravels, and gravel-sand-silt mixtures, which may be poorly graded.
			GC	Clayey gravels, and gravel-sand-clay mixtures, which may be poorly graded.
Do.......	Sands. (More than half of the coarse fraction is smaller than No. 4 sieve size.)	Clean sands. (Less than 5% of material smaller than No. 200 sieve size.)	SW	Well graded sands, gravelly sands, little or no fines.
			SP	Poorly graded sands, gravelly sands, little or no fines.
	...do.......	Sands with fines. (More than 12% of material smaller than No. 200 sieve size.)[1]	SM	Silty sands, and sand-silt mixtures, which may be poorly graded.
			SC	Clayey sands, and sand-clay mixtures, which
Fine grained soils. (More than half of material is smaller than No. 200 sieve size.)	Silts and clays. (Liquid limit less than 50.)		ML	Inorganic silts, clayey silts, rock flour, silty very fine sands.
	...do..........................		CL	Inorganic clays of low to medium plasticity; silty, sandy or gravelly clays.
	...do..........................		OL	Organic silts and organic silt-clays of low plasticity.
Do.......	Silts and clays. (Liquid limit greater than 50.)		MH	Inorganic silts, clayey silts, elastic silts, micaceous or diatomaceous silty or fine sandy soils.
	...do..........................		CH	Inorganic clays of high plasticity, fat clays.
	...do..........................		OH	Organic clays and silty clays of medium to high plasticity.
	Highly organic soils.............		Pt	Peat, meadow mat, highly organic soils.

[1]Materials with 5 to 12 percent smaller than No. 200 sieve are borderline cases, designated: GW-GM, SW-SM.

[2]See Ch. 3, Figure 3-1, for position on plasticity chart.

UNIFIED SOIL CLASSIFICATION SYSTEM

(AFTER U.S. NAVY, NAVDOCKS DM-7, 1971)

Figure 12

intervals wider than 10% of the total discharge may be justified. Since one of the objects of the field work is to produce accurate, reproducible results, the greater the precision with which the measurements are carried out the better.

Temperature

1. Measurements should be taken at approximately mid-depth at every other or every third depth station.

2. Where possible, the thermometer should be read with the bulb immersed.

3. Air temperature and the time of the measurement should also be recorded.

Longitudinal Profile

1. Measured using 2 surveying rods, Abney Level, and a measuring tape.

2. Recorded in gradient (ft/mile) or percentage slope.

3. Measured immediately up and downstream from the cross-section.

3.4.3 Field Survey Form

The field survey form (Fig. 13) organizes field observations and measurements, other than width, depth, and velocity. Most of the categories are self explanatory. A bank or beach is denoted as right or left as the observer faces downstream.

Bank/Edge Condition

1. Bank height is measured using a level line and a measuring rod.

2. The bank condition measured is that caused by normal flow conditions in the natural channel.

3. Measurement is made from the water surface upwards to the upper bank edge.

4. A transect level line parallel to the width transect, in a landward direction, on both banks is continued for 30-50 feet noting significant elevations and changes in slope.

5. Bank material is specified according to Unified Soil Classification Method.

Figure 13

field survey

Sampling location no.

River ______ ADF ______

Nearest USGS Gage ______ Photo # ______

Date ______

Time ______

Temp. ______

Weather ______

CHANNEL CHARACTERISTICS

Width ______

Depth ______

Velocity ______

pH ______

Clarity/turbidity ______

Temperature ______

Odor ______

Taste ______

CHANNEL SECTION

degree of canopy enclosure:

stream bottom characteristics:

vegetation in stream:

observed aquatic fauna

special features: falls O riffle O islands O rocks O dam O other O
point/sand bars O

BANK/EDGE CONDITION

bank height:

bank slope:

floodplain width:

wetted area variations:

"near" field floodplain

"far" field floodplain vegetation:

bank material:

terrestrial fauna:

BEACH CONDITION

width:

depth:

length:

bottom material in water:

bottom material on edge:

debris:

slope to water 75':

distance to 5' water:

vegetation:

Figure 13 (CONTINUED)

"REACH" CHARACTERISTICS

length:
average width:
sinuosity:
variable elements:
visibility from public areas:

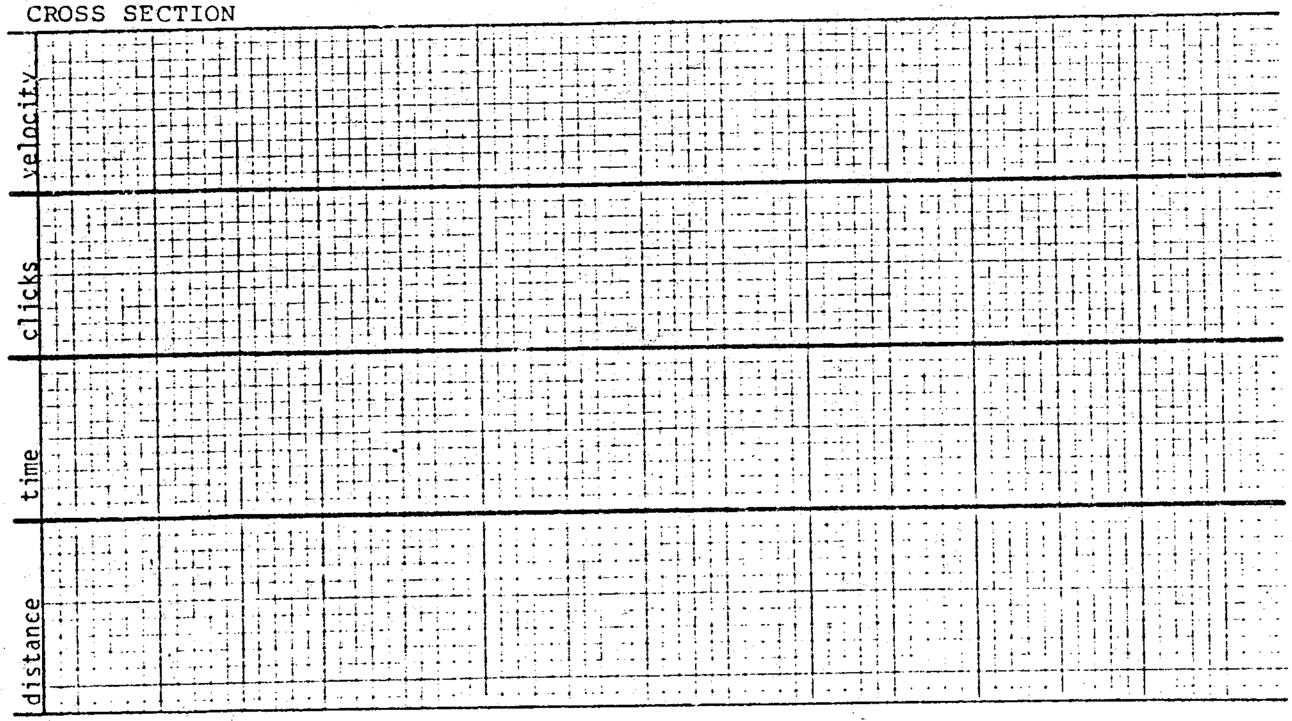
RECREATIONAL USAGE

indicators:

observations:

field interviews:

CROSS SECTION



Beach Condition

1. Bottom material in water and along the edge is classified according to the Unified Soil Classification System.
2. Slope to water is obtainable from previous bank/edge transect. (Where a beach of 30-50 feet in width exists, a level line transect should continue across the beach width.

3.4.4 Photographic Procedures

Photographic procedures can be grouped into two basic areas: establishment of photo points and photographs of recreationists.

Photo points should be established at each site selected for cross-sectional analysis and at sites where physically limiting factors are located, across which transects may be difficult.

The first step in establishing photo points is to indicate very accurately the location of the study transects. If suitable landmarks do not exist, there are many ingenious methods by which the site may be marked for later use. When possible the photos should be taken from upstream and downstream of the transect so that the transect itself appears in the photo. Photographs should be taken looking upstream and downstream, and of bank conditions on both sides. It is often helpful when choosing an area to be photographed, to include features such as point bars and mid-channel bars so that when pictures are taken at later dates, relative flow conditions can be easily visualized. If such features do not exist, surveying rods may be substituted. The exact position of the rod should be indicated in the field notes.

Any reference points which are included in the photo should be described clearly so that later field crews unfamiliar with the site can orient themselves. As an aid to locating a photo point, it is useful to take a copy of the original photographs or slides back into the field so that the frame of view on the photo agrees with that seen through the camera.

In addition to establishing photo points, pictures should be taken of recreationists observed at the time of study. Of particular interest are pictures indicating the effects of instream flows on activity, such as canoeists walking their canoes because of the shallow water or obstructions or canoeists successfully negotiating a stretch where sufficient depths exist.

3.5 Observation of Recreation Activities

The field study program is intended to provide a chance to make physical measurements and observations at places which may be suitable for recreation usage. The timing of the field study is based on the river stage primarily to permit evaluation at a predetermined flow. Thus, the visit may or may not coincide with active recreational use of the river. If recreationists are in fact engaging in fishing, swimming, boating, or some other activity the field team has at hand an additional source of information.

3.5.1 Observation

Observation of the types and kinds of recreation activity underway will reveal part of the potential of the stretch or site under the observed flow. This can be correlated with physical data and serve as a check on preliminary estimates of possibilities.

3.5.2 Interviews

It is also possible to obtain additional information from active recreationists by conducting informal interviews with those willing to cooperate. The thrust of the interview should be to determine the user's estimate of the suitability of the flow (as expressed in terms of depth, velocity, and so on affecting his activity) for his purposes. Those who engage in recreation in the general area of interest, on a more or less regular basis can often provide good qualitative information on minimum and optimum flows. They may note that the observed conditions are just about right or that the flow is nearly too high or too low. For instance, while they will almost never be able to provide this kind of information in terms of actual discharge (in cfs), they may frequently provide information that can be converted into discharge. Thus, they may say that if the water drops below a certain level as evidenced by the appearance of a specified rock in the stream or by extension of a "beach" area to a certain place, the activity of interest becomes difficult or impossible. Such "landmarks" can be measured and their location correlated with river stage.

This kind of interview information can be extremely useful. However, it is not essential to the analysis of most situations. It may not be available if the field program takes place outside of the normal recreation season or in a place not much used because of difficulties of access. Accordingly, the person engaged in a river evaluation study should not depend on access to recreationists. But if the source is available, it should be used.

3.5.3 White Water

The one possible exception to the above generalization is in white water recreation. The flows required for white water boating are very difficult to predict. The general requirements for white water can be identified in terms of gradient, depth of water, nature of rapids, and so on. The actual navigability of the river tends to be extremely flow dependent, on a site specific basis. Thus, in some places when the flow is too low, the river is essentially impassable because of obstructions. At some higher flow the same stretch may provide an excellent experience. At an even higher flow, some stretches will become totally impassable, while others will simply represent a very fast but otherwise dull ride. Similarly, in some places large rafts can be used at flows not suitable for even expert kayakers, while in other places the reverse will hold.

In view of the above, the best measure of the relationship between flow and recreational potential on white water is that obtained from people knowledgeable in the sport and adept or expert in handling a canoe, a kayak, a float boat, or a raft in white water conditions. This suggests strongly that white water conditions should be studied during periods of actual use and that efforts should be made both to observe recreationists on the river and to interview them if possible. The information obtained from the observations and interviews can then be correlated with discharge data and physical measurements such as cross-sections and velocities. If it is necessary to evaluate a potential white water stretch in a place or at a time when use by the public cannot reasonably be expected, it may be necessary to add some experts in kayaking or rafting to the study team to obtain their judgements on the conditions in the river at the observed flow. This appears to be one type of riverine recreation which requires actual participation to support evaluation of the suitability of a given level of discharge.

4.0 SYNTHESIS

When the field work on a river is complete, the accuracy of original predictions of the relationship between flow and recreation made before the field trip can be checked. Generally, the form of these predictions will remain intact; but the detail of them will be improved as a result of field observation. In particular, the field work will have given new insight into site-specific conditions and to longitudinal considerations which were not evident from the remote sensing analysis. The field work will also have provided substantial information on ungaged streams or stream reaches which can then be tied into gaged streams or reaches nearby. In this fashion, the predictions are "tuned" to the observed conditions on the stream at the time of the survey and extrapolation to other flow conditions becomes more precise.

This synthesis occurs in four steps: analysis of the field data; prediction of physical changes at flows different from those seen in the field; prediction of recreation potential at flows different from those seen in the field; and, perhaps, confirmation visits to the field to observe different flows.

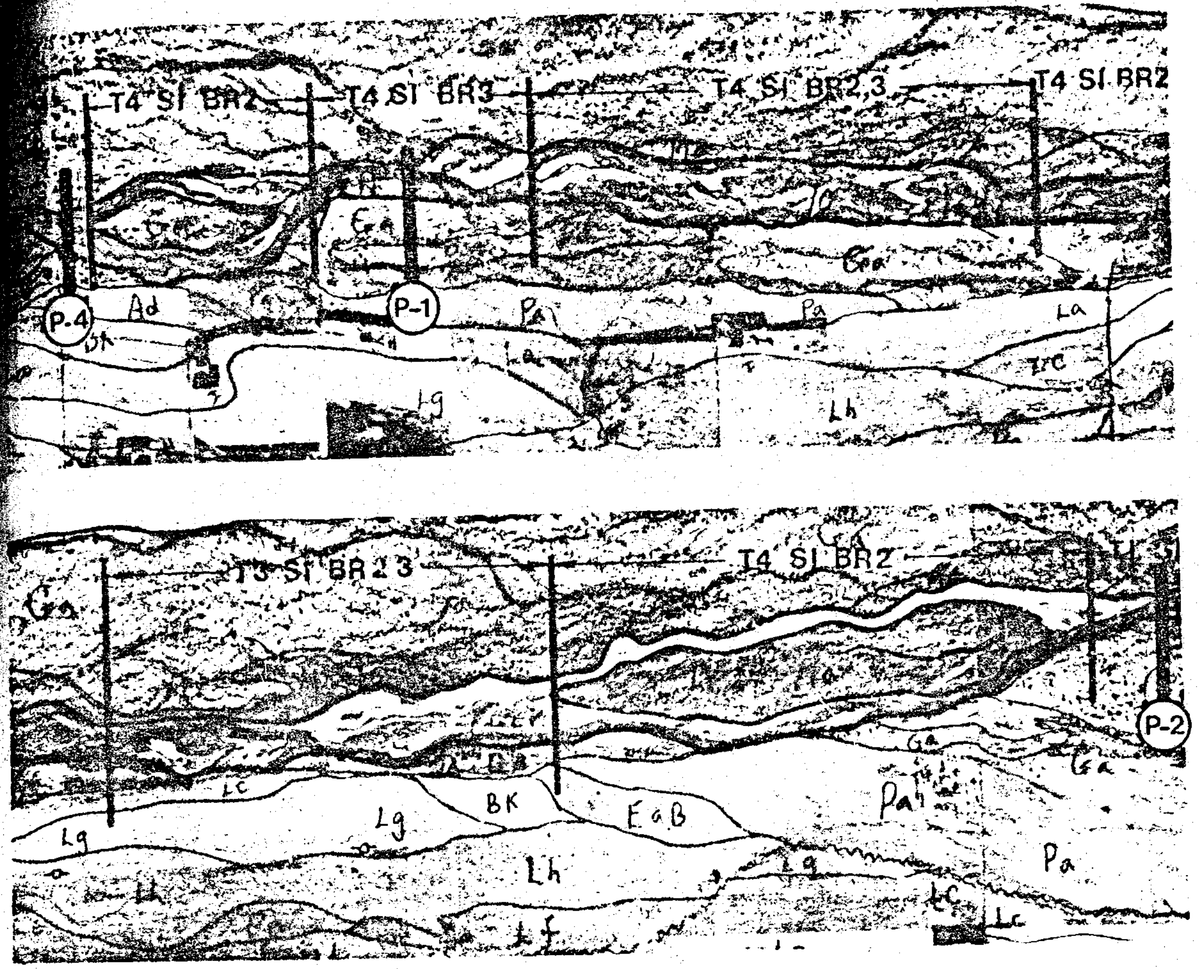
4.1 Analysis of Field Data

4.1.1 Preliminary Analysis

Upon return from field work, data should be prepared for use in plotting cross-sections and determining discharge at the cross-sections. Cross-sections should be drafted or computer plotted for each station which was run (Figure 14). The scale which is used depends upon the size of the river in question and the level of analysis to be carried out. For reference, the discharge at each cross-section in cfs and percentage AAF should be labelled.

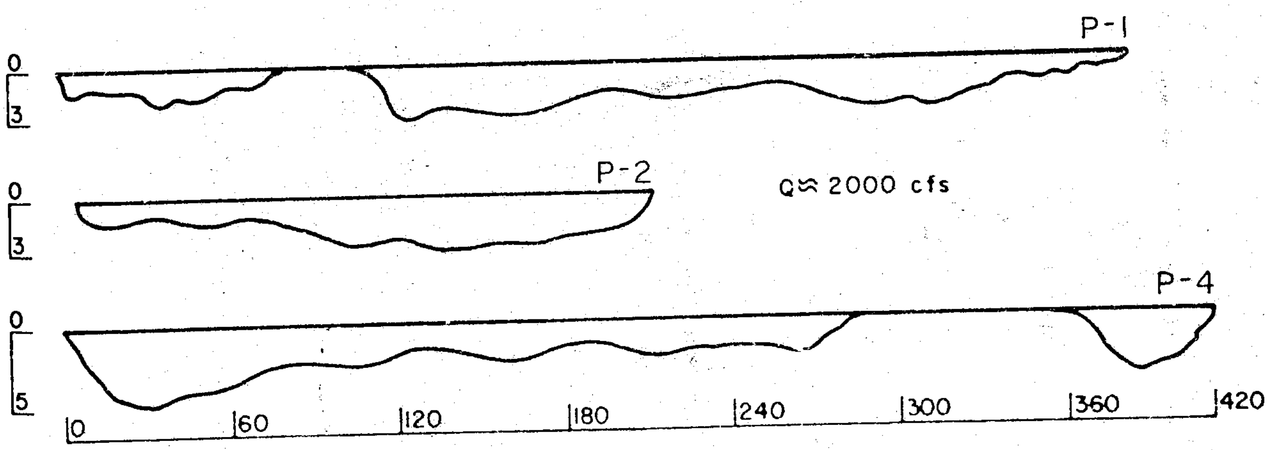
Where possible, bank conditions (vegetation, thickness of vegetation, degree of undercut etc.) and actual and potential access areas should be indicated, along with cross-section locations, on the base map or on air photos. This information for areas between measurement sites should be obtained from "windscreen" surveys, surveys conducted from the water, or from aerial surveying. On many rivers poor access will prevent "windscreen" and walking surveys, necessitating viewing from the water or the air.

Any changes in river classification which were made after field examination should be corrected on the base maps. Pictures taken at the photo points should be labelled as quickly as possible with the location, approximate discharge in cfs, and the direction of the photo (upstream, downstream, or transverse).



MAP SCALE 1:28,800 (appx.)

CLASSIFICATION OF A SECTION OF THE NORTH PLATTE RIVER, EAST OF HERSHEY, NEBRASKA



SURVEYED CROSS-SECTIONS P-1,2,4, NORTH PLATTE RIVER, JULY 1976

VERT. EXAG. 6X
SCALES IN FEET

Figure 14

4.1.2 Site Analysis

For each of the cross sections which were run, the previously discussed physical recreation criteria are now applied. An initial decision must be made as to whether or not a particular recreational activity can take place at the site in question and for the flow(s) encountered. This decision should be based on the width, depth, and velocity requirements considered minimum for different activities. If the conclusion is reached that an activity is not possible at the flow examined, the conclusion should be qualified in light of other sections examined. This may be accomplished by examining the results for every section for one activity at a time. If the activity was not possible at any section surveyed, then the flow examined should be considered below or above that necessary for that activity.

If an activity is possible at some sites and not at others, it should be tabulated as such. For example:

Activity	Flow	No. of Sections	Sections where activity not possible
Swimming	100 cfs	12	11

If the river classification scheme is valid and sites were chosen in a representative fashion, then by using this type of analysis one should be able to say at flow X, a certain percentage of the river is suitable or not suitable for the recreational activity in question.

4.1.3 Limiting Conditions

While a site analysis is satisfactory for site-dependent activities and when the activity is either clearly possible or not, situations are likely to arise when this will not be the case and further analysis will be necessary. One case would be where activities are dependent on stretches of the river meeting minimum requirements over a longitudinal distance. This applies primarily to boating activities, including canoeing, kayaking, sailing, tubing, rowing, and power boating. Analysis of data in this light requires the input of both site cross-section information and surveys run at physically limiting locations. In the data presentation, it is important to indicate that, at the flow conditions encountered in the field survey, there was so much clearance over riffle areas, low dams etc. In the case where riffle or wide shallow areas may extend for a distance in excess of 1/4 mile, over which minimum depth conditions were not met for boating, the area should be reported as being below minimum standards at a particular flow. Areas such as this should be delineated carefully on air photos or maps to indicate their extent and the proportion of the river reach they account for.

If the minimum criteria for a particular activity are not met over the entire width of a cross-section, a higher level of data analysis is indicated. In such an instance, the total usable width of the transect meeting the minimum requirements at the measured flow is calculated. The results are displayed in tabular form, as follows:

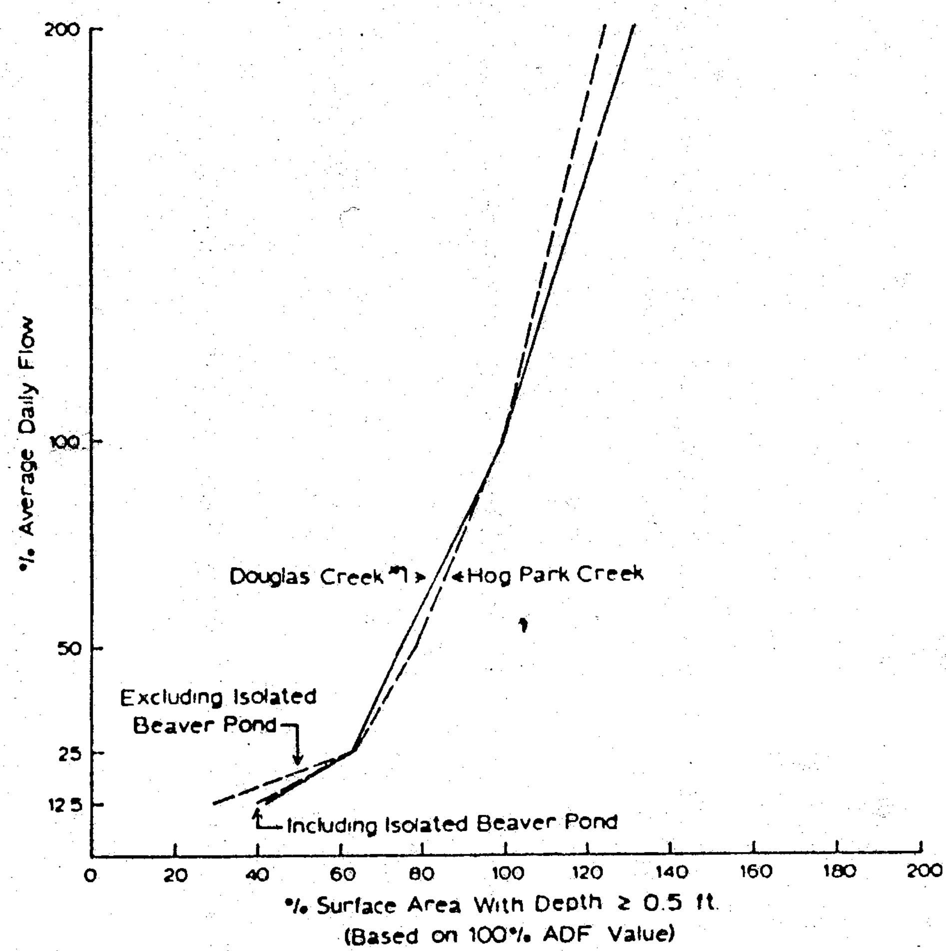
			Width Meeting Wading Criteria		Width Meeting Swimming Criteria	
Site	Flow	%AAF	% of Total	Feet	% of Total	Feet
R-1	250cfs	25	50	40	10	8
R-2	270cfs	25	60	45	5	4

Figure 15 summarizes two such width-discharge relationships for two study areas are indicated over a range of flow conditions. The data gathered during the initial field survey at a site provide a starting point for the development of such graphs relating width, depth, and velocity to flow (in cfs or % of AAF) at each site. Further data points to extend the curves may be obtained through future surveys, through synthetic data generation by hand calculation or computer, or through use of a combination of these techniques.

For most recreational activities, the usable area for an activity in terms of meeting width, depth, and velocity requirements can be expressed as a function of length on the transect and percent of total transect length. This is done by examining field measurement notes and determining how far from either bank the conditions meeting criteria for the activity of interest are met.

4.1.4 Correlation with Hydrological Data

After field data have been analyzed and plotted, they should be correlated with existing hydrologic data. As a first step, the discharge measurements which were calculated should be compared with nearby gage data to estimate the frequency of occurrence of the flows which were studied and to see how ranges of depths and velocities measured at similar flows at the gage station compare with these at the ungaged sites. If the hydraulic regime for both areas is very similar, the gage data may prove to be useful in predicting future events at the ungaged station. If hydraulic geometry relationships have been developed for the gage data, they should be used to test measured parameters away from the station. This will be a first order approximation; as mean measurements are used in developing these relationships, the range and extent of depth and velocities is not indicated.



Changes observed in the surface area having a water depth of at least 0.5 feet as flow was reduced at the Douglas Creek No.1 and Hog Park Creek study areas, expressed as a percentage of the value at 100% of the average daily flow.

Wesche, (1973) p.59

Width Discharge Relationships for Two Sites

Figure 15

On stretches where one is dealing with natural flows with no water development projects, a comparison can be made successfully on a stretch to stretch basis and, where sufficient similarities exist, on a river to river basis. This involves comparing known or gaged flows (minimum or optimum flows) for a given drainage area to unknown or ungaged flows for another drainage area. The ratio of drainage areas should approximate the ratio of discharges (known and unknown). A hypothetical example would be as follow:

Gage	Drainage Area (mi^2)	Minimum Tubing Flow
A	400	600 cfs (measured)
B	360	540 cfs (estimated)

The ratio of drainage area B to A (0.9) is used to estimate the minimum tubing flow at gage B. This is a rough approximation, but it is useful in cases where the data do not permit a more sophisticated approach.

The above mentioned techniques enable the field party to deal quantitatively with recreational potential in terms of where and over what portion of the river conditions occur which satisfy the minimum criteria for different instream activities.

In addition to flow measurements, other observations, both quantitative and qualitative should be included in the complete analysis of a river reach.

Bank conditions observed at measured flows should be summarized and their influence on recreation discussed. This may start out at the specific site level and be extrapolated to the reach, indicating the extent of such conditions laterally and longitudinally. Many attempts have been made to develop means of expressing bank cohesiveness. Because of sampling difficulties, none has been totally successful. It is sufficient to indicate whether difficulty is encountered in entering or leaving the water along a particular stretch because of bank steepness, heavily vegetated bank conditions, etc., and what type of recreation is possible considering these conditions. Depending on the situation, this may not ultimately be flow dependent; however, bank conditions may limit recreation potential even when suitable instream flow conditions are present. When evaluating certain types of recreation such as boating (and perhaps wading-fishing) this may not be critical; but for swimming, bank fishing, hiking, and hunting, it may be.

A general discussion of the aesthetic quality of the stretches at the measured flows should be included. Although it is difficult to quantify aesthetic values, mention should be made of items such as:

1. Water quality (color, odor, and turbidity)

2. Where applicable, whether surrounding urban areas or unsightly structures are visible.

3. The presence of natural debris such as snags, fallen trees along banks, and human litter.

4.2 Prediction of Physical Changes

Methods of utilizing data from field surveys and from other sources to predict physical changes associated with increased or decreased discharge are discussed in the following sections. These methods range from field estimates to computer modelling techniques. The success of any of these methods depends on the accuracy and amount of data that are used, and the level of analysis desired.

4.2.1 Extrapolation Using Known Data

In cases when minimum flow criteria for particular recreational activities have been established or where applicable discharge versus width, depth, or velocity relations are available, it is possible to integrate field survey results with such data in order to predict the minimum recreational flows needed at the survey site.

When minimum discharges have been established for other places in a drainage area, or for very similar drainage basins, a ratio method (sec. 2.4.1.3) using drainage areas and known and unknown discharges can be used to approximate higher or lower flows which may provide requisite minimum widths or depths.

Occasions may arise when minimum flow criteria are established at or near a gaging station or another location for which stream measurements are obtainable. An example of this would be where an instream spawning or fish survival study had been done using flows other than that investigated during the present instream study. Although these flows may not enable the investigator to determine minimum flows for all types of recreation, they would be useful for activities whose minimums or optimums overlap the fishery flows. In many areas these data would be in a form such that individual points of measurement used in determining total discharge may be examined.

When data have been obtained close to long-term gaging stations, it is relatively easy to use w,d, and v versus discharge curves to predict the discharge necessary to provide a minimum width or mean velocity or depth.

4.2.2 Field Estimation

It is important to consider while in the field the effects of higher or lower discharges on recreational potential at individual recreational sites and for the reach as a whole. The first step in this process is to perform a transect and, while measuring the physical flow characteristics of the transect, visualize initially what recreational activities are possible at that flow and then what activities would be possible with increased depth or width, etc. For example, while running a transect it may be determined that an additional foot of water would make swimming possible. The question now becomes, at what discharge will the average depth increase one foot? On a channel transect which has near vertical bank slopes so that with increasing discharge, below bank-full conditions, only depth and velocity increase, a rough calculation of discharge could be made by multiplying width times the mean depth (+ one foot) and multiplying this times the mean velocity. This would result in a "rough" estimate of discharge.

4.2.3 Modified "Slope-Area" Method

On transects where more gentle slopes occur or when a greater level of accuracy is required, the Chezy-Manning equation may be used to estimate the new discharge. This equation states that:

$$Q = \frac{1.486}{n} R^{2/3} S^{1/2} A$$

Where Q = discharge (cubic feet per second)
n = roughness coefficient (from published tables)
R = hydraulic radius (area ÷ wetted perimeter)
S = slope (decimal)
A = area in square feet

Since discharge = velocity x cross-sectional area or Q = V x A, velocity may also be obtained from this relation by dividing both sides of the equation by A (area). The equation then becomes:

$$\text{Velocity (V)} = \frac{1.486}{n} R^{2/3} S^{1/2}$$

This equation is also useful for calculating an accurate value of "n", using values of R, S, and V measured in the field.

Field measurements for a particular transect may be substituted into the equation. Using the example from 5.2.2 , the new depth (R) becomes the old mean depth + one foot. The wetted perimeter, which is the length of wetted contact between a stream and its channel, can be obtained by adding the measured wetted perimeter to that expected with a one foot rise in water level. In the field this can be determined by placing a measuring rod at the waters edge, and then placing one end of a level line on the rod and moving the other end far enough inland until the line is levelled. When this is done the distance from the measuring rod, along the ground, to the end of the line is measured for both banks and added to the old wetted perimeter. The new perimeter, based on mean increase of one foot, results.

For the purposes of a field calculation, the original roughness coefficient (n) and slope (S) are used. It now becomes a matter of substituting these new values into the equation. On the whole this technique allows a reliable estimate of discharge to be made. This method may be worked in reverse if desired. In order for this technique to work reasonably well , bank slope measurements must accompany all cross-sectionsal transects.

4.2.4 Computer Modelling

Various computer programs from which it is possible to predict width, depth, and velocity changes at a number of different discharges are available. Many of the programs utilize a modified form of the slope-area method adapted for rapid, multiple discharge calculations. If computer modelling is under active consideration for use in data analysis, field data forms should be set up to facilitate keypunching or digitizing. If computer models exist for a river under consideration, then the data gathering techniques peculiar to the method should be initially used in field work.

Most modelling techniques initially require field surveys in which numerous cross-sectional transects are measured, along with longitudinal slopes. Estimates of roughness coefficients are determined for different sections of the transects. If the sites selected for recreational study areas coincide with these transects, then it is possible to determine width, depth, and velocity parameters at any discharge of interest. It is also possible to work in reverse; for example, by inputting a known minimum depth the discharge necessary to provide that depth can be calculated. The inherent limitation of methods such as these is that mean depths and velocities are used. Where uniform channel cross-sections are being analyzed this may be satisfactory; however,when non-uniform channels exist, mean depth may not provide enough detailed information.

In most cases, it will not be possible to depend on previously measured cross-sections to predict flow parameter changes. When this situation arises, it is necessary to rely solely on data collected in field surveys for use as input into a chosen computer program.

When trying to determine discharge necessary to provide minimum conditions for a particular activity, it sometimes becomes necessary to run a variety of flows through the computer programs to get plots of stream cross-sections, which are then examined for the depths or widths determined to be minimum values. For example, if at a given cross-section it was necessary to determine what flows would meet velocity and depth requirements for wading, it might be necessary to examine several flows, rather than inputting exact depth and velocity values into the computer model. It is necessary to adopt this approach in most instances because mean depth and velocity values are employed in the equations utilized by the programs. For purposes of recreational activity evaluation, ranges of depths and velocities are often what is needed for minimum flow determinations. Physically limiting factors which may occur on a transect may be studied using these techniques. If for example overhanging trees will adversely affect recreation at or above a certain flow level, it would be possible from field survey results and modelling techniques to determine the increase in wetted perimeter necessary to bring these trees into conflict with recreationists.

The R-2 cross program (See Appendix B) was designed specifically for instream flow studies. Use of this program permits making relatively accurate estimates of flow parameters at varying discharges. Other programs which are of use are the WSP (Water Surface Profile) program and several backwater programs used by the SCS and other agencies in flood damage forecasting. The latter programs are normally used primarily to investigate higher flows than are generally satisfactory for recreation; however, there is no reason why lower flow data cannot be analyzed.

4.3 Refine Recreation-Flow Relationships

The field observations and subsequent analysis will give the planner an opportunity to refine the predictions of recreation-flow relationships in two important fashions: determination of the accuracy of his original predictions and a refinement of those predictions to reflect field conditions.

4.3.1 Compare with Original Predictions

The first opportunity is had by comparing the predictions of recreation potential made in Section 3.6 for the flow observed in the field with the recreation activities actually observed or confirmed to be possible. When there is disagreement between expected and observed activities, three sources of possible error should be considered. First, it is possible that the hydraulic geometry predictions made in Section 3.4 were not applicable to the stream being surveyed. This will have been determined in the data analysis above, but should be kept in mind as a possible error source in recreation predictions. The second source of error could be site-specific, or longitudinal conditions, not anticipated in the pre-field predictions. If, for instance, swimming is expected, but not engaged in, the reason might be found in a lack of suitable beach areas or in a bottom composed of silt and clay. Finally, it is possible that the recreation criteria may require amendation to suit the preferences of recreators and the physical conditions on a particular stream. This is particularly true of activities for which the stream is a surrogate for a lake or reservoir. In these areas, the lack of a nearby lake may cause a lowering of criteria whereby recreators use a marginal stream resource as the only alternate to not engaging in an activity.

4.3.2 Prepare New Predictions

The second opportunity arising from the field effort is in preparing refined predictions of recreation possibility at flows higher and lower than those observed in the field. This effort is done exactly as were the original predictions in Section 3.6, but with the field-confirmed hydraulic geometry as a basis instead of the estimated hydraulic geometry. Additionally, greater precision will be possible in factoring unusual conditions into the analysis. A great part of the field effort will have gone to determining site-specific and longitudinal conditions along the stream and to relating these to flow. Thus, in this re-analysis of the relationship between flow and recreation, the predictions can be made much more accurately than before the field effort.

The final output of this task will be a new version of the tabulated activities for the various flows in the stream. These tabulations may mark the end product of many instream recreation studies, or they may lead to further confirmation in preparation for water acquisition or the setting of rigid instream flow requirements on other users of the stream.

4.4 Confirmation Visits

In some cases, the results of the major field effort will be sufficient for recreation-flow information on a stream. An example of this might be where the field study is undertaken as part of a wild or scenic river study and the need is to generally determine the value and extent of the recreation potential in the stream. In other cases, much more precision may be required in the establishment of minimum flows for recreation. This might occur where a proposed flood control or hydroelectric dam will dramatically alter flow conditions. In this case, the intent of the study would be to determine very accurately the relationship between instream flow and recreation potential so that recreation value can be fairly and accurately reflected in the establishment of minimum flow requirements for the project. Another case in which great precision would be required is when changes to the minimum flow requirements at an existing dam are sought, or where the purchase or condemnation of water rights to provide for recreation is being considered. In these cases, field confirmation of the relation between flow and recreation potential may be essential.

When such confirmation is required, it does not mean that the entire field program should be repeated at other times. Rather, the confirmation visits should consist of simple checks of widths, depths, and velocities at cross-sections run in detail during the major field study. The timing of these check visits should be such that flows both lower and higher than that prevailing during the major effort are examined. Additionally, it may not be necessary to re-visit all sites during such trips. In particular, sites that are near a gaging station will not require confirmation of stage-discharge relationships. At sites more remote from gages or in ungaged streams, the physical predictions made in Section 4.2 above must be confirmed in the field if utmost accuracy is desired. The predictive techniques will have established the expected stage (and hence the expected possible activities) at flows both less than and greater than the flow actually observed. It is these physical predictions which must be "fine-tuned" if great precision is required in the analysis.

5.0 NOTES ON PLANNING, LOGISTICS, AND OPERATIONS

The river evaluation method presented here has been designed with a view to limiting the amount of time that must be spent in the field. This is deliberate. Field work is costly in both time and money. It also is demanding in the sense that the total attention of the party in the field must be devoted to the project in hand. Office work on the other hand, whether done before or after the field visit, can be meshed into other duties.

For this reason a great deal of emphasis is placed upon the preliminary analysis phase of the river evaluation studies process. The work accomplished during this phase, if done well, will permit the acquisition of a maximum amount of information for effort expended during the field study phase.

5.1 First Steps

Once a river has been assigned for study, steps should be taken immediately to order the basic hydrological information covering the reach of interest. These data are readily obtainable in most cases, but there may be some delay between time of order and time of delivery. At the same time maps and aerial photographs should also be procured, from local sources if possible or ordered by mail or telephone. Concurrently, efforts should be made to find any available data on recreation in the river. These may include studies by Federal, State, local , or private agencies. They may also be available in published form, such as the canoeing guides which have been prepared for popular rivers in many parts of the country.

The maps will probably be easiest to obtain. They also represent the logical starting point for the analysis. Preliminary classification of the river reach can usually be accomplished from map information alone, although later consultation of aerial photos will usually be necessary to finish the classification task.

The maps also provide the basis for preliminary planning of the field work. They indicate the relative ease or difficulty of access to points and stretches of interest along the river. Where USGS quadrangle sheets have not been recently updated, it is wise to attempt to find better data on access from county road maps or other sources. The latter might include lumber companies with large holdings along the river in some remote areas, federal agencies such as the Forest Service or Park Service, or State or county highway departments. While the ultimate field work should not be governed entirely by access considerations, it is important to know early in the evaluation phase whether or not access is good. If it is not, the field work must be planned to compensate for this by building reconnaissance from the air, or by boat on the water, or by both into the schedule.

5.2 Manpower Assignments

For most studies a two man team is probably ideal. Working together during the analysis phase, they can insure that all necessary information is gathered and digested before the field work is undertaken. And for most situations two men will be enough to carry out the field work as well. Where the combination of depth and velocity makes wading to conduct a cross-section transit difficult, additional personnel may be needed however, to guarantee both safety and accuracy. As a rule, it is better to have one team conduct all of the field work at the selected sites on a given river reach than to have different teams working different sites at the same time. While the latter option provides for observation under uniform flow conditions, it also means that measurement and observational techniques will not be uniform. It also tends to be much more expensive, unless the study area is within commuting distance of the normal place of assignment. The synthesis following the field work, including any necessary return visits to the field, should be accomplished by the team which did the preliminary analysis and conducted the initial field studies if at all possible.

5.3 Scheduling Field Work

As a rule, the field study should be planned to coincide with periods in which flows approximating those expected to be of interest in terms of defining recreational potential are expected. However, while river flows can be summarized statistically in monthly or seasonal terms, each water year is a bit different from every other water year. Accordingly, once the requisite flow for the field study has been determined and the time when it is apt to be available established, planning for the field visit should start. The plan should be flexible and amenable to adjustment to account for variations in weather conditions on the river to keep track of what is happening to discharge. Such information may be available from USGS personnel in some places. If not, other sources of information should be found. Unless extraordinary events intervene, the schedule adjustment should require moving the tentative field visit dates not much more than a week or two in either direction.

5.4 Conduct of Field Work

Plan on long days in the field. The fewer the number of days required to carry out the whole study, the greater the chance that flow will be more or less uniform at all sites studied. Also, the weather conditions are more apt to remain uniform over a short period of time than for an extended period.

If it is planned to carry out the study during an active recreation season, the work should be planned to permit observations of such activity at the end of the field visit. In most cases this should coincide with a weekend, when use is apt to be highest. However, if heavy recreational use is anticipated, cross-section measurements should be taken during a period of low activity, and not on the weekend, because of possible mutual interference between the study team and recreationists on or in the river.

If the study river must be reached by air, arrangements should be made to have a car or cars available at the airport city. If a river tour is anticipated, arrangements should be made to rent a suitable canoe or other boat. If the rental agency provides "livery" service only one car will be needed. However, in remote areas this may not be feasible. This leaves two possibilities. A third team member can deliver the canoe and crew to the put in point and pick them up at the take out; alternatively, two cars may be employed, with one left at each end of the stretch to be covered by water. These problems should be anticipated and planned for in advance.

Similarly, if reconnaissance from the air is planned, advance arrangements should be made for the necessary aircraft and pilot to insure that both will be available when needed.

5.5 Post Field Trip Studies

Immediately upon return from the field, steps should be taken to write up the impressions obtained while they are still fresh in the mind. Field notes should be transcribed into more complete form. Photographs should be sent out for processing and should be sorted and annotated as soon as they have been returned. The basic analytical tasks may be deferred for some time if necessary. In some cases this may be a forced choice if one has to wait for the availability of gage data covering the period of the field work. (This is on the assumption that it was not possible to obtain access to these data while in the field; if this can be arranged, it should be done.) However, it is very important that the field work be written up as soon as possible before significant details are forgotten.

5.6 Return Trips

In many cases, perhaps most, a single field visit may not suffice. In the event that observations at a different expected flow are indicated as a result of analysis of the results of the initial field work, the basic planning process is essentially the same as before. However, it may not be necessary to make the measurements and observations at all of the sites visited the first time around. Usually, the set of measurements will not be so extensive since cross-sections from the first trip will be in hand. It will be important to insure that when a site is revisited the later measurements are taken at the same place as during the first trip. Except in the most unusual circumstances, it should not be necessary to visit new sites on a return visit (or visits).

APPENDIX A

CONTROLLED RELEASE MEASUREMENTS

Controlled Release Measurements

No controlled release experiments were conducted in the development of the methods discussed above. Where an opportunity to exercise control over flows is present the same procedures may be employed, with some modification.

It will still be necessary to perform preliminary studies of the river in order to identify recreation potential at places (reach, stretch, site) of interest. This will include the development of a range of flows which are expected to bracket the minimum and optimum conditions for recreation activities to be considered. Preliminary field reconnaissance of the study area under existing flow conditions will also be necessary in order to insure that field teams are in place once the controlled flow experiments start. It would also be desirable to make a tie between flows at such sites and discharge data from the nearest gage or from the dam to provide a benchmark for later analysis. However, this can only be done where the existing releases are held constant for a sufficiently long time to permit stabilization of flow.

The best field procedure would involve starting out the experiment at the lowest of the flows to be investigated. If this flow is lower than that obtaining before the start of the series, it may be necessary to allow time for flow stabilization, taking into account not only the reduced discharge from the dam but also contributions from bank groundwater discharge. This stabilization time will vary according to local conditions and should be determined only after consultation with hydrologists expert in the local area. The most detailed observations may be made at this low flow, since much of the river cross-section will be exposed. As flows are increased in pre-determined steps, the requirement for detailed measurements at each increment will not be so stringent. In most cases the initial cross-section will serve for all subsequent flows. It will be necessary to measure variations in width carefully. Spot measurements of depth and velocity will also be required.

The duration of flow at each step in the test discharge series will vary according to local conditions, including the length of the study segment and ground water recharge or discharge from the banks. In general, at least 24 hours at each test flow will be required. Since most experiments will require examination of a range of flows covering a minimum of five steps, this implies a time requirement of from one to two weeks to complete the series. If the segment of interest is relatively short and access is easy, one field team may carry out the entire field program. Where access is difficult and the segment long, it may be necessary to assign separate teams to each observation area. The U.S. Fish and Wildlife Service conducted a controlled flow experiment on the Boise River, studying fish habitat conditions from Boise to the river's mouth, in January 1974; this test required the use of a single two-man team for a period covering 19 days during which six discrete releases from the controlling dam were observed. In the case of the very large scale controlled flow experiments on the Snake River in Hells Canyon carried out in March 1973, it was necessary to deploy 6 observers to cover 10 "recreation sites" in 7 different areas for a period of about a week; this test series involved five discrete flows, each maintained for a period of 24 hours.

The primary advantage of the controlled flow approach to river evaluation is that it permits detailed study of the impact of a known range of flows at the study sites in a relatively short period of time. This approach could be of special value in the case of a controlled stream in which discharges fluctuate markedly on a short-term basis, especially where peak power generating requirements govern releases from the dam. It could also be useful in establishing the optimum flow for a limited white water experience in certain cases; the temporary retention of water behind a flood control dam which normally is operated in a pass-through mode, save in case of flood hazard, offers a potential opportunity to provide an extended white water season, with flows optimized for this activity.

The use of controlled flows also has a number of disadvantages. As suggested above, the requirements for deployment of trained manpower may be quite high. It may require a great deal of advance planning and coordination to effect the required period of test releases. Once the schedule has been arranged, the field personnel will be committed inasmuch as the needs of the dam-owner are paramount. In almost every case, flow modulation experiments must take place outside of the normal recreation season on the river; substantial variation of an existing flow regime to which recreationists have adapted represents both a threat to the quality of their experience and a possible safety hazard. This means that the opportunity to observe actual recreational use of the river is lost. This latter can be overcome to some extent by having the field team attempt to engage in such activities as fishing, wading, boating, rafting, kayaking, and so on, but this also implies additional personnel requirements.

Another factor that may bear on the desirability of resort to controlled flow experiments is related to the basic operation of the dam. On power dams, for example, release increments are governed by generator requirements. This may mean that the controlled releases that can be obtained will be limited to a small number of steps, i.e., minimum release as required by license, one generator, or two. Additionally, the steps between generator controlled flows may be very large, ruling out any "fine tuning" of flow studies, so that conditions pass from below optimum to above maximum in a single step.

The concept of affording the field experimenter direct control over flow in the stream has definite appeal. Yet, while the concept is simple, the execution often may not be. However, controlled flow experiments may have special applicability under some circumstances:

1. If the study area is remote and difficult of access, and the study reach is long, it may be less costly to mount a concentrated one time expedition than to make a series of visits to the sites of interest. This could be true of places like the Hells Canyon area, for example.

2. Where releases vary from hour to hour and day to day in response to power generating demands the river may never exhibit a "normal" stabilized flow of any great duration and seasonal variations may not be apparent. Controlled releases, if obtainable, would offer an opportunity for establishing minima for various potential recreational pursuits. This, in turn, could lead to development of release schedules meeting such needs.

3. It is possible to create or to extend white water opportunities, both in time and in quality of experience, by scheduled releases of specified amounts of water from a dam. Pass-through flood control dams are already so operated on a limited basis in some places, with spring runoff held in temporary storage for weekend release to support recreation. Preliminary controlled release experiments may offer the best opportunity for establishing the discharges to be provided on a particular stream to support a given quality of experience.

4. In cases where it is important because of economic or legal conflicts to obtain a precise measure of minimum releases required for support of recreation, it may be desirable to resort to controlled flow studies about a narrow range of flows after preliminary studies have established the basic flow regime of interest.

APPENDIX B

SAG TAPE METHOD

AND

R-2 CROSS PROGRAM

SAG TAPE TECHNIQUE

The description of the Sag Tape technique which follows has been excerpted from Stalnaker and Arnette (1976).

This technique is a modification of the basic transect approach and is useful for establishing measurements across streams that are too wide to use the tight tape technique. As presently designed one man can conduct all necessary field work. The sag tape technique can be used to provide input data for a computer program, R-2 CROSS. Computerized computation of sag tape (or other transect) data is not a necessity, however. These data can be used in manual calculations. Precautions and sources of error mentioned for computer precision also stand for manual computations.

Special Equipment for Data Collection

Steel Tape or Chain - A 100-foot steel tape is normally used. It is necessary to know or determine the weight in pounds for a 1-foot section of the tape. If this value cannot be obtained, use .0107 lbs/ft (this weight is required if sag tape data are used as computer input).

Tension Scale - A small spring scale (20-30 lb. capacity) used to measure the tension applied when stretching the tape between the two stakes of the transect.

Tape Clamp - A modified (spoonbill) "vise-grip" to hold the tape in tension.

Transect Stakes - Metal stakes 24 to 36 inches in length.

Measuring Rod - Any device suitable for measuring the distance in feet and tenths of feet from the tape to the channel bottom.

Abney Hand Level - This is necessary for leveling the tape and for determining stream gradient.

Field Technique

Once the transect point on the stream is established, a steel tape is stretched from the top of a transect stake to a tape clamp and spring scale, which is attached to another stake on the opposite stream bank. Tension is applied as the tape is drawn up and clamped. The tension shown on the scale must be at least 5 pounds, plus one pound for each 10 feet of transect length, i.e., stake to stake distance. (The computer will correct for depth errors due to tape sag if it is given the weight of the tape in lbs/ft., the length of tape across the transect, and the tension in lbs. on the spring scale. Use the Abney level to make sure the ends of the tape are level.)

Depth measurements are taken from the tape to the ground surface or channel bottom and recorded in feet and tenths of feet. The first and last measurements are always taken at the transect stakes. Measurements may be taken along the tape at fixed intervals, or at any interval desired to show changes in the existing ground surface or channel bottom.

R-2 CROSS PROGRAM

This program is a refinement of two programs ("DEBRIS" and "PLOT-D") designed to calculate sediment volumes for a number of cross-section measurements or channel cross-sections in a debris basin. R-2 CROSS has since been developed by Region 2 of the U.S. Forest Service to calculate hydrologic parameters using field measurements described above in the section on the Sag Tape technique, and using the Chezy-Manning equation (Sec. 4.2.3). One of the uses intended for this program was in instream flow studies. For detailed information about the program, the U.S. Forest Service Region 2 office in Denver, Colorado should be contacted. What follows is a summary of the R-2 CROSS method excerpted from Stalnaker and Arnette (1976).

FIELD DATA REQUIREMENTS

1) Distance in feet from 0-point (at first stake) to last depth measurement (usually at opposite stake); 2) total length (feet) of tape spanning the cross-section (may be same as 1); 3) Manning's n value, roughness coefficient (use .055 or another selected or calculated value); 4) slope (gradient) of the stream.

PROGRAM STEPS AND OUTPUT

Step 1: The basic computer plot of the measured cross-section - Step 1 produces a channel cross-section printout, and if desired a plot (from a Cal Comp Plotter) of the measured cross-section. The printout will also provide cross-section area in sq. ft., maximum depth in ft. (from the water level to channel bottom), wetted perimeter in ft., hydraulic radius (area/wetted perimeter) in ft., measured slope or gradient of the stream reach in percent, selected or calculated Manning's n (roughness coefficient), water flow in c.f.s., and average velocity in feet/second.

The maximum depth value given on the Step 1 printout is used to establish the reference datum line on the graph paper plot (or the cross-section printout). Maximum depth is measured, with a scale, vertically up from the deepest point shown on the cross-section. A line drawn perpendicular to this vertical is the reference datum line and represents the computer corrected tape line. For those hydraulic data listed on the Step 1 printout, the computer has assumed a water level equal to the reference datum line. Measurements from the reference datum line to ~~the~~ actual water level, or selected water levels are used in program Steps 2 and 3.

Step 2: Developing information from which to calculate Manning's n value - In order to complete the CROSS program analysis, it is necessary to have obtained accurate field measurements of the stream discharge or flow. It is also important to have noted on the field form the distance from the 0-point or stake at which both the first and furthest waterlines in the cross-section are encountered (see Transects-Sag Tape). The waterline or level, as interpreted from the field notes, is drawn directly on the graph paper plot, or in the event a Cal Comp Plotter is not available, the cross-section printout can be used. The necessary data to run Step 2 includes: a depth value, identified in the program writeup as "depth to water," which is the difference between the maximum depth from the reference datum to the channel bottom and the actual water depth at that point. In effect, this value is the distance to the nearest tenth-foot from the computer corrected tape level to the waterline; two distance values, the distance in feet from the 0-point to the first streambank-waterline intersect, and the distance in feet from the 0-point to the furthest streambank-waterline intersect. These data are obtained from the cross section plot on which the waterline has been drawn; total length of tape spanning the cross-section, in feet, from stake to stake, or 0-point to end point; a selected or theoretical Manning's n (roughness coefficient) value. A value developed from field observations may be used, or if unknown use .055 for Step 2; the slope or gradient in percent of the stream reach immediately up and downstream from the cross-section.

The purpose of Step 2 is to provide a list of the above described hydraulic parameters for the cross-section as it existed at the time of measurement, along with a second cross section printout. Once the data from Step 2 are obtained, it is used to refine the estimated Manning's n value (used in Steps 1 & 2) for use in the final Step 3. Manning's formula is solved for n, using the area, hydraulic radius, and slope data from the Step 2 print-out, and the field measurement of stream discharge for the Q value.

Step 3: Stream discharge and hydraulic parameters at various or selected water stages, above or below the waterline existing at the time of field measurement - The purpose of Step 3 is to provide a range of hydraulic parameter values related to changes in the water stage of the cross-section.

To run Step 3, simply change the depth to water value (the distance from the reference datum to the new or selected water line) and determine the corresponding changes in waterline-streambank intercept distances using the plot from Step 1 (or the cross-section printout). The remaining information necessary for running Step 3, includes the same total length of tape and slope data as used in Step 2. Step 3 will produce a cross-section and printout with the above described hydraulic parameters for each new or selected water stage.

The program produces a computer plot of the measured cross-section; and with completion of the three program steps, computes 1) stream discharge, 2) average flow velocity, 3) wetted perimeter, 4) cross-sectional area, 5) maximum water depth, and 6) hydraulic radius for the actual streamflow at the time of measurement as well as for various selected water stages.

Man and Wildlife in Arizona

The American Exploration Period
1824–1865

Based on a Master of Science Thesis
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The trapper lived off the land. He traveled lightly, carrying scant provisions of salt, flour, tea, and coffee. Deer, antelope, turkey, and bear kept him supplied with meat. Beaver tail was relished, but the rest of the animal was eaten only in times of want (Cleland 1950:30–31).

Each man's equipment generally included a rifle with an extra lock, one hundred flints, twenty-five pounds of powder, one hundred pounds of lead, a powder horn, a double shot bag, a butcher or skinning knife, a tomahawk or shingling hatchet, and several traps (Cleland 1950:17).

In the 1820s, the trapper's rifle, upon which his life depended more than any other piece of equipment, was a .40 to .60 caliber muzzle-loading flintlock. The best of these "plains rifles" were handmade in the renowned gun works of two brothers, Jacob and Samuel Hawken, of St. Louis. The barrel was thirty to forty inches long, rifled, of soft iron instead of steel. This weapon fired a round ball patched with linen cloth and used from two to four times as much powder as the smaller caliber Kentucky rifle of Daniel Boone's day. The plains rifle could deal with bison, grizzlies, elk, and Indians, but firing a round ball, its effective range was not much over one hundred yards. By 1830, flintlocks were being superseded by percussion cap firearms (Cleland 1950:28–29).

Because of the lack of navigable rivers in much of the Southwest, trappers had to use pack trains for transportation. These consisted of one or more riding animals equipped with saddles of Mexican design, and two pack mules or horses. Packed in the Mexican fashion, each animal carried from 200 to 250 pounds of supplies. The stock foraged for themselves, and when grass failed the inner bark of cottonwood trees served as an emergency food (Cleland 1950:27–28).

The mountain men usually each carried about six traps, similar in design to the leg-hold traps in use today. At a promising site, the trapper waded into the stream to hide his set. The trap was placed in a few inches of water a short distance from the bank. It was attached by a chain to a strong stick which the trapper drove into the bed of the stream a full chain's length from the trap. The chain was about 5 feet long, with a swivel near the end to keep it from kinking. Immediately over the trap, a twig was positioned so that one end was some four inches above the surface of the water. The twig was smeared with a pungent musk from the beaver's castors, a pair of anal scent glands found in both sexes but quite dead, floating on the slimy pool, the other winged, with a pellet in his brain, too, perhaps, he tumbles so wildly over the mud, soiling his snowy plumage. How the birds for half a mile around are croaking! There'll be no more shooting at this particular spot; we may as well go home to breakfast. It is eight o'clock, and already the sun glares fiercely (Coues 1874:514–515).

Although primarily an ornithologist, Coues published *The Quadrupeds of Arizona*[3] in 1867, which detailed his observations on the mammal life of the territory. This modest paper is a landmark publication in the field of southwestern natural science. It is the first scientific paper on the fauna of Arizona that is more than a mere listing of collected specimens, as it includes discussions of the distribution, abundance, and habits of many species. It is also the first scientific paper produced as a result of a period of residence in Arizona by the author rather than a journey across its lands. The following excerpts from *The Quadrupeds of Arizona* describe the territory's diversity of natural history and discuss the larger mammals of primary importance to this study.

The wild and primitive region which constitutes the Territory of Arizona exhibits a remarkable diversity of surface on its mountain ranges, grassy plains, and desert wastes; and its Fauna and Flora are varied in a corresponding degree. The traveller meets, at each successive day's journey, new and strange objects, which must interest him, if only through the wonder and astonishment they excite. In every department of Natural History, there is ample field for observation and study; and even at this late day, opportunities for discoveries in Zoology and Botany. First in importance, as they are also in general interest to the observant traveller, are undoubtedly to be ranked the quadrupeds of the country; and so savage and unreclaimed is its condition, that they are there to be seen in what is truly a state of nature. Their habits, and even their numbers have been as yet scarcely subjected to modifying influences by contact with civilization; and he must be stolid indeed, who, under such rarely favorable circumstances, does not look about him with interested attention, and learn

[3] Elliott Coues, 1867. *The Quadrupeds of Arizona.* The American Naturalist, Vol. 1, pp. 281–292, 351–363, 393–400, 531–541.

. . . [the beaver] is found abundantly on all the streams of the Territory. Judging from the accounts of old trappers, its numbers seem even to have increased of late; owing, doubtless, both to the diminished value of its fur, of which so many articles now take the place, and to the Indian difficulties, which prevent the penetration of the hunter to its abodes. Particularly upon the Rio Salado [Salt River] and San Francisco [Verde River] as it is very abundant; and its dams occur, in some places, every few hundred yards. The almost unbroken seclusion of these retreats gives the animals such a sense of security, that they are less strictly nocturnal in working or playing than in most localities. I have frequently seen them swimming about in broad daylight.

. . . Both naturalists and hunters distinguish two species of Deer in Arizona, called the Black-tailed and the White-tailed. Of these the former is by far the most abundant and characteristic; although, judging from accounts formerly given of it, it has considerably decreased in numbers owing to the persecution to which it is subjected so constantly from both the native tribes and the white settlers. It is . . . also called the "Mule Deer," from the length of its ears. . . . This deer forms no small share of the food and clothing both of the Indians and white settlers. . . .

The horns of this species differ somewhat in configuration, though not materially in size, from those of the Virginian, or of the Columbian Deer. . . . The horns are shed in the spring, and the new ones are in the velvet during the great part of the summer. . . . By October, both sexes have finished changing their light coarse summer vesture for the softer and thicker winter coat, which, for some time after the change is completed, is extremely sleek and glossy. Its color is darker than it is in summer, being chiefly mouse-gray. . . . In summer, there is much of a brownish or even fulvous tinge on many parts. The fawns are brought forth in June or July, either one or two at a time. . . .

Except at certain seasons, this deer is more apt to be found singly than in herds of any size. But frequently in the autumn, two or three are seen together; and on one occasion in October, I

SONORAN DESERT TRADERS

The Pima-Maricopa Confederation

(*Akimel 'O'odham, Kohatk, Pee Posh*)

By

Henry F. Dobyns

15 September 2002

In the 1690s, Wa:k contained the largest population concentration that colonial explorers reported in Northern Piman country, 800 to 900 persons.[44] Wa:k's populousness suggests that it might have functioned as a trading center.[45] Certainly its size made Wa:k a significant market among Northern Piman settlements, along with San Agustin de Oiaur, with 800 inhabitants, a short day's journey down the Santa Cruz River at its confluence with the Rillito.[46]

Colonial explorers found Wa:k inhabitants raising macaws in 1701,[47] showing that at least part of its population participated in the international feather trade. The Pueblo Market absorbed numerous macaws, parrots, and their feathers which originated in the tropics or other macaw-raising ultra tropical settlements such as Casas Grandes, Chihuahua. The Akimel 'O'odham and other Northern Pimans were primarily middlemen in the macaw and parrot trade. They consumed some such feathers themselves. As late as 1723, Northern Piman warriors bound to battle donned red macaw plumes during their rituals.[48]

The Western Shell Trade

The 1697 post flood food crisis among the Akimel 'O'odham on the middle Gila River also revealed to colonial explorers Northern Piman-Northern Panya (*Hal Chedom*) commerce. After a single post flood growing season, the *Huhu'uhla* tribesmen residing at Au:p Oidak ("Enemy Fields") at the western terminus of the river's Great Bend imported white tepary beans from the Northern Panya trading center on the lower Colorado River.

More indicative of normal international commodity exchange between the Northern Panya trading center and the Kohatk trading center on the middle Gila River--Kohatk Oidak--was a buckskin wrapped around red hematite thoroughly worked into deer tallow. Northern Panya middlemen had routed that Northeastern Pai export southeast to Kohatk-on-Gila instead of bartering it to Cahuilla or Gabrielinos to their west. Always dreaming of striking it

[44] Burrus, *Kino and Manje*, 348.
[45] In November, 1697, Juan M. Manje reported that "the natives of the great rancheria of the Va:k" carried off two children from hostile Apaches by lower San Pedro River warriors led by Chief Humari (Manje in Burrus, *Kino and Manje*," 338). Thus Manje implied Wa:k's participation in the colonial frontier slave trade.
[46] Manje reported counting 800 people in 186 houses (in Burrus, *Kino and Manje*, 347-48).
[47] Kino, *Kino's Historical Memoir of Pimeria Alta*, I:291-92 ["They gave us . . . red feathers of the many macaws which are raised here."]
[48] José Agustín de Campos, "Texto del Primero Documentos de Campos." Pp. 249-57 in *Etnologia y Misión en la Pimería Alta 1715-1740: Informes y Relaciones Misioneras*, Edición de Luis González R. México: Universidad Nacional Autónoma de México, 1977, 250.

rich, colonial explorers deluded themselves into thinking that the red stained melting tallow was mercury. A young man using the red hematite to paint his face reported that he traveled five days northwest to obtain it--at the Northern Panya trading center. The riverine Kohatk "generously shared their food with the soldiers" and lodged at least a missionary and army officer in a house made of poles covered with mats.[49]

Kohatk, other Piman, and Northern Panya traders traveled at least three paths between the middle Gila and lower Colorado Rivers. Prior to 1650, traders took a major trail due north from Shoo:tak shon and its Akimel 'O'odham companion rancheria *Skai'kaik* ("Many Rattlesnakes") on the north side of the stream to Salt River.[50] There, travelers turned downstream to Las Colinas, a redoubt-warehouse type settlement like Casa Grande. An area at the edge of Las Colinas where exclusively Lower Colorado River Buff Ware ceramic sherds have been discovered identifies where Northern Panya traders either camped during periodic visits, or perhaps resided year round at an Akimel 'O'odham port-of-trade.[51] The pathway paralleled Salt River downstream (westward) to its confluence with the Gila River. Then the trail curved around the Great Bend of the Gila River to where Centennial Wash flows--when it flows--from the west-northwest into the perennial stream. Traders often chose to leave the riverine oasis to follow Centennial Wash across the arid desert from mountain spring to mountain spring and the Colorado River.

Alternatively, traders could take a more circuitous route, following the Gila River all the way around the Great Bend and then westward along the lower reach to the trickle entering the north side from Aguas Caliente (Hot Springs). Another trans-desert trail conducted merchants to the Northern Panya trading center on the lower Colorado River. Piman guides led Jesuit explorer Jakob Sedelmayr over this route in 1744.[52] The newcomer could

[49] Burrus, Kino and Manje, 210-11.
[50] David R. Wilcox, Thomas R. McGuire and Charles Sternberg, *Snaketown Revisited: A Partial Cultural Resource Survey, Analysis of Site Structure and an Ethnohistoric Study of the Proposed Hohokam-Pima National Monument.* Tucson: University of Arizona, Arizona State Museum, Cultural Resource Management Division, Archaeological Series No. 155, 1981, 98-101.
[51] Patricia L. Crown, "Analysis of the Las Colinas Ceramics." Pp. 87-169 in *The 1968 Excavations at Mound 8, Las Colinas Ruins Group, Phoenix, Arizona,* edited by Laurens C. Hammack and Alan P. Sullivan. Tucson: University of Arizona, Arizona State Museum, Cultural Resource Management Section, Archaeological Series No. 154, 1971.
[52] Jakob Sedelmayr, "Sedelmayr's Relacion of 1746," translated by Ronald L. Ives. Pp. 97-117 in *Anthropological Papers.* Bureau of American Ethnology, Bulletin 123. Washington, D. C.: Government Printing Office, 1939, 107.

confuse the trading path entering the lower Colorado River oasis. Sedelmayr did: "The sheep and deer, of which there are an infinite number on the banks of the river, where they go to drink, have made many wide trails in their wandering. The labyrinth of trails confused us, as we could not tell which was the trail of the people. On the valley floor these trails divide."[53] Walapai traders exchanged commodities at the Northern Panya trading center; they also carried commodities eastward to the Hopi Pueblos. In return, they transported Hopi textiles to the Colorado River trading center. Thus, Akimel 'O'odham obtained Hopi textiles, and perhaps ceramic vessels, via a long, circuitous trade route.

Pacific Coast Marine Shells. The Jesuit pioneer missionary among Northern Piman speaking natives, Eusebio F. Kino, S.J., was a cartographer. He explored the Colorado River delta and a portion of the Sonoran shore of the Gulf of California during his Piman mission which began in 1687. Earlier, Kino had sailed to the Peninsula of Lower California with Admiral Isidro de Atondo y Antillón early in 1685. Kino hypothesized that the Peninsula was not an island, as colonial maps then showed it, but truly a peninsula.

Kino saw blue abalone shells on the gulf coast of Lower California, but not on the Sonoran coast. Yet he saw abalone shells in a Piman speaking ranchería near the confluence of the Gila and Colorado Rivers on 21 February 1699. Kino reasoned that the abalone shells reached the Gila River overland, inasmuch as the natives living along the shores of the Gulf lacked craft sea worthy enough to carry them across it. Then the leader of the Gila River Cocomaricopas (*Kokomalik au:p,* the Piman term for the Southern Panya, or *Kavelt Chedom*) sent Kino a string of twenty abalone (blue) shells which he received at his Remedios mission on 20 March 1700.[54]

The Kavelt Chedom leader could have obtained California coastal abalone shells from two trading partners. One trade route is the Panya trading center to middle Gila River Akimel 'O'odham route with Centennial Wash and Agua Caliente alternatives already described.

The other route by-passed the Gila River, as a result of the amity-enmity network of lower Colorado River tribes. It started on the California coast in the modern Los Angeles

[53] Sedelmayr, "Sedelmayr's Relación of 1746," 111.
[54] Earnest J. Burrus, S.J., ed., *Kino and Manje, Explorers of Sonora and Arizona; Their Vision of the Future: A Study of Their Explorations and Plans.* Rome: Jesuit Historical Institute, 1971, 114, 140, 155.

area, crossed the desert to the Colorado River Quechan. In Kino's time, two rancherías on the lower Gila River, immediately above its confluence with the Colorado, were inhabited by Piman-speakers and some Yuman-speaking Kavelt Chedom. The Pimans belonged to the northern band of the westernmost Hia' Ced tribe, then and later trading peacefully with the riverine Quechan and sharing their resources. The Hia' Ced were one of the Tohono 'O'odham tribes; they traded with the Akimel 'O'odham and the other Tohono 'O'odham tribes to their east. In 1706, Kino identified Quechan as the source of gift abalone shells sent to him at Sonoita.[55]

Probably the Northern Panya routed nearly all of the abalone shells reaching their lower Colorado River trading center eastward via their Walapai trading partners to the Hopi Pueblo of Oraibi. For the Pueblo peoples considered abalone shells sacred and utilized them in ceremonies. Consequently, the Northern Panya and Walapai traders could have anticipated more profitable exchanges at the Oraibi Pueblo gateway to the Puebloan Market than they could have anticipated from the Akimel 'O'dham. After all, the peoples along the southern trading route reportedly prosaically employed abalone shells as drinking cups.[56]

The Akimel 'O'odham apparently bartered primarily cotton textiles for their marine shell imports. They exported cotton blankets to the Northern Panya trading center on the lower Colorado River. The Northern Panya in turn exported some Gila River Pima cotton blankets westward to the Pacific coast tribes[57] which harvested abalone and sent abalone shells eastward.

The traders among the Northern Panya also dealt in Hopi woolen textiles that Hopi men wove from the wool of sheep they acquired from the Spaniards. Some Hopi blankets they routed southeastward toward the Akimel 'O'odham. In 1770, Francisco Garcés, O.F.M., visited the middle Gila River to baptize children afflicted by epidemic measles. West of the three rancherías comprising the Great Town of Shootak Shon,

[55] Kino, *Kino's Historical Memoir*, II:185. Kino identified another tribal source of abalone shells as "Quiquimas," but this is merely a Northern Piman term for Piman-speakers of unknown affiliation, so constitutes no evidence of actual identity.
[56] "Complete Text of Salvatierra's Journal." Pp. 587-618 in Burrus, *Kino and Manje*, 591.
[57] Ezell, *The Hispanic Acculturation of the Gila River Pimas*, 29; George P. Hammond, "Pimeria Alta After Kino's Time," *New Mexico Historical Review* 4 1929) 220-38, 231.

Garcés passed two Kaveltchedom rancherías. He reached the second on 26 October. "There I arrived at noon, and saw a lot of new Hopi blankets."[58] In November of 1775, Garcés described the Shootak Shon Kohatk and Akimel 'O'odham of the other middle Gila River rancherías as wearing both cotton and woolen blankets. "Go dressed do these Indians in blankets of cotton (*fresadas de algodon*) which they fabricate, and others of wool, either of their own sheep or obtained from Moqui."[59]

Minerals. At least one precious stone apparently passed through the Northern Panya trading center en route to the Akimel 'O'odham. Turquoise excavated from the earlier (pre-redoubt-warehouse) portion of *Skai' Kaik* ranchería was quarried in Southern Paiute territory in modern Southern California, near modern Baker.[60] Ancestral Chemehuevis--the southwesternmost Southern Paiutes--conceivably exchanged that turquoise with Northern Panya traders for marine shells from the Gulf of California which ended up on sites in Death Valley.[61] The Northern Panya could then have exchanged the precious blue/green stones over the Aguas Calientes or Centennial Wash routes to the middle Gila River (or at that period over the Walnut Creek Trail to the Northern Piman traders on the middle Verde River). From Tuzigoot, traders carried turquoise along trails paralleling the Verde River downstream to its confluence with the Salt River. There they turned westward downstream to the Akimel 'O'odham market on that stream and on the middle Gila River.

Turquoise has been persistently valued by the Akimel 'O'odham. In the early 1870s, Indian Agent Capt. F. E. Grossman reported that Gila River Pimas picked up turquoise from the ground surface near ruined earlier villages. "Stones of this kind are highly prized by the Pimas, and worn as charms."[62] .

[58] Francisco H. T. Garcés, Diario que se ha formado por el viaje hecho al Rio Gila," translated by Paul H. Ezell. Archivo General de la Nación, Ramo de Historia 396.
[59] Francisco H. T. Garcés, *On the Trail of a Spanish Pioneer: The Diary and Itinerary of Francisco Garcés (Missionary Priest) In His Travels Through Sonora, Arizona, and California 1775-1776*, translated by Elliott Coues. New York: Francis P. Harper, 1900, I:108.
[60] Anne Sigleo, "Turquoise Mine and Artifact Correlation for Snaketown Site, Arizona," *Science* 189:4201 (1975) 459-60; Haury, *The Hohokam: Desert Farmers & Craftsmen*, 277-78.
[61] Richard E. Hughes and James A. Bennyhoff, "Early Trade." Pp. 238-55 in *Great Basin. Volume 11*, edited by Warren L. D'Azevedo, in *Handbook of North American Indians*, Gen. Ed. W. C. Sturtevant. Washington, D. C.: Smithsonian Institution, 1986, 254.
[62] F. E. Grossman, "The Pima Indians of Arizona." Pp. 407-19 in *Twenty-Sixth Annual Report of the Board of Regents of the Smithsonian Institution . . . for the Year 1871*. Washington, D. C.: Government Printing Office, 1873, 410.

Chapter 3

Akimel 'O'odham Irrigation Horticulture

The extant historical and anthropological literature about Gila River Pimas and Maricopas describes their aboriginal crop irrigation technology in oversimplified terms. This analysis attempts an accurate, yet reasonably brief, description.

Akimel 'O'odham Canal and Ditch Technology

The Gila River Pimas employed not one kind of irrigation ditch, or *waikka*,[1] but a range of field laterals, ditches, and primary canals to convey irrigation water from the Gila River to fields with growing crops. This complex technology reflected many centuries of experience with the Gila-Salt River oasis and the streams sustaining it.

Default: subterranean irrigation

Each *shon* along the middle reach of the Gila River fed and maintained a pond (*shongam*)[2] or lake (*Gu shuhdagi*) surrounded by marsh rich in shellfish, fish, aquatic vegetation, endemic and migratory waterfowl, and oasis and desert game animals drinking the water. The pond and marsh water as well as the surfacing aquifer sub-irrigated some acres of crop land surrounding each marsh. The Gila River Pimas had only to sow seed in these sub-irrigated fields, pull or hoe weeds, and harvest the crops on these naturally irrigated fields. This was technologically the simplest style of oasis horticulture, so it is labeled the "default" mode.

Dual function primary canal

Hydrostatic pressure in the aquifer kept ground water surfacing at the several *shoshon* at a fairly steady rate. Despite the high rate of evaporation from the pond and marsh surface, sufficient water surfaced via the shon so that the pond or marsh overflowed, even when dammed by beavers. The Akimel 'O'odham excavated canals to conduct that pond-marsh overflow to cultivated fields down-gradient in the middle Gila River Valley--approximately west-northwest.

Being riverine springs, the *shoshon* were close to the Gila River channel or in its

[1] Dean Saxton & Lucille Saxton, *Dictionary: Papago & Pima to English, English to Papago & Pima.* Tucson: University of Arizona Press, 1969, 65.
[2] Saxton and Saxton, *Dictionary*, 85, 78.

1694 and 1697, failed to mention the "island."[10] Kino's not mentioning the island is, of course, not conclusive. He could have seen it and not reported it; he could have not noticed it.

On the other hand, Kino's description of Casa Grande furnished good clues to the chronology of Blackwater village's primary irrigation canal abandonment and replacement. In 1697, the Casa Grande-Blackwater village's main canal remained very visible, with embankments three yards high and six or seven yards wide. "This very great aqueduct, as is still seen, not only conducted the water from the river to the Casa Grande, but at the same time, making a great turn, it watered and enclosed a champaign many leagues in length and breadth, and of very level and rich land."[11] The condition of the canal in 1697 indicates that it had then not long been abandoned, inasmuch as a canal of such dimensions disintegrates quickly without annual maintenance.

Kuupa

The instream structure diverting stream flow into a primary irrigation canal was crucial to Akimel 'O'odham pre-Columbian and historic life as River People. The Akimel 'O'odham called this diversion structure *kuupa*. The English language lacks a word of equivalent specificity. A dam touches both banks of a stream, and backs up stream flow even if it is not high enough to impound it. A dam may be constructed of metal, concrete, stone, squared wooden pieces, soil, and so on. *Kuupa* may be glossed in English as "river water flow diverting structure made entirely of local vegetative materials." The kuupa was central to Akimel 'O'odham life as irrigation gardeners and farmers.

Most Akimel 'O'odham and Pee Posh uses for the mesquite tree and its products can be equated with Euroamerican or European uses of trees in analogous habitats. One distinctive although not unique Gila River Pima and Maricopa use for mesquite tree trunks was historically crucial to Akimel 'O'odham crop irrigation, and even to the self image as

[10] Kino, *Kino's Historical Memoir of Pimeria Alta*, I:127-29; 172-73. Lacking writing, cities, the wheel, animal power, etc., the Hohokam culture did not qualify as a civilization. The Hohokam did not, on the other hand, abruptly disappear in A. D. 1450, although most regional archeographers have inferred a magical (usually labeled "mysterious") disappearance at that time. The "disappearance" amounted to an Akimel 'O'odham abandonment of massive public structures and the Casa Grande-Blackwater primary canal, one village migrating a short distance to the riverside near Blackwater Slough, and a population crash which the author attributes to Old World contagious diseases transmitted by Native American traders and dates to A. D. 1520-1650.

[11] Kino, *Kino's Historical Memoir of Pimeria Alta*, I:172. *Champaign* (French) = *campiña* (Spanish).

THE STATE OF ARIZONA

OFFICE OF THE STATE CLIMATOLOGIST

MAJOR STORMS AND FLOODS IN ARIZONA 1862-1977

Compiled from the records of the National Weather Service

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Office of the State Climatologist

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National Weather Service

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December 1883

The Hassayampa River at Wickenburg, which had been dry for several months, suddenly rose on the 22nd beyond the fording stage, remained high over the 23rd, and then fell rapidly. Phoenix reported a fourteen-foot rise on the Salt River, and the dam and canal headgates were ripped out by the water.

March 1884

A cloudburst on the 7th at Florence flooded the streets four feet deep.

On the 10th, several miles of track were washed away east of Yuma. The Gila River rose two feet, five inches overnight so that the gauge read twenty-three feet, five inches on March 10. Reports were circulated that the river was rising east of town, but no immediate action was taken by the residents to evacuate their goods until water began rushing into the village during the night of the 10th. On the 11th, the Gila continued its rampage, broke through its levees at Yuma, and flooded that city. All of the buildings in the flooded area were constructed of adobe and most washed away. No lives were lost.

June 1884

The Colorado River at Yuma was at flood stage on the 9th. The railway west of town was seriously damaged, but the town itself was not damaged because levees had been reconstructed since the March flood of the Gila.

July 1884

The flooded Colorado washed away parts of the railway bridge at Yuma on the 1st and the 3rd.

September 1885

A freshet occurred on the 9th at Pantano. The railroad track was damaged and covered with water to a depth of several feet.

August 1886

This was a month of floods at Yuma. Light rain fell most of the day of the 1st. The rainfall was heavy seventy-five miles west of Yuma. The railroad was washed out and trains were delayed.

On the 15th, there was a thunderstorm with rainfall measuring 1.57 inches of which 0.80 of an inch fell in twenty minutes. This rainfall

October 1895

A railroad bridge near Maricopa was ripped out by floods on the Gila.

October 1896

On October 1, two cloudburst in the Whetstone Mountains sent flash floods through Benson. Two mothers and four children drowned.

September 1897

On the 11th and 12th, nearly all crop correspondents reported water plentiful, the ground moist on the ranges, water holes full, and the streams supplying the canals and ditches with water needed for irrigating purposes. The rainfall at a few places was excessive, and downpours caused short-lived floods that damaged the aggregate canal and other property to a considerable extent. An excessive fall (1.89 inches in fifty-five minutes) occurred at Phoenix on the 11th. The shower also covered the valley below Phoenix. From previous recent lighter rains in the valley above Phoenix and in the mountainous part of the Salt River watershed, the river was well up and the canals full when the storm occurred. The river was not able to hold the additional supply. The banks gave way in many places, and the country was flooded for a few hours.

Severe wind and rain hit Tempe also. The Salt River was nowhere fordable and people were obliged to cross the river on foot by way of the railroad bridge.

July 1898

The Florence stage due at Mesa on the night of the 15th did not reach there until noon on the 16th. The delay was caused by the rise of the Gila at Riverside where the stage from Globe had overturned in the river, throwing all the mail and two passengers into the raging current.

Reports from the Phoenix Daily Enterprise of July 19 stated: "Even the most incredulous now believe that there has been rain in the mountains. The town ditch is brim full and running over with muddy water. For several blocks through the city the overflow has been so great that one could have floated over the vacant lots in a skiff."

The Holbrook Argus reported on July 30 that two Indian girls were killed when they rode onto a bridge on the flooded Puerco. Bystanders shouted warnings, but the bridge gave way and the girls were carried downstream. Efforts to save them were of no avail.

December 1898

The month was remarkable for the general severity of the weather, and this severity was evidenced not only by reports received from voluntary observers in all sections of the Territory reciting personal experiences, but also by a comparison of the mean temperature of stations, which showed a deficiency of nearly five degrees.

With the exception of the southwestern part, a snowstorm pervaded the whole Territory, the snowfall recorded varying from a trace to thirty inches. In the vicinity of Phoenix, the snow melted almost as fast as it fell; but it was estimated that the measurement would have exceeded six inches had the snow lain upon the ground. Since the meteorological records of this station extend over a period of only three years and during that time there is no record of snow, we depend upon tradition when we state that it was the heaviest snowfall within the recollection of the oldest inhabitant. The snowfall apparently occurred on the 10th. As the weather observer at Peoria stated: "On the 10th it snowed about twelve hours commencing about 1:00 a.m. and continuing until 12:00 midnight, making about three inches on the level which remained on the ground forty-eight hours before melting. This was the greatest snowfall ever recorded at this station."

January 1905

The rainfall was decidedly in excess of the normal amount over the greater portion of the Territory during January. That which fell occurred principally between the 8th and 18th. In Yavapai, Mohave, Coconino, Navajo, Apache, Graham, and Gila counties, the depth of snowfall was greater than for several winters past. In consequence, the runoff produced by the melting snow and large rainfall flooded many streams beyond their banks. In the Salt and Gila River watersheds, some damage was wrought by the floodwaters which washed away railway and turnpike bridges, embankments, dams, and telephone and telegraph poles and delayed traffic for about ten days. At the end of the month, there were from three to five inches of snow upon the ground in the northern tier of counties and a much greater amount upon the mountains. In the mountain ranges within Maricopa county, a thin covering of snow was visible until the 27th.

February 1905

Frequent and unusually heavy rainfall was measured throughout the Territory. In some localities, particularly Maricopa, Gila, Yavapai, Pinal, and Coconino counties, the monthly amounts ranged between 3.00 and 10.00 inches. At Phoenix, the total for February was 4.64 inches. The amount recorded this year to date is 7.95 inches--2.38 inches greater than that which occurred during the entire year of 1904. There was slightly less snowfall in the mountains than during January. That which fell in the northern sections of the Territory during the first two decades began to melt slowly on the 21st, and by the end of the month the runoff, augmented by the rainfall, filled the river beds to overflowing and caused several washouts.

March 1905

There was frequent and heavy rainfall in the south and heavy snowfall in the north portion of the Territory from the 1st to the 18th. Farmwork was practically suspended during the second decade of the month. Rapidly melting snow produced flood stages in the Salt, Gila, and Little Colorado basins, which washed lands badly, injured crops, and caused much damage to railroad property, thereby delaying traffic for several days.

April 1905

Above normal precipitation continued over much of the Territory. In the northern counties farm work was greatly delayed by the moist condition of the soil and by the thick coverings of snow. There, grass grew very slowly. Lands were irrigated in the central and southern counties according to the small need of water for growing crops. The supply of water was adequate for all purposes.

November 1905

Precipitation was excessive over the entire Territory during November, the departures ranging from plus 1.25 inches to plus 5.00 inches. Twenty to 40.0 inches of snowfall was measured over the San Francisco range near Flagstaff and 11.0 to 20.0 inches over the Bradshaw range near Prescott. This is considered the greatest depth of snow on record for November. The heavy precipitation of the 26th swelled the streams to very large proportions, washed roadbeds, and damaged toll and railway bridges.

August 1906

The precipitation was greatly in excess of the normal with the exception of a few localities in the southern counties where the departures ranged from minus 0.75 of an inch to minus 1.60 inches. The departure over the northern counties was plus 1.29 inches; and, for the western section, the departure was plus 1.52 inches.

The runoff produced by the generous and heavy rains of the first two decades added large volumes of water to the bounteous supplies within the river beds. Many of the streams were unfordable from the 13th to the 21st. The depth of water within the river beds throughout the month was variously estimated at being between three and eight feet. The supply of water was so plentiful that the larger canals and cross-cut canals were running under full head and flow during the entire month without any intermissions. At the end of the month, the volume of summer irrigation water available was fully 30 percent greater than the supplies of any other summer during the past six years.

December 1906

During the month, there was excessive precipitation. The northern division received the largest amount of precipitation and the southwestern section the smallest. Under the influence of the warm rains of the 1st, 2nd, 3rd, and 4th over the watersheds, the accumulated snow of November melted rapidly. This runoff filled the river beds, causing freshets in many of the streams and severe floods in the San Francisco River, a tributary of the Gila, on the 3rd, 4th, and 5th, whereby many lives were lost from drowning, much property was destroyed, and railroad traffic was delayed for more than a week. Additional rain and snowfall on the 12th, 26th, and 27th kept the Colorado, Little Colorado, Gila, Salt, San Francisco, San Pedro, and Verde rivers at high and unfordable stages during the last half of the month.

October 1907

Exceptionally heavy rains occurred over the entire Territory and were general on the 4th, 5th, 15th through 18th, 23rd, and 31st.

At most of the stations in southern Maricopa, western Pima, and Yuma counties, the amounts that fell in October were in excess of the total amounts of precipitation recorded during the preceding six months. At Mohawk Summit, the heavy rains of the 23rd damaged county roads and railroad beds, delaying traffic for several days. The region of greatest precipitation embraced the San Francisco, the Black Mesa, the Mogollon, and the Mount Graham ranges and extended from northern Coconino County southeastward to northern Graham County. The amounts within this area ranged from 2.70 inches to 8.50 inches. As usual, the area of least precipitation included Pima, southern Pinal, southern Maricopa, and Yuma counties, the amounts varying from 0.86 of an inch at Vail to 1.32 inches at Yuma.

February 1908

The average precipitation was largely in excess of the normal, being exceeded only twice during the past twelve years, in 1901 and 1905. Precipitation was general over the Territory on the 3rd and 4th, the 10th through 12th, and the 22nd. The precipitation on the 3rd was exceptionally heavy, with amounts equalling or exceeding 2.00 inches reported at a number of stations (maximum 4.55 inches at Pinal Ranch).

On the 3rd and 4th and the 9th through 13th, the combined rain and snowfall produced a large runoff in the upper drainage areas of the Salt, the Gila, the San Pedro, the Hassayampa, the Auga Fria, and the Bill Williams Fork rivers, filling the river beds to moderate depths for their entire lengths.

December 1908

The average precipitation for the Territory was largely in excess of the normals. In the northern counties snow fell on the 3rd, and there was alternating rain, sleet, and snow from the 14th to 17th. Rain occurred in the southern counties on the 3rd, 14th to 16th, and on the 26th. The area of greatest precipitation covered the Bradshaw, the San Francisco, and the Mogollon ranges, the amounts ranging from four to seven inches. The heavy rainfall of the 15th and 16th caused some damage from washouts in Navajo and Coconino counties.

March 1912

The month was cold and stormy. The greatest monthly amounts of precipitation were reported from stations in the central and south central portions of the state. Reporting stations throughout the state, however, almost without exception recorded monthly amounts of from two to four times their respective monthly averages. A general storm on the 9th and 10th contributed largely to this excess although there were an unusual number of lesser storms during the month.

July 1914

The month was chiefly notable for the frequency of showers at elevations above two thousand feet and for the prevalence of an unusual amount of cloudiness at lower levels in the southwest.

A comparison of the July records for the state for the last eighteen years shows that there has been no preceding July on record with so many rainy days and so few clear days even though in most years the temperature has held higher than that of the current month and in two instances the rainfall has been greater.

December 1914

The excessive precipitation was the most notable feature of the month's weather, the monthly average for the state never having been equalled in December during the eighteen years of authentic record and having been exceeded only four times in other months during the same period.

Two general storms occurred during the first half of the month. The first important snowfall of the season in the mountain districts came with the storm of the 1st and 2nd. From the 17th to the 24th, inclusive, rain or snow fell every day over the greater part of the state, and this, together with another heavy rain on the 27th with intervening unsettled weather, constituted the most protracted and excessively stormy period that has occurred in Arizona for many years. Floods resulted in the various streams, dry beds, and washes of the southern half of the state, causing considerable damage to bridges and to the diversion dams of the smaller irrigation projects.

December 1915

Precipitation was about twice the normal amount. The excess was attributed to the heavy amounts that occurred in the storm at the end of the month. Periods of stormy weather lasting two or three days began on the 4th, 14th, and 29th. In the central part of the state, the storm of the 29th through 31st was one of the heaviest that has ever occurred. New records of heavy snowfall were established at many places in the Verde and Agua Fria watersheds. At Flagstaff, several poorly constructed buildings collapsed from the weight of the snow. During and following the storm, there was great difficulty in moving range stock to places with feed and shelter, but no serious losses were reported.

January 1916

January 1916 will go on record as the wettest month since the establishment of the Arizona climatological service in 1892. Moderate winter temperatures prevailed throughout the month except during the storm periods when some of the nights were unusually warm. Storm conditions prevailed continuously from the 15th to the 21st and from the 26th to the 30th.

Because the ground was saturated from the melting of the December snows, the series of heavy rains beginning on the 15th caused general flood conditions throughout the state from the 17th to the 24th. The storm beginning on the 26th caused more floods from the 28th to the 31st. According to reliable sources, the highwater marks of the Salt and the Gila rivers this January have not been exceeded since 1891. Four lives were lost. The property damage sustained is estimated at $305,000, the principal items of loss being bridges, irrigation works, and agricultural land. Traffic over the various railroads and stage lines was interfered with and in some cases was entirely suspended.

September 1916

The rains of the 8th and 9th were excessive on the uplands bordering the Salt River Valley, and the resulting floods broke the main canal and flooded a portion of the Project. The damage to the canal system amounted to about $10,000, while the direct loss to the farmers occasioned by the washing of newly planted crops and by the injury to hay and cotton from the heavy rains was undoubtedly much greater.

July 1919

The outstanding feature of the weather for July 1919 was its record-breaking rainfall. Thunderstorms accounted for practically all of the rainfall, which in a number of cases approached the dimensions of a cloudburst. Amounts in excess of 2.0 inches in twenty-four hours fell at sixteen stations. Benson (Cochise County) reported 2.43 inches in less than one hour. The heavy rains washed out roads badly and caused heavy loss to railroads from wrecks, bridges destroyed, and track washed out. Some damage to irrigating systems was reported on the San Pedro River. The Salt River and Tonto Creek, flowing into Roosevelt Reservoir, showed the remarkable runoff of 215,380 acre feet during the month, Tonto Creek being higher than at any time last winter or spring. The Gila River also reached the highest stage of the year.

November 1919

The outstanding feature was the heavy precipitation. While falling far short of the state average of 5.22 inches recorded in November 1905, it was exceeded only by that month during the last twenty-three years. The daily falls were remarkably heavy for November, several stations recording more than 4.0 inches for the twenty-four-hour period.

The heavy rains of the 26th and 27th resulted in an unusual rise for the season in the streams of the north central counties. The Hassayampa attained a stage of five feet at Wickenburg on the 27th, and the wagon bridge at that place was carried away by the force of the water backed up by the accumulation of debris. Eight feet was reached on the same day in the Agua Fria at Marinette, and bridges at Avondale were carried away. A stage of 12.5 feet was attained by the Salt River at Phoenix on the 28th. Warnings were issued to points on the Gila; and the rise, as was forecast, reached Yuma on the morning of the 30th.

February 1920

Except over the southeastern portion of the state, precipitation was decidedly above normal. Two general storm periods are to be noted: from the 7th to 10th and 19th to 23rd, the latter yielding much heavier rainfall. High water in many streams resulted from the storm of the 19th to 23rd and caused much damage to roads and bridges. The loss to the state highways alone was placed at $342,000. For the first time in four years, on February 17, the water reached the level of the waste weirs.

August 1921

Excessively heavy rains throughout the mountain regions of the state continued from the latter part of July with little abatement until the close of August when they ceased as abruptly as they had begun. Channel water continued in the Gila over most of its length, preventing crossing except at bridges. Many floods occurred, owing to excessively heavy local rains. The most noteworthy occurred on the 21st from the usually dry channel of Cave Creek. Ashdale Ranger Station reported 6.25 inches in two days. This flood washed out the irrigation ditches and overflowed about four thousand acres of cultivated land, causing an average damage of about $10 an acre. The basement of the Capitol was flooded and the first floor was covered by several inches of water. The total damage, including crops, irrigation ditches, equipment, loss of records, damage to homes, etc., is estimated at $240,000.

August 1922

A heavy rainfall on the 2nd in the Chocolate Mountains north of Yuma caused three serious breaks in the main canal of the Yuma irrigation project, which cut off the water supply in the irrigation ditches in the Yuma Valley for about ten days. The storm also occurred in Mohave and Yavapai counties where small bridges and culverts were washed out and highways were somewhat damaged.

September 1923

While there were not many rainy days and the mean precipitation for the month was not unusually large owing to the deficiencies in the southeastern and extreme northwestern portions, the fact that most of the rain occurred almost continuously from the 16th to the 18th and was particularly heavy in the north central and northeastern portions caused many washouts in the highways and railroads in that section. The rains were particularly bad in the vicinity of Cosnino and Holbrook. One man drowned near the latter place, and much property was damaged. Trains were delayed and had to be rerouted. A serious train wreck in which four men were killed was indirectly due to the heavy rain.

November 1923

November was a mild month, neither very warm nor very cold. The outstanding feature was the large amount of precipitation that fell, especially on the 9th and 10th and again on the 16th and 17th. Phoenix had a twenty-four-hour rainfall of 2.40 inches on the 9th and 10th. This was the greatest twenty-four-hour rainfall on record at this station with one exception, July 1 and 2, 1911, when 4.98 inches fell in the twenty-four-hour period.

September 1925

On the 15th, general rainstorms accompanied by thunder and high winds overswept the state and lasted until the 19th. Many highway washouts occurred in southwestern Arizona; highways were rendered impassable near Florence where minor crop damage occurred. The Winkelman branch of the Southern Pacific was washed out as was the United Verde extension railroad. The Eastern Canal near Gilbert, Queen Creek near Chandler, and the San Carlos canal near Florence overflowed. The bridge four miles from San Carlos was washed out, delaying the Southern Pacific train for four hours. The Gila River crossing at Gillespie Dam was closed to traffic for three days because approximately 4.5 feet of water poured over the apron of the dam.

September 1926

On the 26th and 27th, one of the most damaging rainstorms in Arizona history swept over central and southeastern Arizona and extended as far south as central Mexico and as far east as El Paso, Texas. Excessive rainfall lasting in many instances for forty-eight hours occurred. The Southern Pacific Railroad suffered from damaged roadbeds, washed-out bridges, and suspended traffic west of Douglas from the morning of the 27th to the afternoon of October 1 and between Phoenix and Maricopa on the 27th and 28th. The Agua Prieta River ran half a mile wide, submerging bridges and highways. The Gila River was above flood stage at Kelvin.

On the 30th, the crossing at Gillespie Dam was closed, with water four feet deep on the crest of the dam. It remained closed for three days. Thatcher, Nogales, Douglas, and Safford were flooded and many adobe houses crumbled. The Southern Pacific Railroad placed its damage at $375,000. Camp Little at Nogales was damaged to the extent of $12,000 by the rains. Bisbee reported the heaviest monthly rainfall ever known there--10.19 inches. The State Bureau of Highways placed the damage to improved roads and small bridges at $60,000.

September 1927

Heavy rains were general from the 11th to the 13th, culminating in the first severe autumn flood of the season. One death at Coolidge Dam, serious damage to the Verde supply and intake system of the Phoenix waterworks, railroad tracks washed out between Pima and Central and also between Kelton and Pearce, the overflow of many rivers, streams, and washes, and a rise of six feet in the Gila River at Ray Junction resulted from the storm.

July 1928

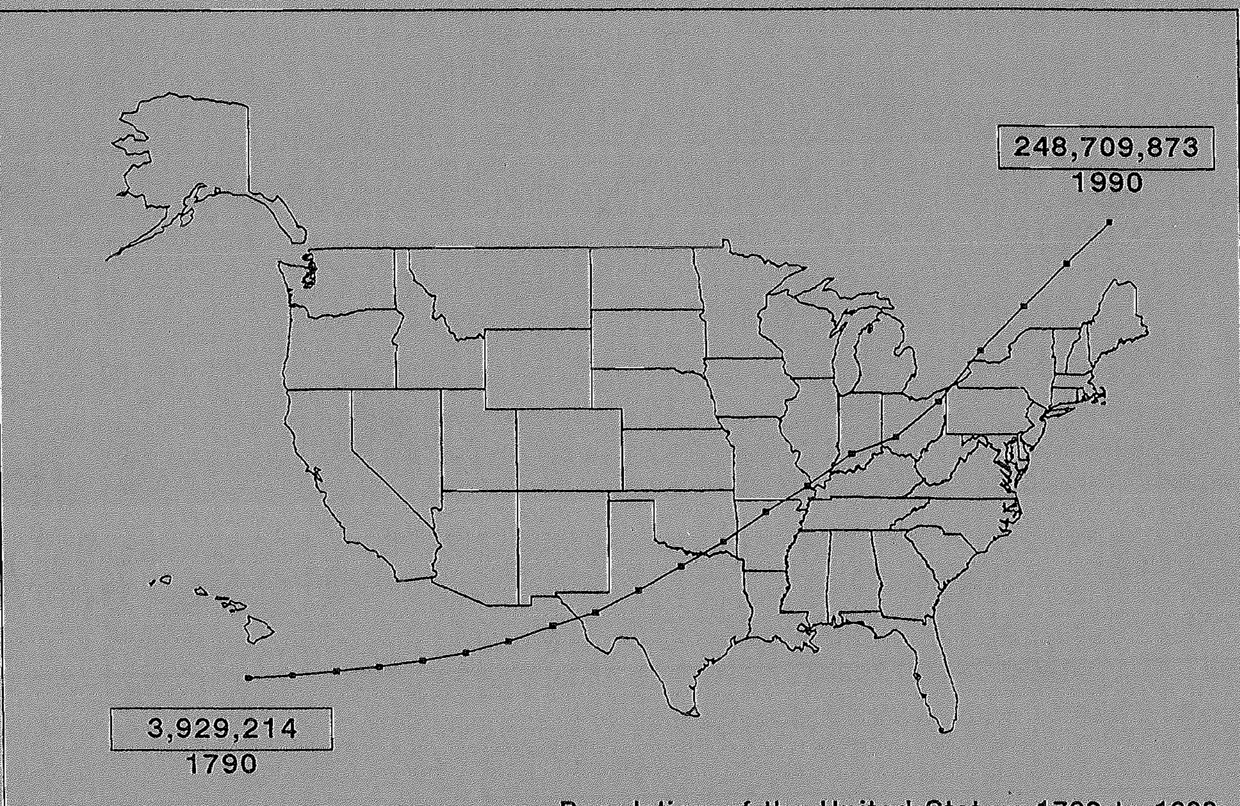
A flood occurred at Miami on the 27th, doing about $300,000 damage to property. A wall of water swept down Miami Wash from the Pinal Mountains and spread out over the town, demolishing houses and uprooting trees. The business section of Miami was under four feet of water at the crest of the storm.

September 1929

From the 19th to the 24th, damaging wind and rain storms and flood waters occurred in south central and southeastern Arizona. The prison at Florence was damaged by wind and rain. A flood in the Little Colorado isolated the Leupp Indian agency, and a cloudburst occurred between Safford and Pima. Highway 80 east and west of Douglas was washed away in places. Benson was marooned by washouts on railroads and highways, and traffic was

PB96-119060

Population of States and Counties of the United States: 1790 - 1990



Population of the United States: 1790 to 1990

Compiled and edited by Richard L. Forstall

DEPARTMENT OF COMMERCE
U.S. Bureau of the Census
Population Division

Population of States and Counties of the United States: 1790 to 1990

From the Twenty-one Decennial Censuses

March 1996

U.S DEPARTMENT OF COMMERCE
BUREAU OF THE CENSUS

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POPULATION DIVISION
Arthur J. Norton, Chief

Compiled and edited by Richard L. Forstall

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This population category consistently has included U.S. military and naval personnel stationed abroad, or in home waters but not credited to any State; in some censuses it also has included such groups as U.S. merchant seamen, diplomatic personnel, U.S. citizens employed abroad by the government, and citizens abroad on private business.

The 1870 census was widely recognized to have underenumerated the population of the Southern States. In the report of the 1890 census, the 1870 undercount was estimated at 1,260,078, and the correct U.S. total for 1870 as 39,818,449 (Census Office, *11th Census, 1890, Report on Population of the United States...*, Part 1 (Washington, 1895), p. xii). This estimate was made by assuming that the White population of the Southern States as a group (comprising Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, Virginia, and West Virginia) increased by the same percentage from 1860 to 1870 and from 1870 to 1880, and that the Black population of these States likewise increased by the same percentage in the two decades. This approach was seen as justified, because after incorporating the results of this estimate the resulting U.S. growth rates for the two decades were quite similar to the observed growth rate for 1880-1890. However, the hypothesis of equal growth in 1860-70 and 1870-80 seems to make no allowance for above-average losses of population during the 1860s resulting from the Civil War. No estimates of the 1870 undercount were published for individual States, and the 1870 data in this report do not reflect any corrections.

American Indian Population

American Indians generally were not counted in the censuses prior to 1890, unless they were considered to be part of the broader non-Indian society, as evidenced by their paying local taxes and living in settled communities, often alongside non-Indians. The censuses from 1850 through 1880 included estimates of American Indians "retaining their tribal character," sometimes by State or Territory.

In 1890, most Indians were enumerated, but were reported separately from the general population, usually by reservation rather than by county. A volume of the 1890 reports dealt exclusively with Indians and included a historical review of earlier estimates (Census Office, *11th Census, 1890, Report on Indians...* [Vol. X] (Washington, 1894). Beginning with the 1910 census reports, the 1890 Indian population has been included in the appropriate State totals. In Part III of this publication, the tables report the 1890 Indian population by county when that is possible, and by reservation in Oklahoma and South Dakota; notes explain cases where Indians are included in State totals but not in any State subdivision.

The inclusion of most American Indians in the census beginning in 1890 naturally has some effect on comparisons for the relevant States and counties with censuses before that date. However, even if earlier censuses had enumerated all of the Indian population, much of it would not have been found at its 1890 location at the earlier dates, because of extensive forced removal, migration, and resettling as the settlement frontier advanced and Indian reservations were established.

State History

Since 1790 many new Territories and States have been created, some States have been formed from others, and territory sometimes has been transferred between States. In Part III, just before the numbered notes for each State, two paragraphs appear giving a historical summary for the State. The first paragraph outlines the territorial evolution of the State, and the second paragraph describes the extent of its census coverage.

The territorial description extends from the time the Nation was established in the case of the 13 original States and the States subsequently formed from them, and from the time of acquisition by the United States for the other States. This historical summary is designed to indicate the geographic extent of each State (or Territory) at the time of each census in which it was reported. (The U.S. census of course did not cover any State or Territory prior to its acquisition by the United States.) The discussion of territorial evolution is based in large part on *Boundaries of the United States and the Several States*, by Franklin K. Van Zandt (Geological Survey Professional Paper 909; Washington, DC, U.S. Government Printing Office, 1976). In the notes on individual States, wording referring to "essentially the current boundaries" is intended to remind users that there may have been other very minor boundary changes besides those documented here.

POPULATION OF COUNTIES -- ARIZONA: 1890-1990

County	1990	1980	1970	1960	1950	1940	1930	1920	1910	1900	1890
ARIZONA	3,665,228	2,718,215	1,770,900	1,302,161	749,587	499,261	435,573	334,162	204,354	122,931	88,243
Apache	61,591	52,108	32,298	30,438	27,767	24,095	17,765	13,196	9,196	8,297	4,281
Arizona	—	—	—	—	—	—	—	—	—	—	—
Cochise	97,624	85,686	61,910	55,039	31,488	34,627	40,998	46,465	34,591	9,251	6,938
Coconino	96,591	75,008	48,326	41,857	23,910	18,770	14,064	9,982	8,130	5,514	—
Gila	40,216	37,080	29,255	25,745	24,158	23,867	31,016	25,678	16,348	4,973	2,021
Graham	26,554	22,862	16,578	14,045	12,985	12,113	10,373	10,148	23,999	14,162	5,670
Greenlee	8,008	11,406	10,330	11,509	12,805	8,698	9,886	15,362	—	—	—
La Paz	13,844	—	—	—	—	—	—	—	—	—	—
Maricopa	2,122,101	1,509,052	967,522	663,510	331,770	186,193	150,970	89,576	34,488	20,457	10,986
Mohave	93,497	55,865	25,857	7,736	8,510	8,591	5,572	5,259	3,773	3,426	1,444
Navajo	77,658	67,629	47,715	37,994	29,446	25,309	21,202	16,077	11,471	8,829	—
Pima	666,880	531,443	351,667	265,660	141,216	72,838	55,676	34,680	22,818	14,689	12,673
Pinal	116,379	90,918	67,916	62,673	43,191	28,841	22,081	16,130	9,045	7,779	4,251
Santa Cruz	29,676	20,459	13,966	10,808	9,344	9,482	9,684	12,689	6,766	4,545	—
Yavapai	107,714	68,145	36,733	28,912	24,991	26,511	28,470	24,016	15,996	13,799	8,685
Yuma	106,895	90,554	60,827	46,235	28,006	19,326	17,816	14,904	7,733	4,145	2,671

ARIZONA NOTES

Arizona was acquired from Mexico in 1848 and 1853. It was established as a territory in 1863 from New Mexico Territory, and acquired essentially its present boundaries in 1866. Arizona was admitted as a State on February 4, 1912.

In 1850 present-day Arizona had no census coverage. The 1860 population is for Arizona County, New Mexico Territory, which comprised most of present-day Arizona south of the Gila River. Northern and central Arizona first had census coverage in 1870.

County Notes:

Note 1: Population for 1860 is for Arizona County, New Mexico Territory.

Note 2: Totals for 1890 and 1900 include population of certain Indian reservations not reported by county (1890: 28,623; 1900: 3,065).

Note 3: La Paz County (1980 pop. 12,557) was formed from Yuma County in 1983.

POPULATION OF COUNTIES -- ARIZONA: 1860-1880

County	1880	1870	1860	Notes
ARIZONA	40,440	9,658	6,482	See notes 1 and 2
Apache	5,283	—	—	*Yavapai
Arizona	—	—	6,482	To Pima, Yuma; Yavapai
Cochise	—	—	—	*Pima
Coconino	—	—	—	*Yavapai
Gila	—	—	—	*Maricopa, Pinal, Yavapai; Apache
Graham	—	—	—	*Apache, Pima
Greenlee	—	—	—	*Graham
La Paz	—	—	—	*Yuma; see note 3
Maricopa	5,689	—	—	*Yavapai, Pima
Mohave	1,190	179	—	
Navajo	—	—	—	*Apache
Pima	17,006	5,716	—	*Arizona, Dona Ana (NM)
Pinal	3,044	—	—	*Pima, Yavapai
Santa Cruz	—	—	—	*Pima
Yavapai	5,013	2,142	—	
Yuma	3,215	1,621	—	*Arizona; see note 3

POPULATION OF COUNTIES -- CALIFORNIA: 1850-1880

County	1880	1870	1860	1850	Notes
CALIFORNIA	864,694	560,247	379,994	92,597	See notes 1 and 2
Alameda	62,976	24,237	8,927	—	
Alpine	539	685	—	—	*El Dorado, Amador, Calaveras, Tuolumne
Amador	11,384	9,582	10,930	—	*Calaveras, El Dorado
Butte	18,721	11,403	12,106	3,574	
Calaveras	9,094	8,895	16,299	16,884	
Colusa	13,118	6,165	2,274	115	
Contra Costa	12,525	8,461	5,328	—	See note 1
Del Norte	2,584	2,022	1,993	—	*Trinity
El Dorado	10,683	10,309	20,562	20,057	
Fresno	9,478	6,336	4,605	—	*Mariposa; Calaveras, Tuolumne
Glenn	—	—	—	—	*Colusa
Humboldt	15,512	6,140	2,694	—	*Trinity
Imperial	—	—	—	—	*San Diego
Inyo	2,928	1,956	—	—	*Tulare, Fresno
Kern	5,601	2,925	—	—	*Tulare, Los Angeles
Kings	—	—	—	—	*Tulare
Klamath	—	1,686	1,803	—	*Trinity; to Siskiyou, Humboldt
Lake	6,596	2,969	—	—	*Napa, Colusa, Mendocino
Lassen	3,340	1,327	—	—	*Shasta, Plumas
Los Angeles	33,381	15,309	11,333	3,530	
Madera	—	—	—	—	*Fresno
Marin	11,324	6,903	3,334	323	
Mariposa	4,339	4,572	6,243	4,379	
Mendocino	12,800	7,545	3,967	55	
Merced	5,656	2,807	1,141	—	*Mariposa
Modoc	4,399	—	—	—	*Siskiyou
Mono	7,499	430	—	—	*Fresno, Calaveras; Amador, Mariposa
Monterey	11,302	9,876	4,739	1,872	
Napa	13,235	7,163	5,521	405	
Nevada	20,823	19,134	16,446	—	*Yuba
Orange	—	—	—	—	*Los Angeles; San Diego
Placer	14,232	11,357	13,270	—	*Yuba, Sutter
Plumas	6,180	4,489	4,363	—	*Butte; Yuba
Riverside	—	—	—	—	*San Diego, San Bernardino
Sacramento	34,390	26,830	24,142	9,087	
San Benito	5,584	—	—	—	*Monterey
San Bernardino	7,786	3,988	5,551	—	*San Diego, Mariposa, Los Angeles
San Diego	8,618	4,951	4,324	798	
San Francisco	233,959	149,473	56,802	—	See note 1
San Joaquin	24,349	21,050	9,435	3,647	
San Luis Obispo	9,142	4,772	1,782	336	
San Mateo	8,669	6,635	3,214	—	
Santa Barbara	9,513	7,784	3,543	1,185	
Santa Clara	35,039	26,246	11,912	—	See note 1
Santa Cruz	12,802	8,743	4,944	643	
Shasta	9,492	4,173	4,360	378	
Sierra	6,623	5,619	11,387	—	*Yuba
Siskiyou	8,610	6,848	7,629	—	*Shasta, Trinity
Solano	18,475	16,871	7,169	580	
Sonoma	25,926	19,819	11,867	560	
Stanislaus	8,751	6,499	2,245	—	*Tuolumne, San Joaquin
Sutter	5,159	5,030	3,390	3,444	
Tehama	9,301	3,587	4,044	—	*Colusa, Shasta, Butte
Trinity	4,999	3,213	5,125	1,635	
Tulare	11,281	4,533	4,638	—	*Mariposa; San Diego

POPULATION OF COUNTIES -- CALIFORNIA: 1890-1990 (Continued)

County	1990	1980	1970	1960	1950	1940	1930	1920	1910	1900	1890
Tuolumne	48,456	33,928	22,169	14,404	12,584	10,887	9,271	7,768	9,979	11,166	6,082
Ventura	669,016	529,174	376,430	199,138	114,647	69,685	54,976	28,724	18,347	14,367	10,071
Yolo	141,092	113,374	91,788	65,727	40,640	27,243	23,644	17,105	13,926	13,618	12,684
Yuba	58,228	49,733	44,736	33,859	24,420	17,034	11,331	10,375	10,042	8,620	9,636

CALIFORNIA NOTES

California was part of the region acquired from Mexico in 1848, and was admitted as a State on September 9, 1850 with essentially its present boundaries.

Although the 1850 census covered the whole State, the 1850 returns are incomplete; those for Contra Costa and Santa Clara Counties were lost before reaching Washington, and those for San Francisco County were destroyed by fire.

County Notes:

Note 1: The 1850 total is incomplete; the returns for Contra Costa and Santa Clara Counties were lost before reaching Washington; those for San Francisco County were destroyed by fire. The State census of 1852 showed a population of 2,786 for Contra Costa, 36,154 for San Francisco, and 6,764 for Santa Clara; the 1852 State total was 215,122, excluding El Dorado County, whose population was not enumerated but was estimated at 40,000.

Note 2: Total for 1890 includes population (5,268) of certain Indian reservations not reported by county.

POPULATION OF COUNTIES -- CALIFORNIA: 1850-1880 (Continued)

County	1880	1870	1860	1850	Notes
Tuolumne	7,848	8,150	16,229	8,351	
Ventura	5,073	—	—	—	*Santa Barbara; San Luis Obispo, Kern
Yolo	11,772	9,899	4,716	1,086	
Yuba	11,284	10,851	13,668	9,673	

THE

RESOURCES OF ARIZONA.

ITS MINERAL, FARMING, GRAZING AND TIMBER LANDS; ITS HISTORY, CLIMATE, PRODUCTIONS, CIVIL AND MILITARY GOVERNMENT, PRE-HISTORIC RUINS, EARLY MISSIONARIES, INDIAN TRIBES, PIONEER DAYS, ETC., ETC.

THIRD EDITION.

REVISED AND ENLARGED, WITH NEW MAP AND ILLUSTRATIONS.

BY PATRICK HAMILTON.

SAN FRANCISCO:
A. L. BANCROFT & COMPANY, PRINTERS.
1884.

quicksilver. This is the process which prevails in the Tombstone, and other districts where the ores are free from base combinations. Where silver occurs in connection with other metal, the ores are first crushed dry, after which they are roasted, and then passed thorough pans and settlers. Smelting ores of gold or silver are not plentiful, and there are only a few establishments where the smelting process is employed. The percentage of loss is very small, and a saving of ninety-five per cent. is not an unusual result.

We have said there is here the finest opening for capital presented by any mining country in the west, and the results already achieved will justify the assertion. Although not one-twentieth part of the money has been invested in Arizona that has found its way to Colorado or California, yet the dividends from the Territory, for the years 1881–82, have exceeded those from either of those States. Although the shipments of bullion from the country, eight years ago, were but a little over a hundred thousand dollars, it now stands third on the list of producers, and is destined in a short time to occupy the first place. We have seen what the building of two railroads has done for Arizona within a short few years, and it is not unreasonable to look for a corresponding improvement for the building of others. It has been clearly demonstrated that cheap and rapid communication is the chief aid which Arizona requires to place her in the front rank of the bullion-producing States and Territories, and from present appearances the day is not far distant when every county in the Territory will be provided with it.

As showing the wonderful increase in the yield of Arizona, since the opening of the Southern Pacific Railroad, we give the figures compiled by Wells, Fargo & Co's Express, for the past four years :

Production for	1879	$1,942,403
" "	1880	4,472,471
" "	1881	8,198,766
" "	1882	9,298,267

From being seventh in the list in 1879, Arizona became fifth in 1880, fourth in 1881, and third in 1882. A large quantity of rich ore and base bullion which finds its way out of the country is not included in the above, and it is

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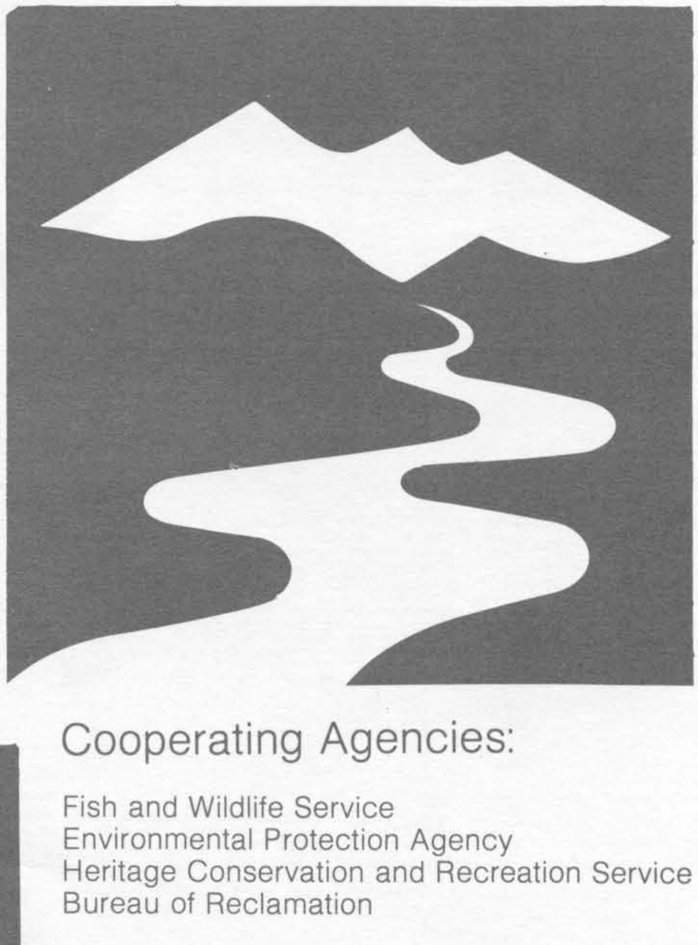
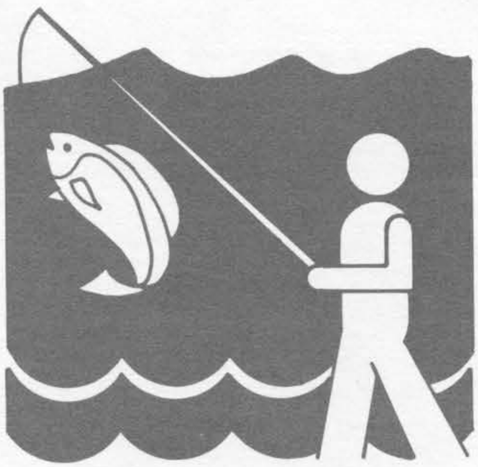
Methods of Assessing Instream Flows for Recreation



COOPERATIVE
INSTREAM FLOW
SERVICE GROUP

INSTREAM FLOW INFORMATION PAPER: NO. 6

FWS/OBS-78/34
JUNE 1978



Cooperating Agencies:

Fish and Wildlife Service
Environmental Protection Agency
Heritage Conservation and Recreation Service
Bureau of Reclamation

COOPERATIVE INSTREAM FLOW SERVICE GROUP

The Cooperative Instream Flow Service Group was formed in 1976 under the sponsorship of the U.S. Fish and Wildlife Service. Primary funding was provided by the U.S. Environmental Protection Agency. The group operates as a satellite of the Western Energy and Land Use Team. It is a part of the Western Water Allocation Project, Office of Biological Services.

Cooperative Instream Flow
Service Group
333 West Drake Road
Fort Collins, Colorado 80521
(303) 493-4275 FTS 323-5231

While the Fish and Wildlife Service is providing the initiative and leadership, the IFG is conceived as a multi-agency, multi-disciplinary program which is to become a "center of activity," providing a focus for the increasing importance of instream flow assessments.

The multi-agency, multi-disciplinary nature of the group is provided through the Intergovernmental Personnel Act transfer of state personnel, and details from other Federal agencies.

Interagency Energy-Environment
Research and Development Program
Office of Research and Development
U.S. Environmental Protection Agency

FWS/OBS-78/34
June 1978

METHODS OF ASSESSING INSTREAM FLOWS FOR RECREATION

Instream Flow Information Paper No. 6

by

Ronald Hyra[1]
Cooperative Instream Flow Service Group
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2625 Redwing Road
Fort Collins, Colorado 80526

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Cooperative Instream Flow Service Group
Western Energy and Land Use Team
Office of Biological Services
Fish and Wildlife Service
U.S. Department of the Interior

[1]Detailed to the Cooperative Instream Flow Service Group from the Heritage Conservation and Recreation Service.

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ABSTRACT

The Instream Flow Group (IFG) has conducted research into methods of quantifying instream flow needs for fish, wildlife, and recreation. This paper describes two techniques developed by IFG for performing recreational instream flow studies. The single cross section method is relatively simple and provides a base flow figure which will provide for the boating activities which make use of the of river. The incremental method is more sophisticated and may be used to develop recommendations regarding streamflows required for various types of recreation, or to provide a recreation analysis of any streamflow. Streamflow suitability criteria for recreation are presented for both methods.

INTRODUCTION

It has been long recognized that there are many competing demands for the use of stream water. Diverting stream water for irrigation, water supply, and energy developments can deplete streamflows to the point where opportunities for recreation and the associated environmental values of the stream are seriously impaired. Numerous water planning studies, both basin-wide and project oriented, have emphasized the need to quantify the amount of water required to support recreation, fish and wildlife resources, and to maintain aesthetic conditions.

The tools and techniques for estimating streamflows required for recreation and aesthetics, and for insuring reasonable consideration of recreation and aesthetics in the allocation of stream water, are currently undergoing study. Instream flow requirements and values for recreation, in the past, have often been based only upon the amount required to maintain a fishery. However, several studies have indicated that recreation and aesthetic requirements, at times, may not be the same as for a fishery.

This paper presents the techniques of assessing instream flows for recreation. These techniques were developed by the Cooperative Instream Flow Service Group and closely parallel techniques used to assess instream flows for fisheries. The data collection procedures, the physical and hydraulic simulation of the stream, and the computer models which analyze the data are the same for both fisheries and recreation. The major difference between the two techniques is the response of the individual fish or recreationist to various physical parameters of stream flow. These responses to stream flow by different user groups are the criteria which are basic to the methods introduced here.

The first method is called the single cross section approach. This method is useful primarily for identifying flows below which a recreation activity is not feasible and results in a so called "minimum" flow recommendation.

The second method is called the incremental method. With this method the recreation planner is able to analyze various flows and determine the recreation potential of a stream at different flows.

This paper is being distributed with four objectives in mind. These are:

1. To bring the problem of preserving instream flows to the attention of recreation agencies and the research community in order to encourage more research in this vital and neglected area.

2. To discuss the development of the recreation probability-of-use curves and of recreation criteria in general, which are necessary for quantifying instream water requirements for recreation.

3. To obtain review and comment on the recreation criteria and probability-of-use curves, and to request data which may be used to test or improve the criteria or curves.

4. To describe the two approaches for assessing stream flows and discuss how various recreation planning processes can be served by their application.

Both methods of instream flow analysis discussed in this paper utilize computer modeling techniques. Both approaches also require that streamflow data be collected. The single cross section approach, as its name implies, requires that information be collected at only one location on the stream. The incremental method requires that data be collected at multiple locations on the stream. In addition to cross sectional data, data relating the streamflow parameters to recreation potential are necessary. These data are termed recreation criteria.

Recreation criteria for instream flow methodologies are the recreation activity information bases necessary to describe a relationship between the quantity of water flowing in a stream, and the quantity and quality of a particular recreation activity which takes place in the stream.

SINGLE CROSS SECTION METHOD

This method requires that only a single cross sectional measurement be taken across a stream. The product of such an approach is a determination of the lowest flow acceptable for recreation. 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. When this area provides minimum depths for boat passage, the flow at this level may be defined as a minimum acceptable flow. It is assumed that when sufficient water to support boating is available in these critical areas, other areas will have sufficient water to support most of the other instream recreation activities. This approach is best applied to those streams in which flows are expected to be higher than the minimum most of the time.

Criteria for this approach are set forth in Table 1. Criteria have been developed for boating activities only, but for various types of boating craft. Only minimum criteria are presented because this approach provides information on "minimum flows." Criteria are measured in terms of stream depth and width. Velocity is not considered because a minimum velocity is not considered necessary for this approach.

Table 1. Required stream width and depth for various recreation craft as determined by single cross section method.

Recreation Craft	Required depth (ft)	Required width (ft)
Canoe-kayak	0.5	4
Drift boat, row boat-raft	1.0	6
Tube	1.0	4
Power boat	3.0	6
Sail boat	3.0	25

The criteria of Table 1 are minimal and would not provide a satisfactory experience if the entire river was at this level. However, the cross section measured for this method is the shallowest in the stream reach. Therefore, these minimum conditions will only be encountered for a short time during a boating trip, and the remainder of the trip will be over water of greater depths and widths. An important assumption is that all water greater than the minimum is equally useful for the activity (i.e., more is better until bank-full stage).

A computer program (IFG-1) has been developed which predicts width and depth across the transect of any stage (water surface elevation). The output shows discharge and the width with depth equal to or greater than a specific depth. Different water surface elevations may be put into the computer model which are translated into flow in cubic feet per second. When a flow provides the minimum width and depth necessary for an activity, discharge may be considered minimum. Such a minimum indicates that significant losses, if not elimination of this activity, will occur if minimum flow is not equaled or exceeded.

THE INCREMENTAL METHOD

This method, more sophisticated than the single cross section method, describes a relationship between the amount of water in a reach of stream and the associated recreation potential. The incremental method can describe the potential for any recreation activity at any streamflow. A major difference between the methods is that the single cross section method can only be used to identify low flow and cannot be used to assess the recreation potential at any other flow; the incremental method can be used to assess the potential at other flows or to calculate the change in receation potential caused by a change in stream flow.

The incremental method involves a modeling procedure whereby the surface area of a stretch of stream is calculated. In addition to the total surface area of the reach of stream, the area which has certain depths and velocities is calculated. The usable surface area for each activity is then calculated by use of depth and velocity requirements.

It is necessary to make three assumptions regarding the relationship between the quantity of water and the recreation uses of the water: (1) water depth and water velocity are the two streamflow components which are most important in determining whether or not a certain recreation activity may be safely and pleasurably engaged in[1]; (2) there are

[1]Other parameters such as water quality and temperature are also very important in determining the amount of instream recreation use but in many cases are not significantly influenced by flow. Width is also important but is considered outside of the computer model (i.e., width is not a part of the calculation of usable surface area).

certain measures of water depth and water velocity which may be considered minimum, maximum, and optimum for an activity; and (3) the measurement of water surface area which meets certain requirements of depth and velocity is a viable method of describing recreation potential for instream recreation uses.

This method is comprised of four components: (1) computer simulation of a stream reach, (2) determination of the combinations of stream depth and velocity, (3) determination of a composite probability-of-use for each combination of depth and velocity, and (4) calculation of a weighted usable surface area.

1. Simulation of the Stream. The stream reach simulation model utilized in this approach uses several cross sectional transects, each of which is subdivided into subsections. For any stage (water surface elevation) the mean depth and velocity of each subsection is calculated. Typically, a transect would be established across a pool, a riffle, and an intermediate area. Together these cross sectional measurements would represent a stream reach which may extend several miles. In Table 2 a 100 foot length of stream is represented.

Table 2. Depth velocity matrix showing total surface area of stream in square feet.

Depth (ft)	Velocity in feet per second				
	<0.5	0.5-1.0	1.0-1.5	>1.5	Total
<1	500	400	100	0	1,000
1-2	600	700	800	300	2,400
2-3	100	300	500	100	1,000
>3	0	0	100	0	100
Total	1,200	1,400	1,500	400	4,500

2. Distribution of Combinations of Depth and Velocity. The output of the stream reach simulation model is in the form of a matrix showing the surface area of a stream having different combinations of depth and velocity. Table 2 illustrates a depth velocity matrix. The outlined number in the upper left matrix cell refers to 500 square feet per 100 feet of stream having a combination of depth less than 1.0 foot <u>and</u> velocity less than 0.5 foot per second. This figure is the sum of the areas within the stream reach with this combination of depth and velocity.

In order to evaluate the effect of these physical changes upon a streams desirability for recreation, it is necessary to develop an information base for each recreation activity. Such an information base should identify a relationship between depth and velocity of the water, and the desirability of such water for each recreation activity. The information base, called recreation criteria, has been developed and is set forth in the following pages.

3. Composite Probabilities-of-Use. Determination of the probability-of-use for an activity on a certain area of water requires multiplying the probability-of-use for the depth by the probability-of-use for the velocity. For example, from Figure 1 the probability-of-use for the depth of 2.6 feet is 0.9. The probability-of-use for the velocity of 6 feet per second is 0.24. The composite probability-of-use for a depth of 2.6 feet <u>and</u> a velocity of 6 feet per second, is 0.216 (0.9 x 0.24). The probability-of-use is also the weighting factor for calculation of the weighted usable surface area.

4. Weighted Usable Surface Area. The weighted usable surface area equates an area of low desirability to an equivalent area of optimal desirability. For example, if 1,000 square feet of surface area had a composite probability-of-use of 0.216 (see above) it would have a weighted usable surface area of 216 square feet (total surface area times composite probability-of-use). These 1,000 square feet of surface area would be considered to have the same recreation potential as 216 square feet of surface area having optimum depths and velocities.

An example of a matrix is shown in Table 3. In each cell of the matrix, the upper number refers to the surface area of a stream having a depth velocity combination as indicated. The numbers in parentheses refer to the weighted usable surface area.

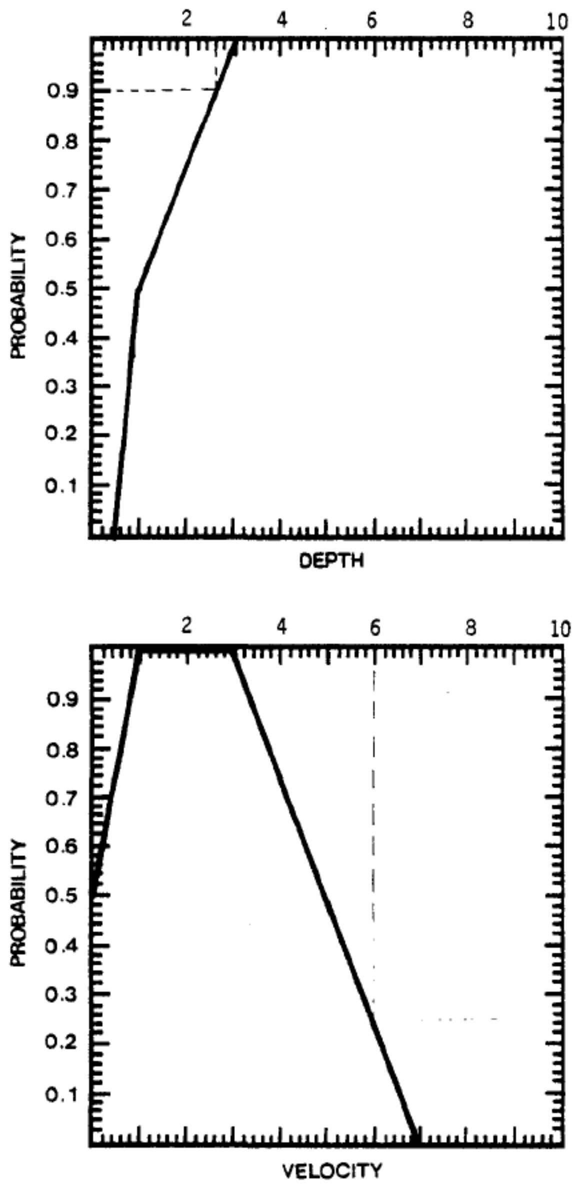

Figure 1. Probability-of-use curve for stream fishing (boat non-power) in relation to depth and velocity.

Table 3. Total surface area of stream and (weighted usable surface area) for a hypothetical recreation activity in square feet.

Depth (ft) and (Probability-of-use)	Velocity in feet per second and (probability-of-use)				
	<0.5 (1.0)	0.5-1.0 (0.8)	1.0-1.5 (0.4)	>1.5 (0)	Total
<1 (0)	500 (0)	400 (0)	100 (0)	0 (0)	1,000 (0)
1-2 (0.3)	600 (180)	700 (168)	800 (96)	300 (0)	2,400 (444)
2-3 (0.8)	100 (80)	300 (192)	500 (160)	100 (0)	1,000 (432)
>3 (1.0)	0 (0)	0 (0)	100 (40)	0 (0)	100 (40)
Totals	1,200 (260)	1,400 (360)	1,500 (296)	400 (0)	4,500 (916)

A separate matrix is required for each recreation activity being considered. A separate matrix is also developed for each of a number of different flows and a different weighted usable surface area is calculated for each flow. Comparison of the matrices provides information on the "best flow" or shows the change in weighted usable surface area due to a change in flow.

RECREATION CRITERIA FOR THE INCREMENTAL METHOD

Recreation activity definitions and a discussion of criteria are presented below.

Minimum and Maximum Criteria

Criteria, as discussed in this section, refer to the parameters of depth and velocity, and deal with the minimum and maximum values. The assumption is made that the recreation activity in question cannot be engaged in outside of the range described by the minimum and maximum values. Optimum values are determined in a somewhat different manner and will be discussed later. Minimum and maximum criteria are of two major types: (1) physical criteria and (2) safety criteria. Regarding physical criteria, recreation activities have certain physical or absolute limits or requirements which must be met (i.e., a boat requires a certain minimum depth of water to float). In the case of safety criteria there are no absolutes; however, it can generally be stated that certain depths or velocities may be unsafe for the average participant. Safety criteria may also be considered a preferred physical limitation.

Optimum Criteria

Minimum and maximum criteria are used to establish the range of depths and velocities which provide a usable surface area for river recreationists. It is also possible to identify a preferred depth or velocity or range of preferred depths and velocities which could be called optimum. Obviously, optimum will not be agreed upon by all recreationists since they represent such a heterogeneous group. However, the total range can be narrowed and a preferred range established. An optimum value of depth or velocity or a preferred range of depths and velocities will be that value or range of values which is usable to the largest number of potential participants.

There are "psychological" criteria that also might be used for selecting optimum depths or velocities. Psychological criteria relate to the quality of the experience. However, in order to evaluate the quality of the experience, one must determine what experience is sought. A number of the recreation activities included in this report have expectations that appear to be unrelated to flow. Therefore, for such activities only the physical and safety criteria need to be considered. Other activities have flow-related expectations and it appears that the experience desired and expected should be a part of the criteria. According to Schreyer and Nelson (1978) the "white water" activities, have an "action-excitement" expectation, and certain types of water are necessary to realize that expectation. Stream depths and/or velocities which produce action-excitement are not easily identified because of the differing skill levels and experience of recreationists. Consequently, psychological criteria, in terms of depth or velocity, are not listed at this time.

The activities which have action and excitement as an expectation are the last four activities listed under boating (below). However, not all of the persons who engage in these activities seek action and excitement. Therefore, a wide range of optimum velocity values is necessary to include the action excitement expectation as well as the other expectations. Each of these four activities may be viewed as two separate activities, one which occurs on tranquil water and one which occurs on non-tranquil water.

Recreation Activities

The stream-oriented recreation activities considered in this report are shown below:

Fishing	Water Contact	Boating
Wading	Swimming	Sailing
Boat, power	Wading	Low power
Boat, nonpower	Water skiing	High power
		Canoeing-Kayaking
		Rowing-rafting-drifting
		Tubing-floating

Definitions

Fishing

Wading: fishing while walking in the stream.
Boat power: fishing from a power boat.
Boat nonpower: fishing from a nonpower boat.

Water Contact

Swimming: propelling oneself through the water with no, or only occasional, contact with the bottom.
Wading: walking in the water, including water play.
Water skiing: being towed behind a boat on skiis.

Boating

Sailing: wind powered boating.
Low power: power boating, motor less than 50 horsepower.
High power: power boating, motor greater than 50 horsepower.
Canoeing-kayaking: using a canoe or kayak in a river.
Rowing-rafting-drifting: using a row boat, raft, or drift boat in a river.
Tubing-floating: floating on a device which is not a full-sized boat or raft. May include inner tubes, small rafts, air mattresses, etc. This activity is also a water contact activity. It is placed here for its similarity to rowing-rafting-drifting.

PROBABILITY-OF-USE CURVES

Development of recreation probability-of-use curves builds upon the recreation criteria discussed in the previous section. Minimum, maximum, and optimum criteria are translated into probablities-of-use and recreation probability curves are developed.

The recreation criteria may be graphed with depth (or velocity) on the X axis and the desirability of certain depths for the recreation activity in question along the Y axis (Figure 2).

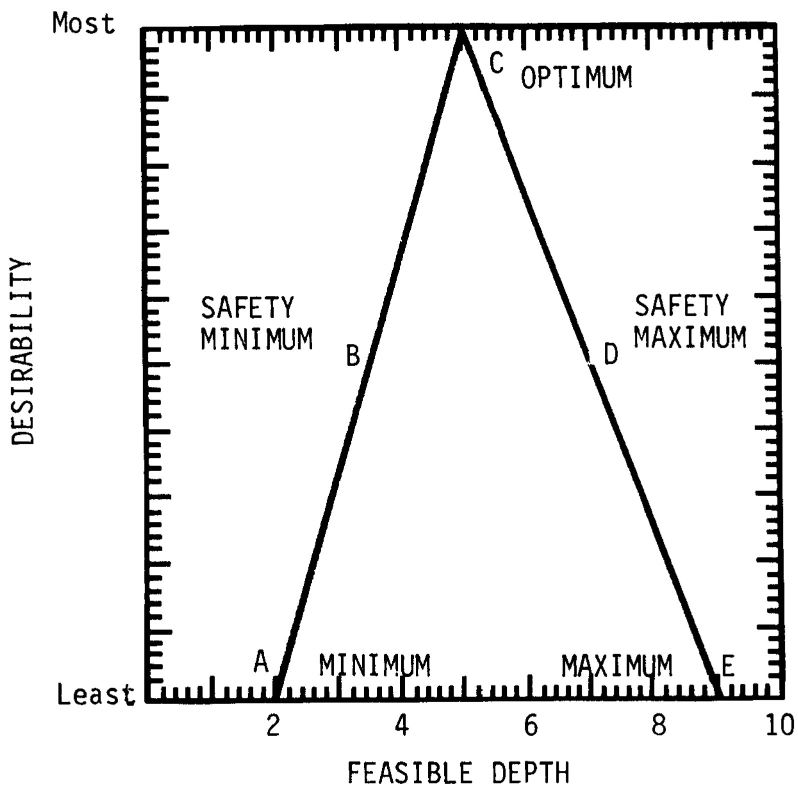

Figure 2. Desirability of stream depth graph for a hypothetical recreation activity.

The physical minimum is shown on the graph as "A" and is the least desirable depth at which the activity is possible. Preferred low flows are the least depth at which the activity can be participated in safely is shown as "B" on the graph. Safety values are somewhat arbitrary because they depend upon experience and skill of the recreationist. In this context, it is assumed that it is an average figure, and that up to 50 percent of the potential participants will find depths between "A" and "B" usable. Point "C" on the graph indicates the most desirable or optimum depth and it is assumed that 100 percent of the potential participants would find such a depth usable. Point "D" indicates the preferred or safety maximum and "E" indicates the physical maximum.

If the Y axis is changed from a desirability scale to a probability scale, with 1.0 on top and 0 on the bottom, the "probability-of-use" may be read off the Y axis.

If Figure 2 represents a probability-of-use curve for an activity in a region where the resource is experiencing capacity use, then the following assumptions can be stated:

1. Areas having depths less than "A" or greater than "E" will have no use.

2. Areas having depths equal to "C" will be experiencing capacity use.

3. Areas having depths equal to "B" and "D" will be experiencing 50 percent of the use of area "C."

Appendix A sets forth the depth and velocity criteria in tabular and graphic forms and defines depths and velocities in terms of desirability as follows:

Optimum	Depth or velocity usable by all; probability-of-use or weighting factor 1.0
Acceptable	Depth or velocity between safety limit and optimum; probability-of-use or weighting factor 0.5-0.99
Marginal	Depth or velocity between physical and safety limits; probability-of-use or weighting factor 0.01-0.49
Unacceptable	Depth or velocity unusable; probability-of-use or weighting factor 0.0

Appendix B shows the probability-of-use curves which are developed from the depth and velocity criteria.

APPLICATION

There are situations where the single cross section method or the incremental method is best suited to do instream flow studies.

The single cross section approach is best suited to situations where:

1. A minimum of time is available.

2. A low flow recommendation is all that is necessary.

3. The low flow recommendation will be exceeded for most of the recreation season.

The incremental method is best suited to situations where:

1. Increments of flow need to be analyzed.

2. The change in streamflow needs to be related to change in recreation potential.

3. The most "exact" answer, available with today's state-of-the-art, is desired.

Opportunities for preserving instream flows for recreation may occur within several programs and processes. Planners did not always take advantage of these opportunities in the past because no method existed by which to quantify the instream flow need.

Opportunities exist within the State water adjudication procedures wherein all water rights will be adjudicated including the Federal reserved rights. When the purpose of the Federal reservation of land includes recreation, the quantity of water necessary to accomplish the purpose must be quantified, and this includes the instream flow required.

Both Federal and State wild and scenic river programs contain language that may be used to preserve instream flows for recreational or aesthetic purposes. The licensing and relicensing procedures of the hydroelectric utility companies call for exhibits to be prepared which describe the recreation resource and the benefits to the public from such a license or project.

Whenever a water project is proposed the impact of the project on recreation is studied. The incremental method will permit the stream portion of such analysis to take its place alongside the reservoir portion.

Use of the incremental method will permit full consideration of recreation by water management agencies as they make decisions about water allocation, conduct hearings for diversion permit requests, or determine low flows.

In general, whenever proposals are made which will change an existing streamflow or flow regime, the impact upon recreation can be determined and be considered in the planning process.

LIMITATIONS

The limitations of the methods discussed in this paper should be understood prior to field testing.

The single cross section is limited to making minimum flow recommendations to accommodate the boating recreation activities. It is less exact than the incremental method and the location of the cross sectional measurement is critical.

The incremental method may be used to describe the impact of a change in flow or used to identify an optimum flow. However, there is no such thing as an optimum flow or flow regime for recreation. Each recreation activity has its own unique flow requirement and frequently flow requirements conflict among activities. For example, a greater flow resulting in higher velocities may benefit the white water boaters, but would all but eliminate fishing while wading. Usually a flow recommendation would be provided in terms of a flow regime. The recommendation of a flow regime would recognize the variable supply of water throughout the year as well as the periods of greatest demand for instream water. A flow regime for recreation would take into account the greater recreation demand during the recreation season, during the weekends, and perhaps even during the daylight hours.

Use of the incremental method can provide only a measure of recreation potential and cannot provide adequate information for developing a recommended flow regime based on the demand for recreation. If such a recommendation is necessary, or if knowledge of a change in recreation use or benefits, due to a change in flow, is desired, a demand-supply study should be undertaken. A demand-supply study would use the output from the incremental method as the supply component.

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6. Hyra, Ronald. Methods of Assessing Instream Flows for Recreation. Fort Collins, Colorado, Cooperative Instream Flow Service Group, May 1978, 49 pages. (NTIS Accession Number: PB ; Library of Congress Catalog Card No. -).

APPENDIX A

CRITERIA DEVELOPMENT

Sources of Information Used to Develop the Criteria of Appendix A:

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5. U.S Bureau of Outdoor Recreation. 1977. Resource Requirements for Water Related Recreation. S.E. Regional Office. Draft Report. pp. 15.

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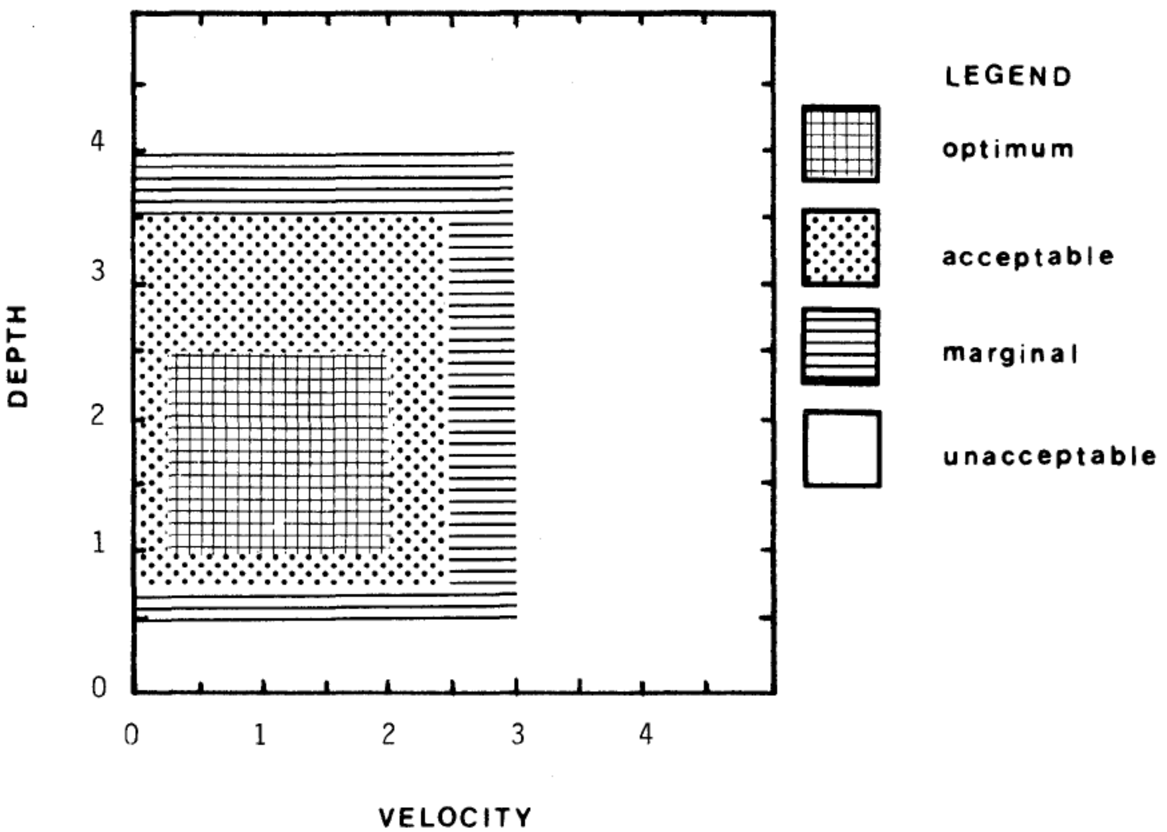
FISHING WADING

CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			1.0-2.5 ft
minimum	0.5 ft	0.75 ft	
maximum	4.0 ft	3.50 ft	
VELOCITY			0.25-2.0 fps
minimum	0.0 fps	0.0 fps	
maximum	3.0 fps	2.5 fps	

COMMENTS: Depth in ft multiplied by velocity in fps should equal 10 or less. Safety depends upon height and weight of individual as well as substrate type.

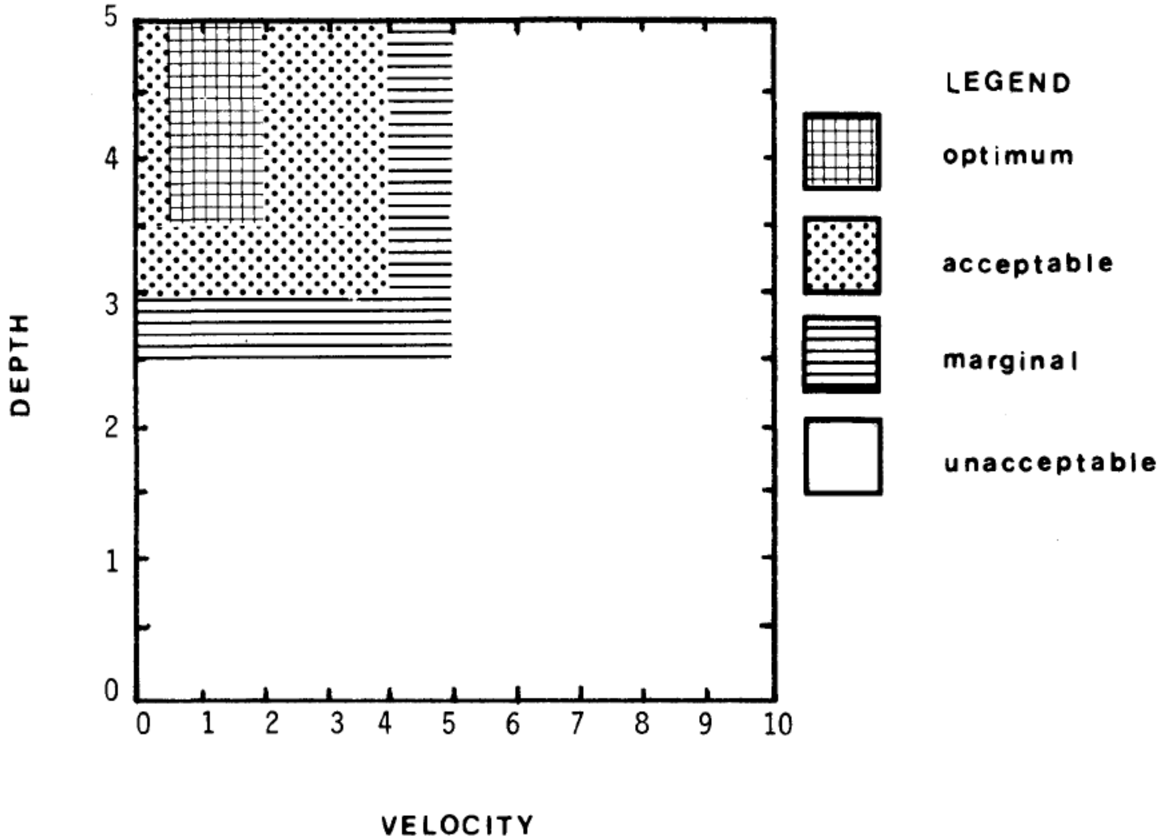


FISHING BOAT POWER

CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			3.5 ft +
minimum	2.5 ft	3.0 ft	
maximum	NA	NA	
VELOCITY			0.5-2.0 fps
minimum	0 fps	0 fps	
maximum	5 fps	4 fps	

COMMENTS: Size of boat and motor important. Generally includes boats of low power.

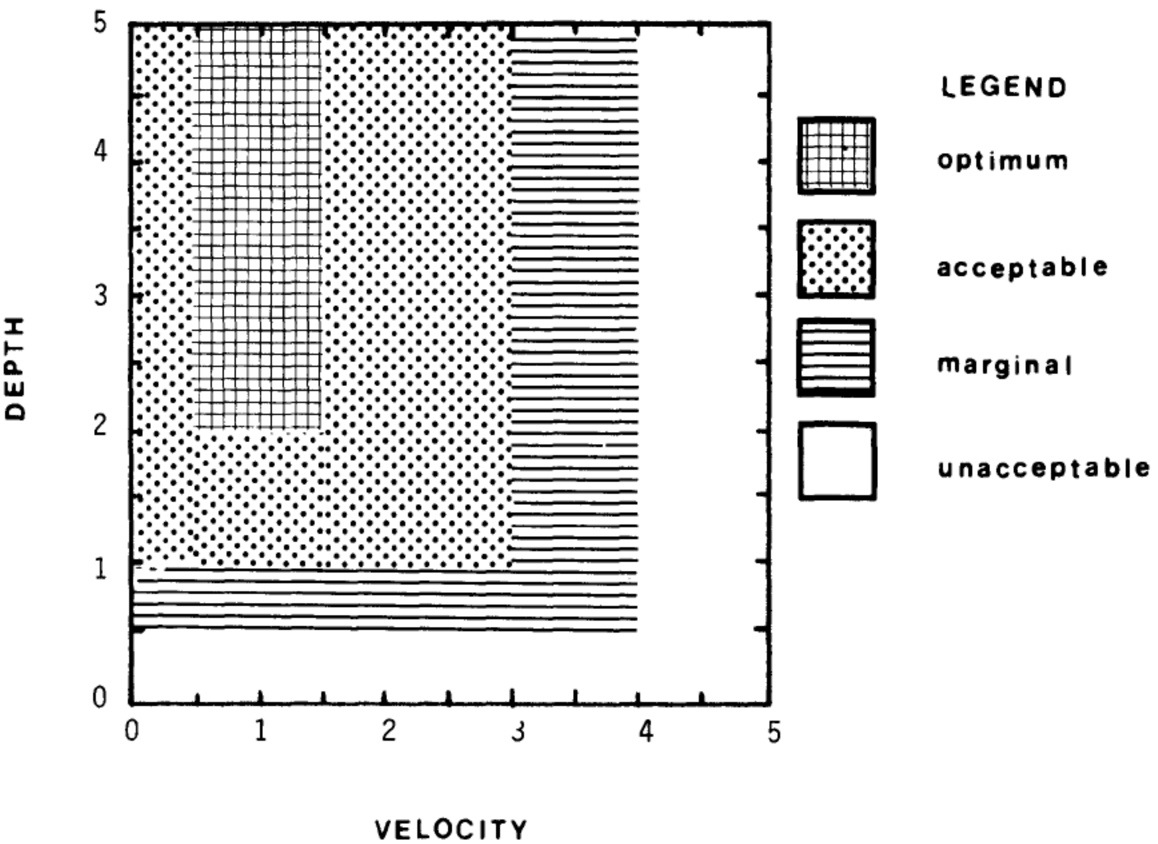


FISHING BOAT NON-POWER

CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			2.0 ft +
minimum	0.5 ft	1.0 ft	
maximum	NA	NA	
VELOCITY			0.5-1.5 fps
minimum	0 fps	0 fps	
maximum	4 fps	3 fps	

COMMENTS: Type boat important.

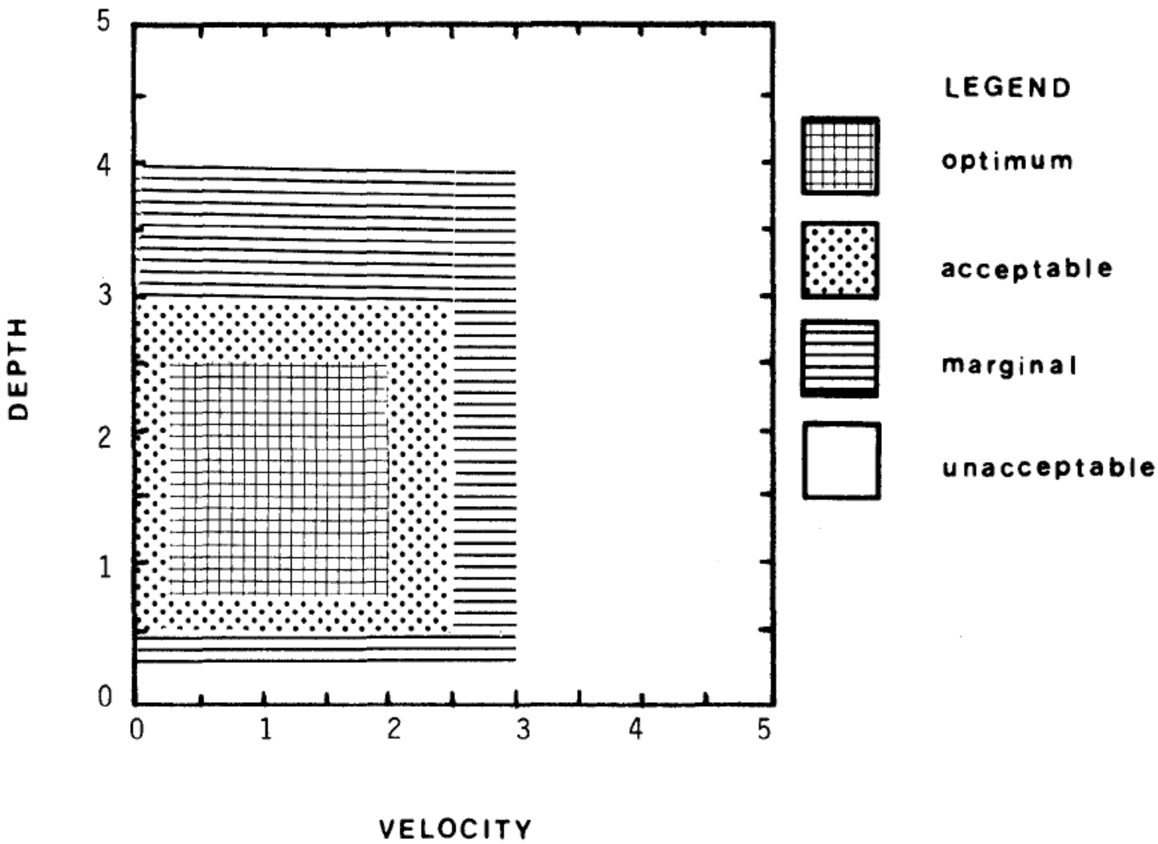


WATER CONTACT WADING

CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			0.75-2.5 ft
minimum	0.25 ft	0.5 ft	
maximum	4.0 ft	3.0 ft	
VELOCITY			0.25-2.0 fps
minimum	0 fps	0 fps	
maximum	3.0 fps	2.5 fps	

COMMENTS: Depth in feet multiplied by velocity in fps should equal 10 or less. Saftey depends upon height and weight of individual as well as substrate type.

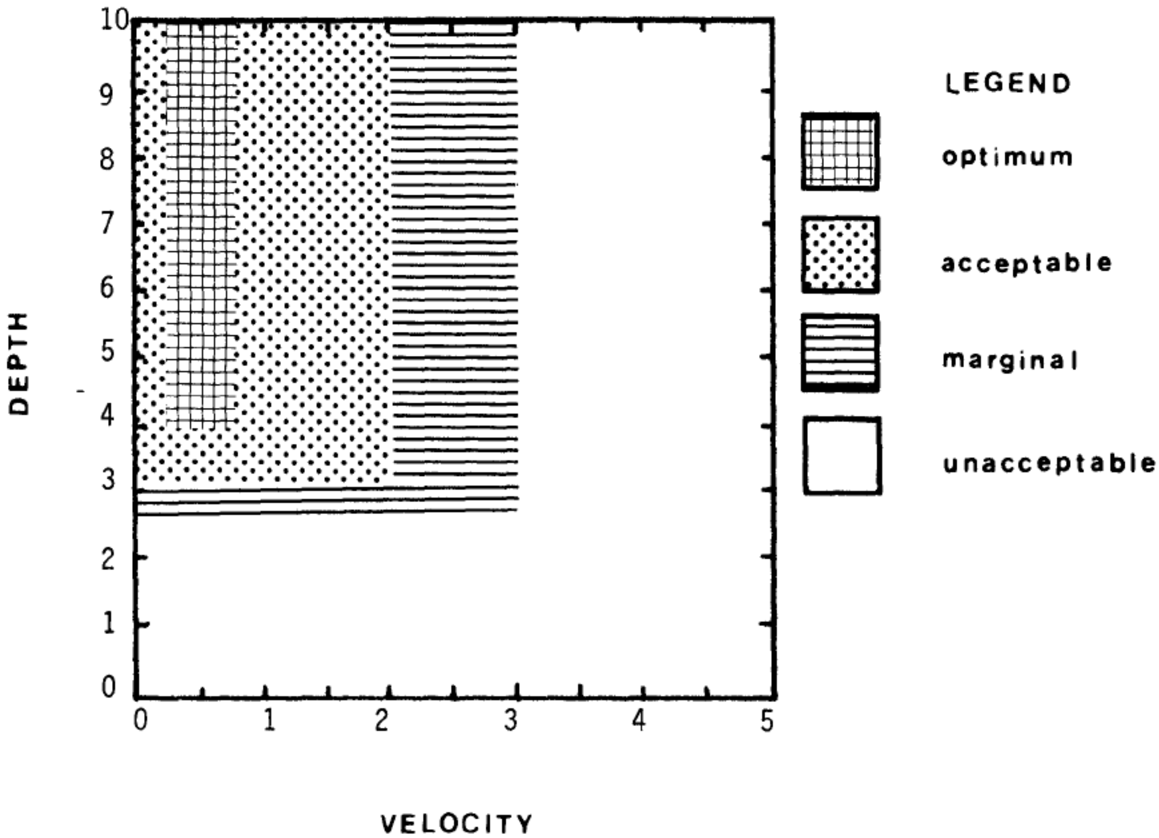


WATER CONTACT SWIMMING

CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			4 ft +
minimum	2.5 ft	3.0 ft	
maximum	NA	NA	
VELOCITY			0.25-0.75 fps
minimum	0 fps	0 fps	
maximum	3.0 fps	2.0 fps	

COMMENTS: Water quality, temperature, slope of beach, visibility and underwater slope important. Depth safety criteria does not permit diving.

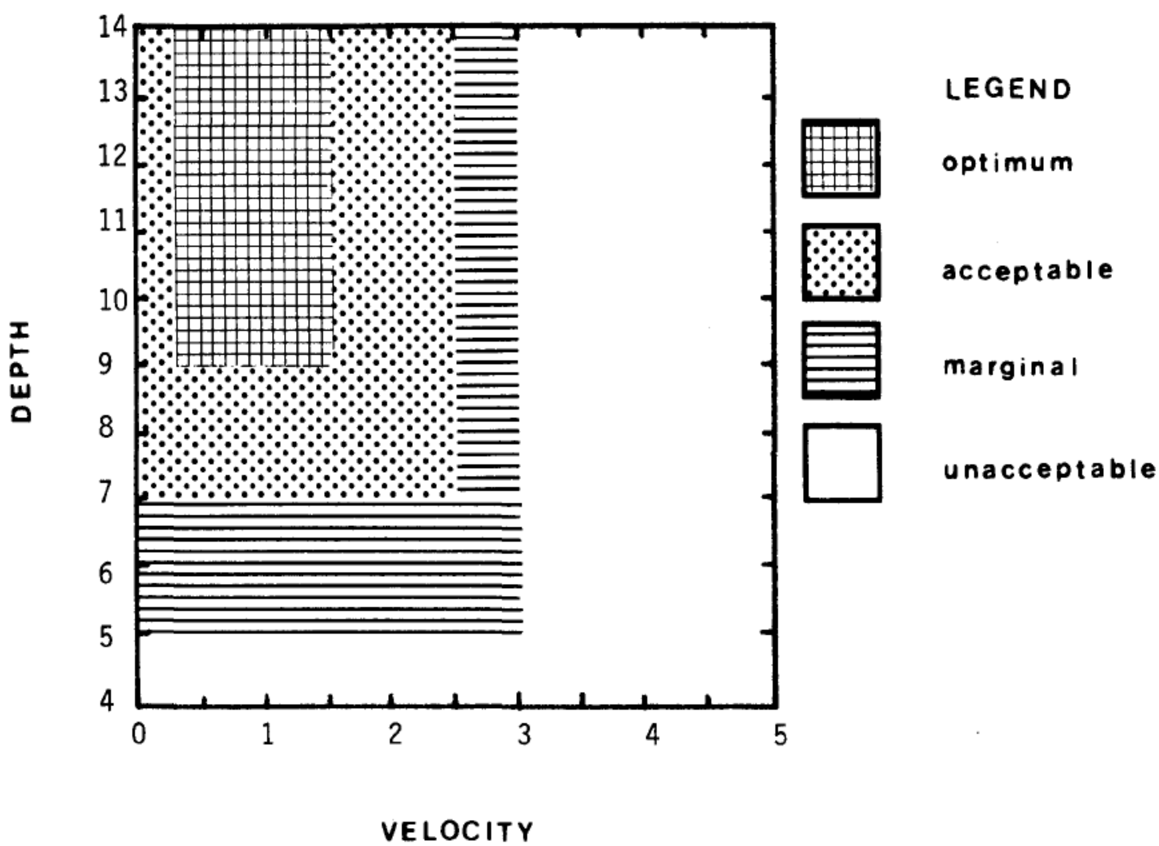


WATER CONTACT WATER SKIING

CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			9 ft +
minimum	5 ft	7 ft	
maximum	NA	NA	
VELOCITY			0.25-1.5 fps
minimum	0 fps	0 fps	
maximum	3.0 fps	2.5 fps	

COMMENTS: Width is critical also.

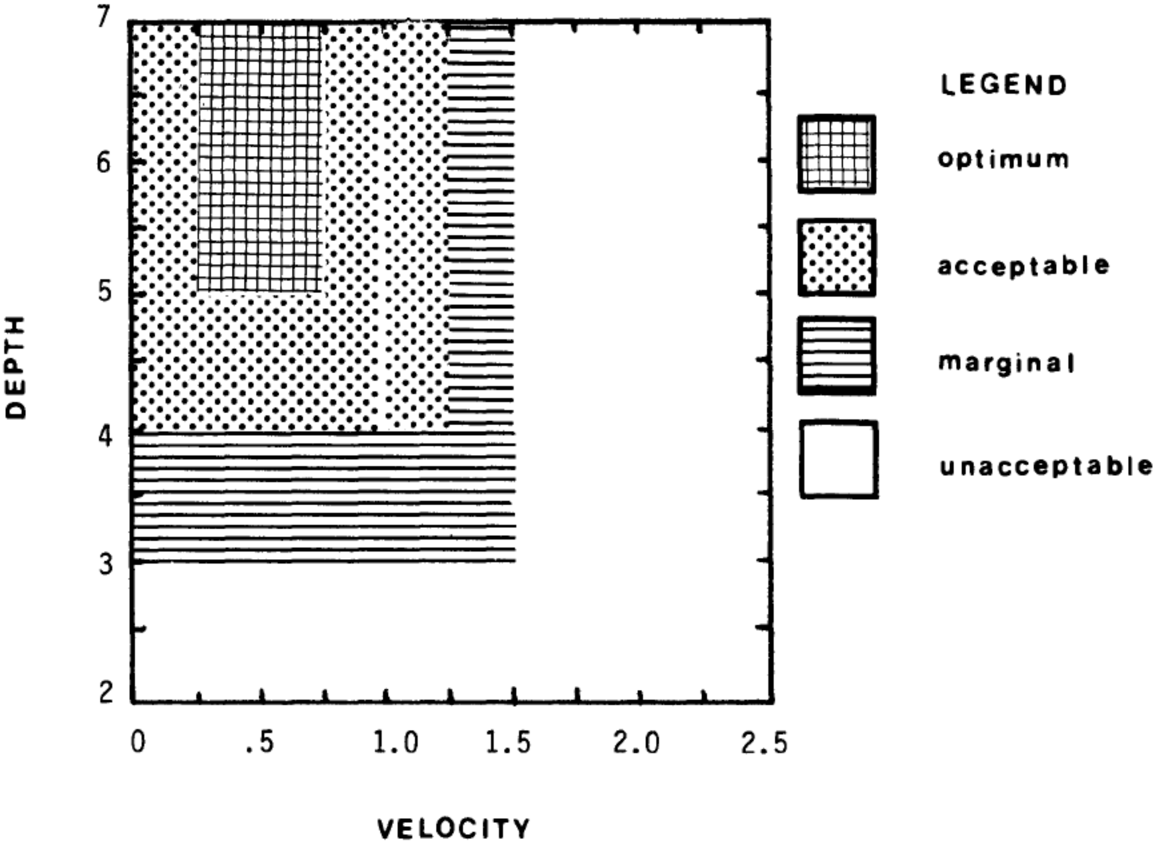


BOATING SAILING

CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			5 ft +
minimum	3 ft	4 ft	
maximum	NA	NA	
VELOCITY			0.25-0.75 fps
minimum	0 fps	0 fps	
maximum	1.5 fps	1.25 fps	

COMMENTS: Keel or centerboard depth is critical.

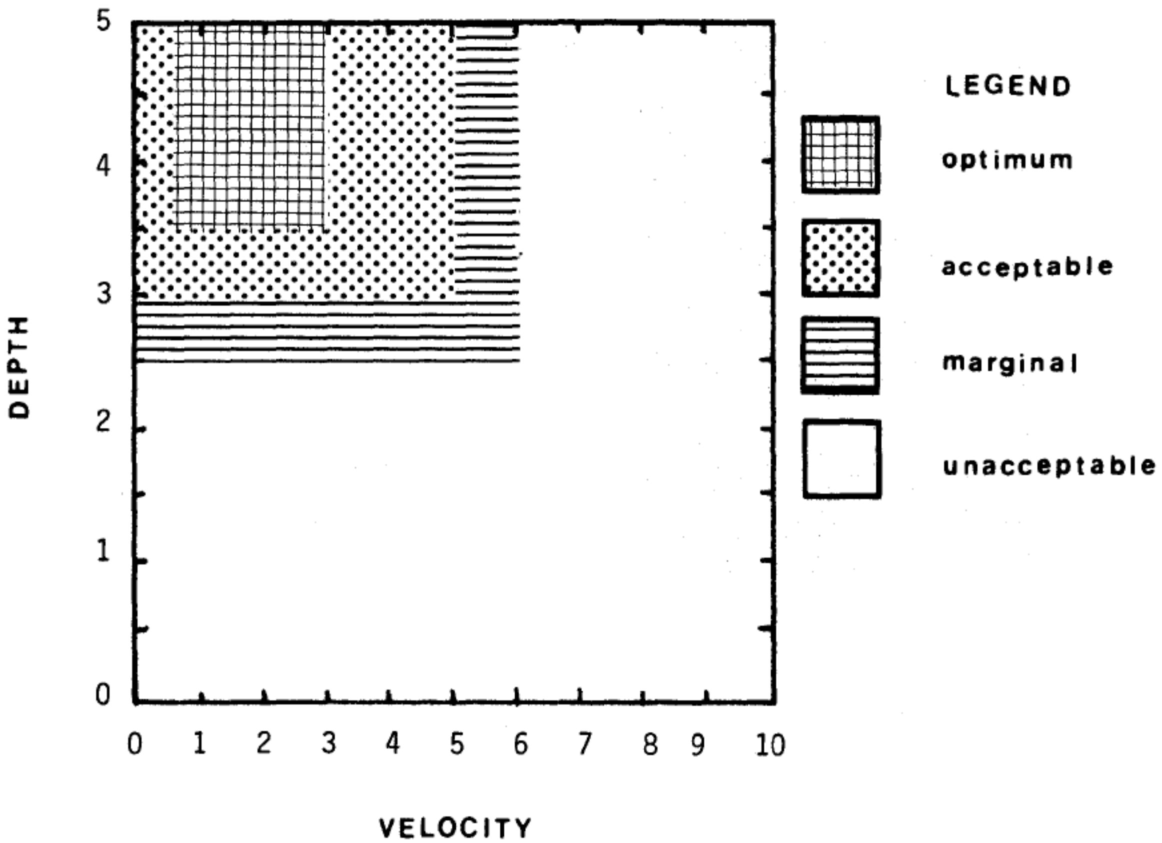


BOATING LOW POWER

CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			3.5 ft +
minimum	2.5 ft	3.0 ft	
maximum			
VELOCITY			0.5-3.0 fps
minimum	0 fps	0 fps	
maximum	7 fps	6 fps	

COMMENTS: Low power boats are less than 50 hp.

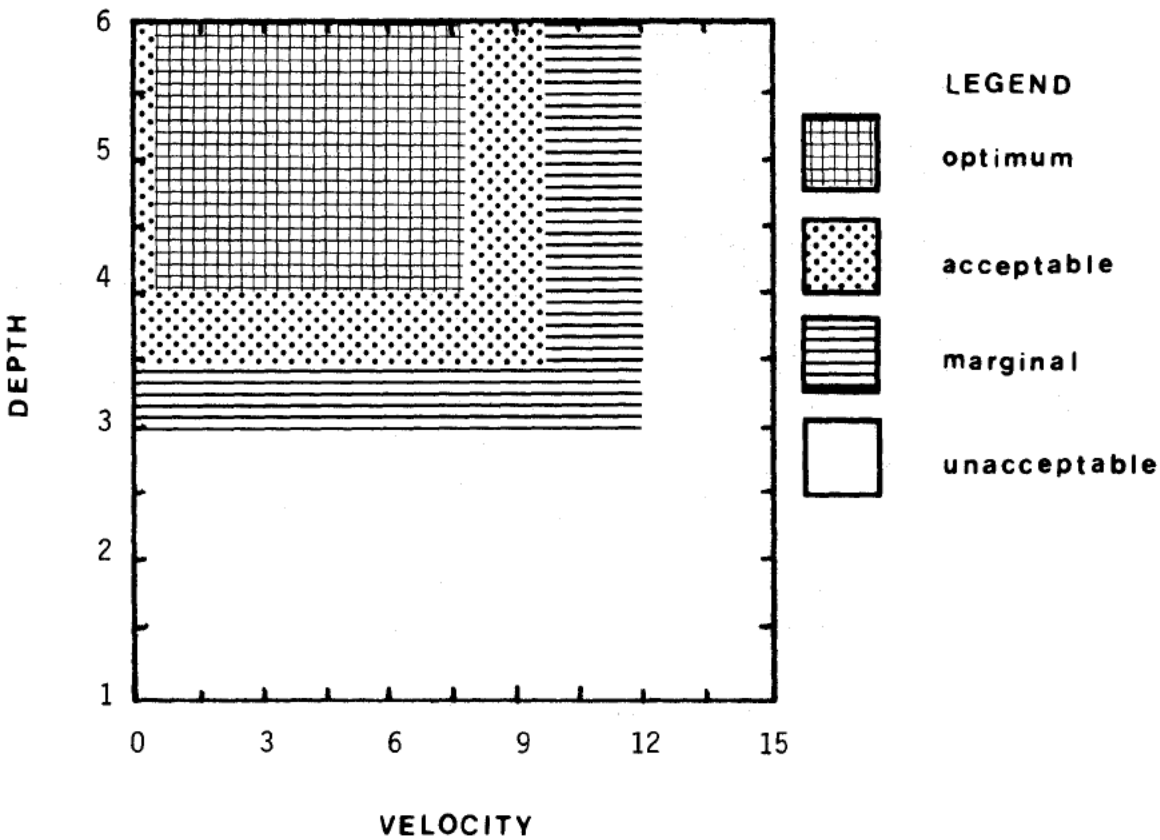


BOATING HIGH POWER

CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			4.0 ft +
minimum	3.0 ft	3.5 ft	
maximum	NA	NA	
VELOCITY			0.5-8.0 fps
minimum	0 fps	0 fps	
maximum	12.0 fps	10.0 fps	

COMMENTS: High power is greater than 50 hp. Jet boats or sleds require only 1.0 ft ± water depth. Higher velocities safe only under certain conditions.

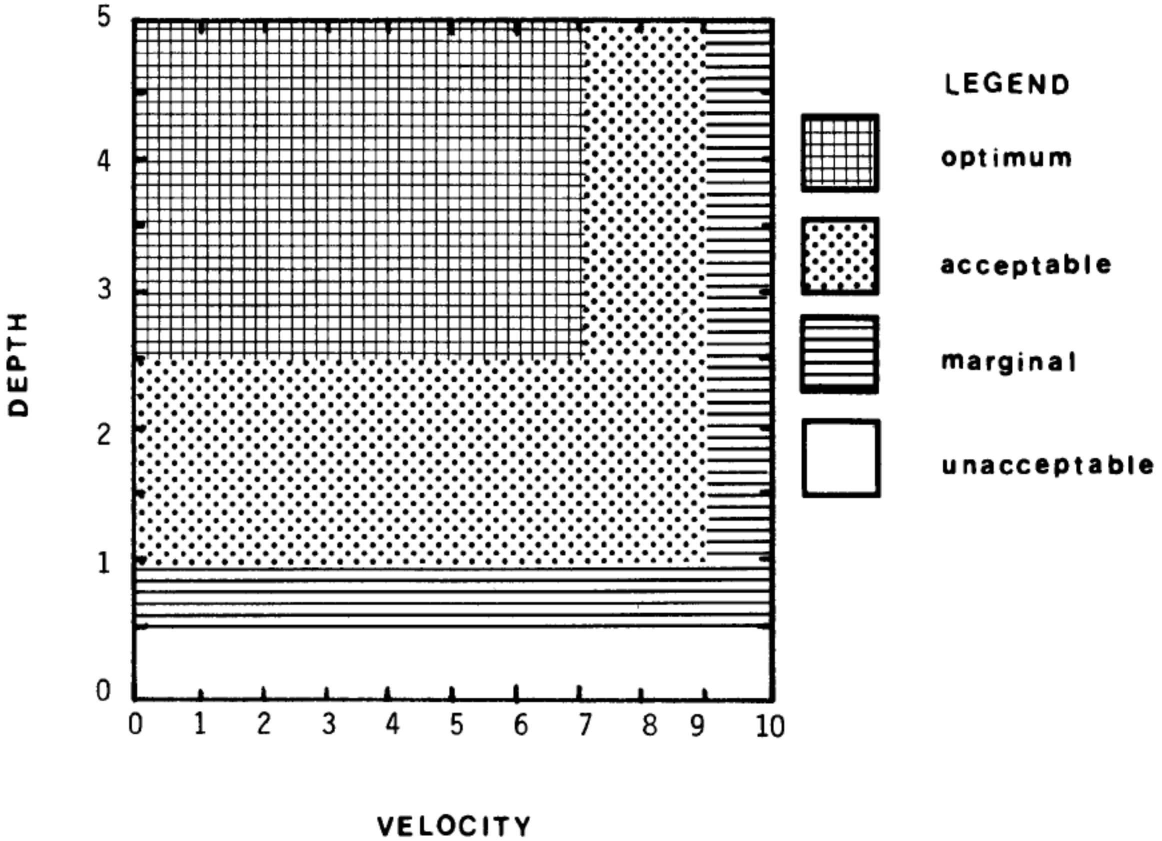


BOATING CANOEING-KAYAKING

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.

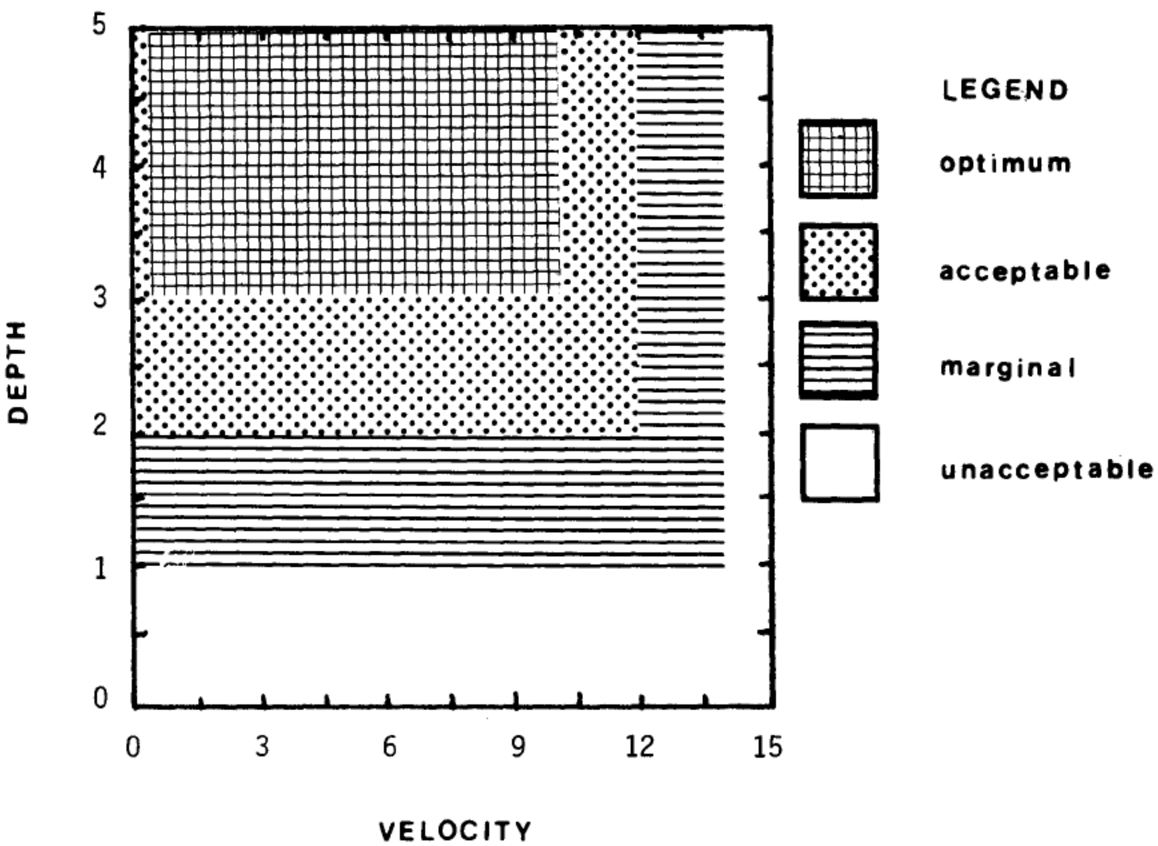


BOATING ROWING-RAFTING-DRIFTING

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.

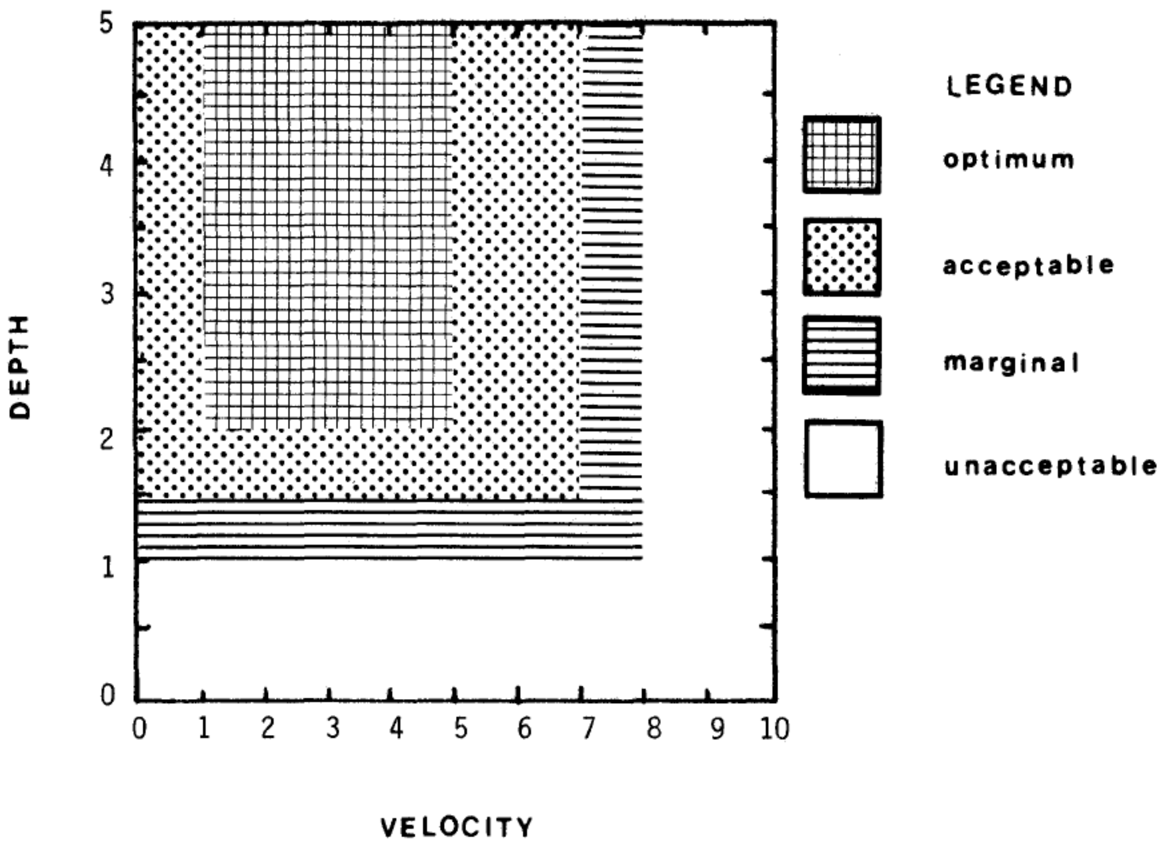


BOATING TUBING-FLOATING

CRITERIA

	PHYSICAL	SAFETY	OPTIMUM
DEPTH			2.0 ft +
minimum	1.0 ft	1.5 ft	
maximum	NA	NA	
VELOCITY			1.0-5.0 fps
minimum	0 fps	0 fps	
maximum	8.0 fps	7.0 fps	

COMMENTS: Higher velocities safe only under certain conditions.

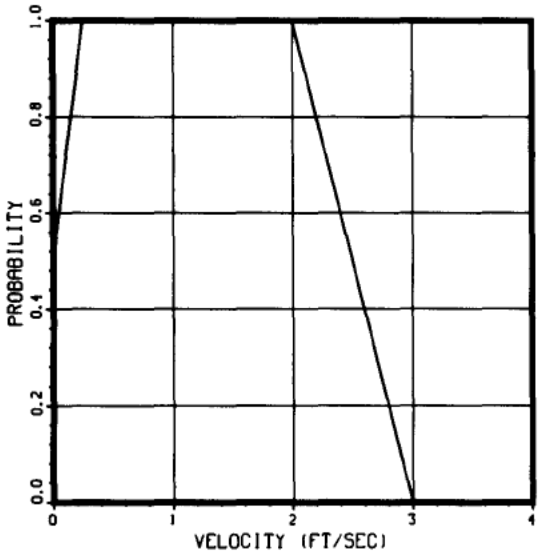


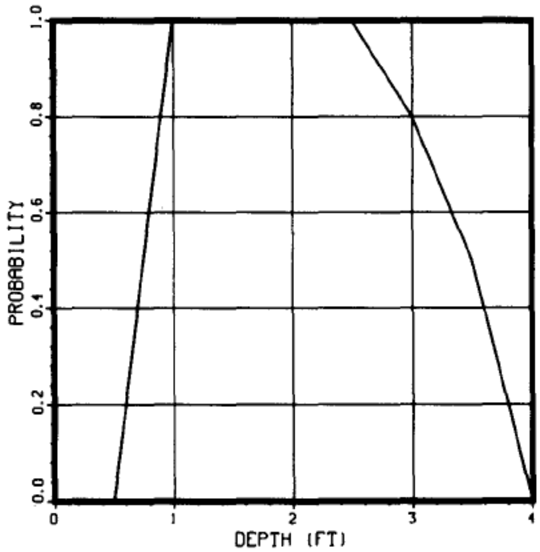
APPENDIX B

PROBABILITY-OF-USE CURVES

FISHING WADING

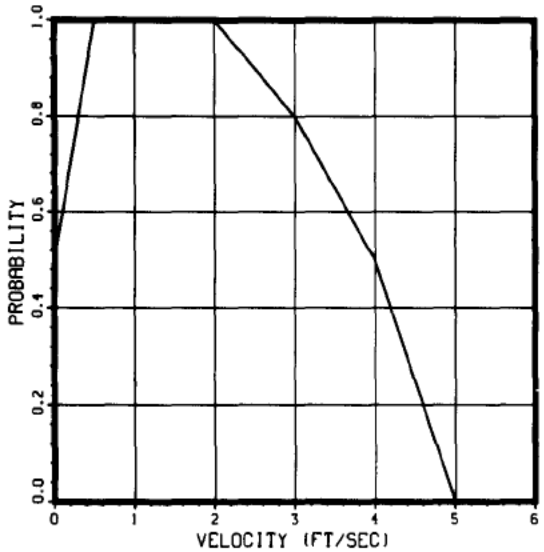
700000 78/06/26.

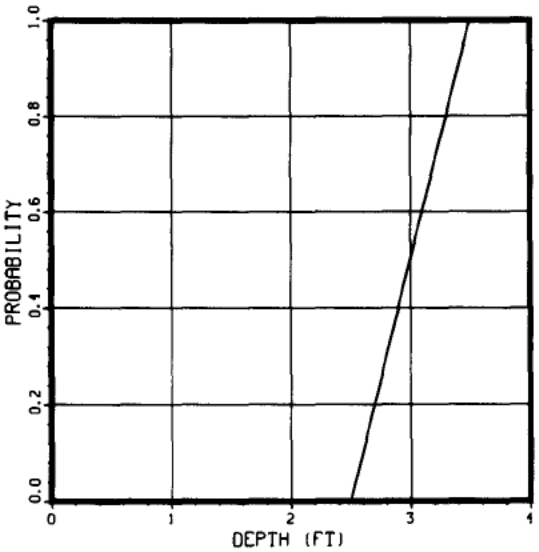




FISHING BOAT POWER

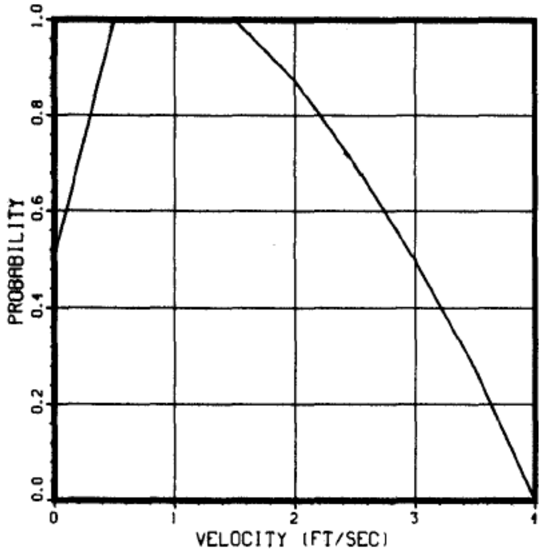
700100 78/06/26.

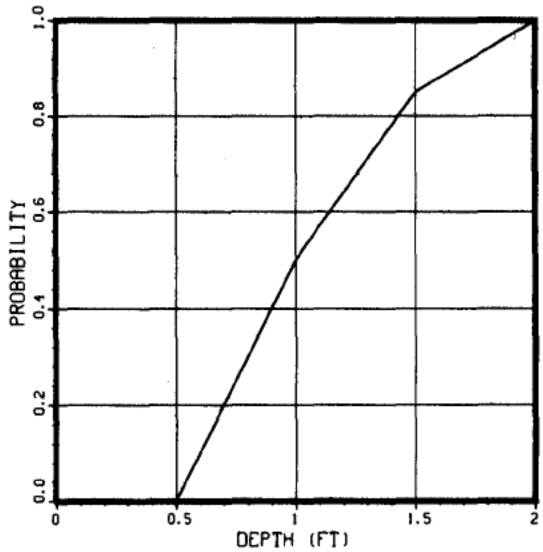




FISHING BOAT NON POWER

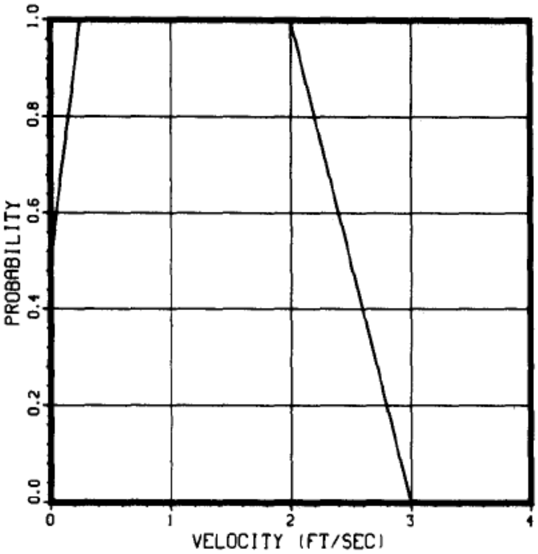
700200 78/06/26.

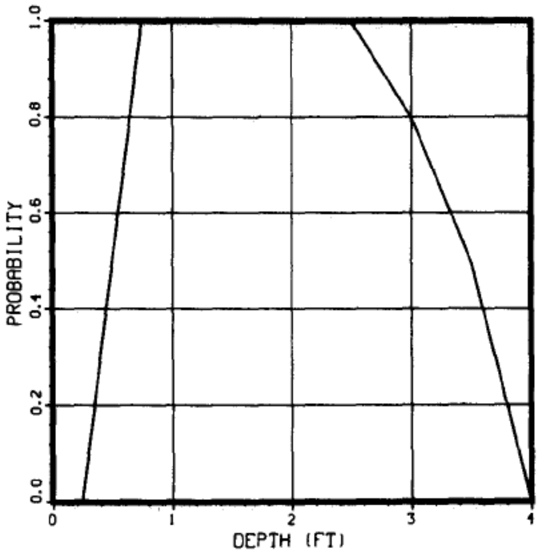




WATER CONTACT WADING

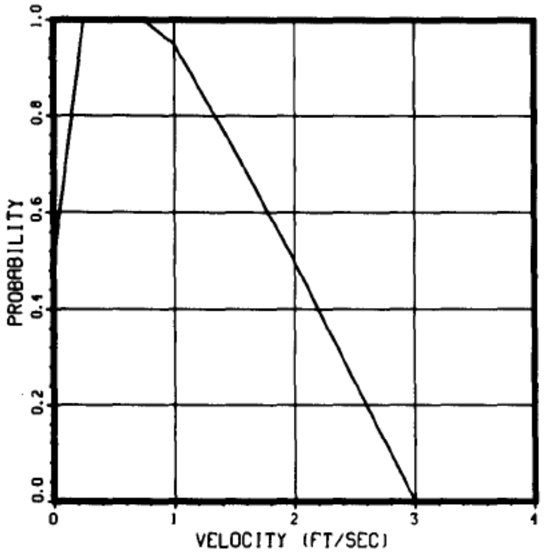
710100 78/06/26.

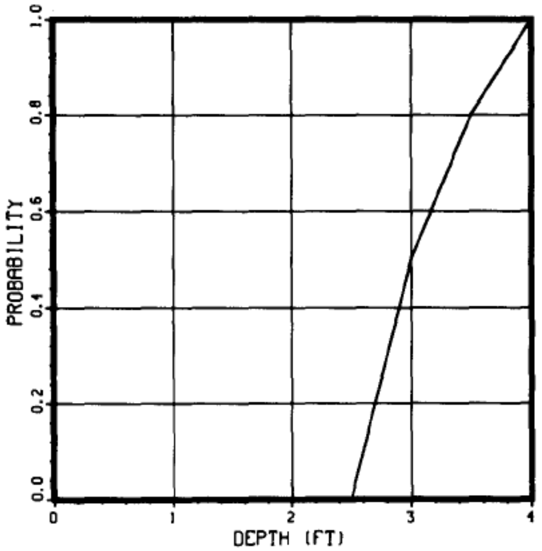




WATER CONTACT SWIMMING

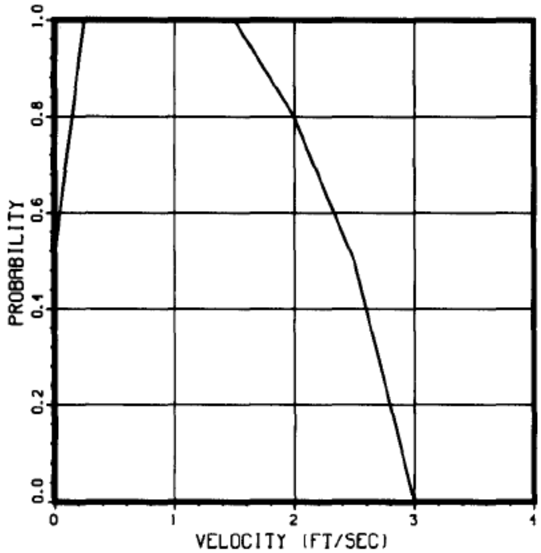
710000 78/06/26.

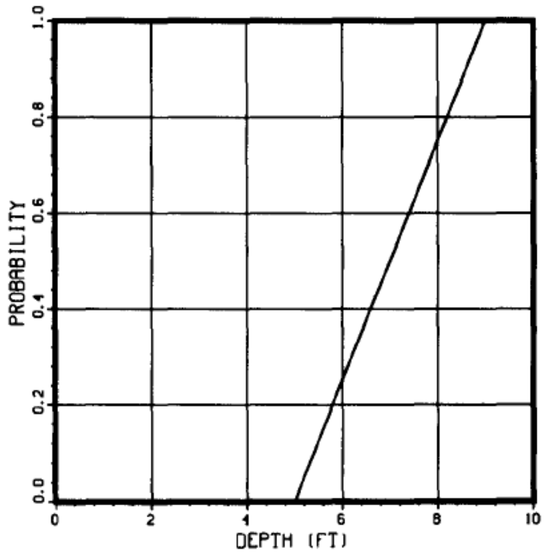




WATER CONTACT WATER SKIING

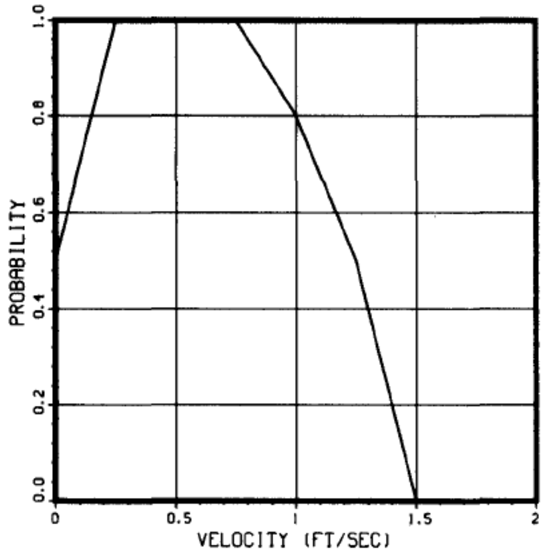
710200 78/06/26.

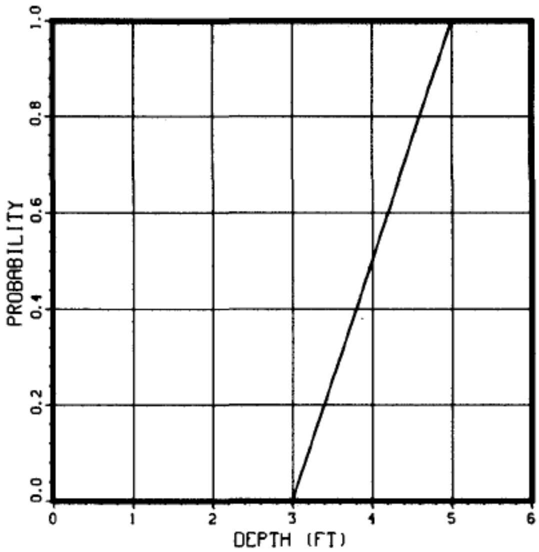




BOATING SAILING

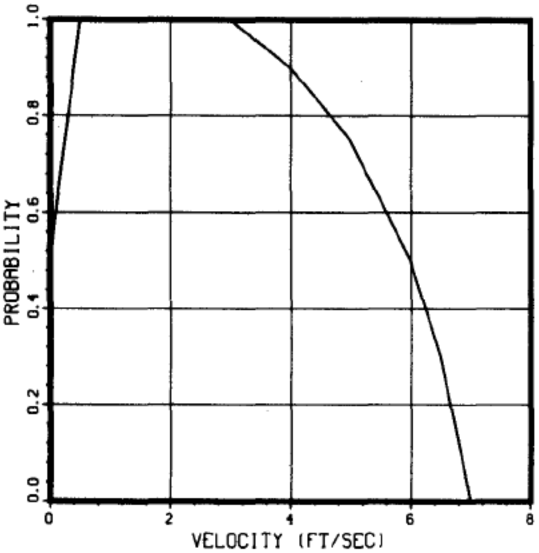
720000 78/06/26.

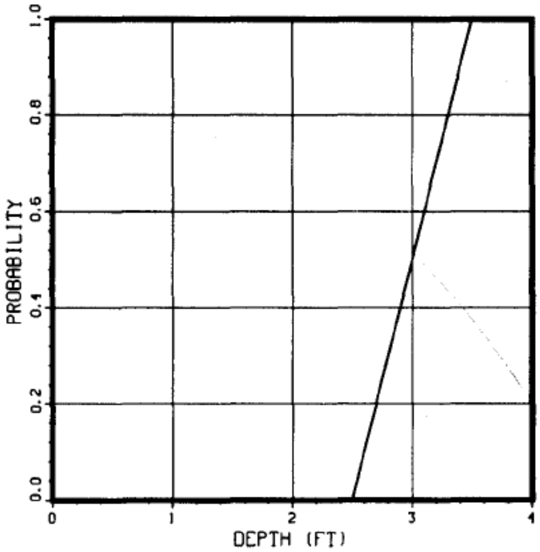




BOATING LOW POWER

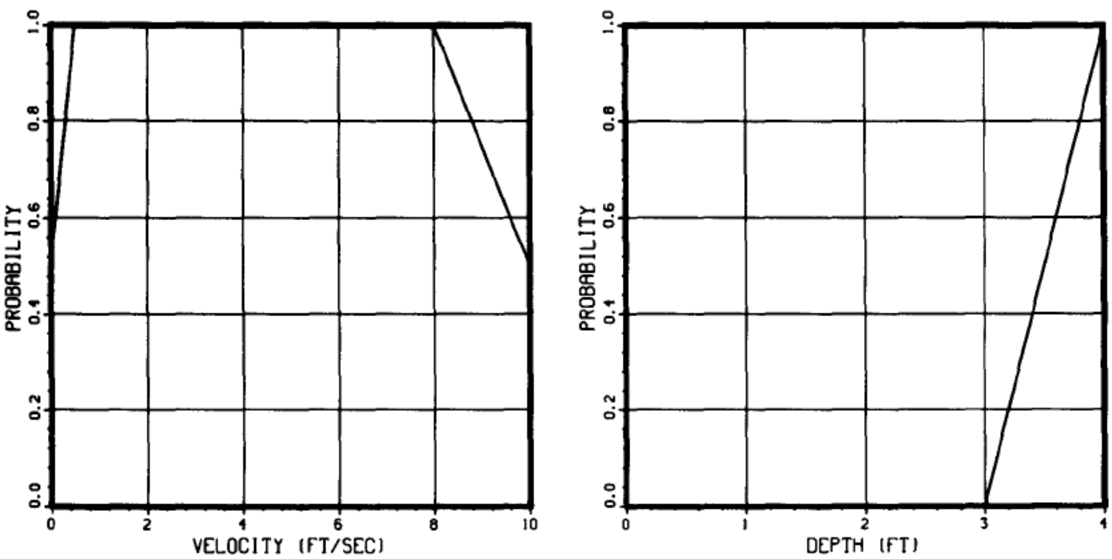
720100 78/06/26.





BOATING HIGH POWER

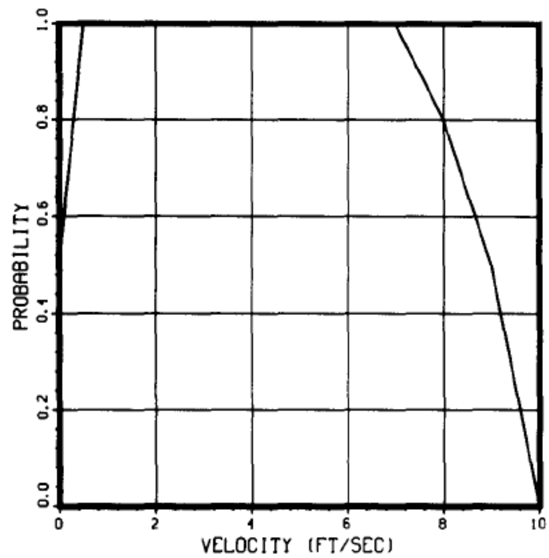
720200 78/06/26.

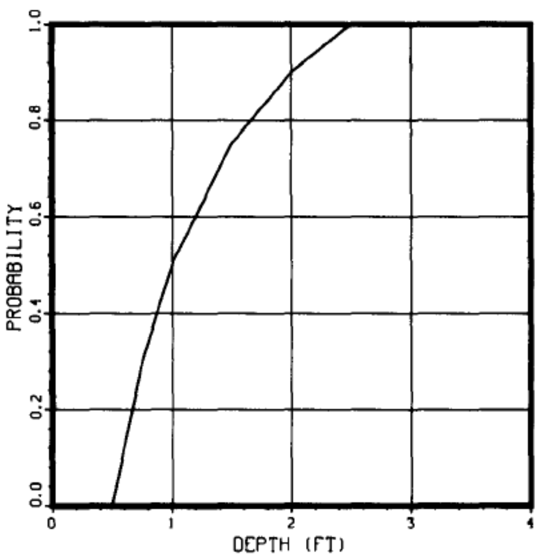


NOTE: Velocity plots have a maximum of 10 fps. The curves for the velocity for this activity reaches a probability of 0.0 at 12 fps.

BOATING CANOEING KAYAKING

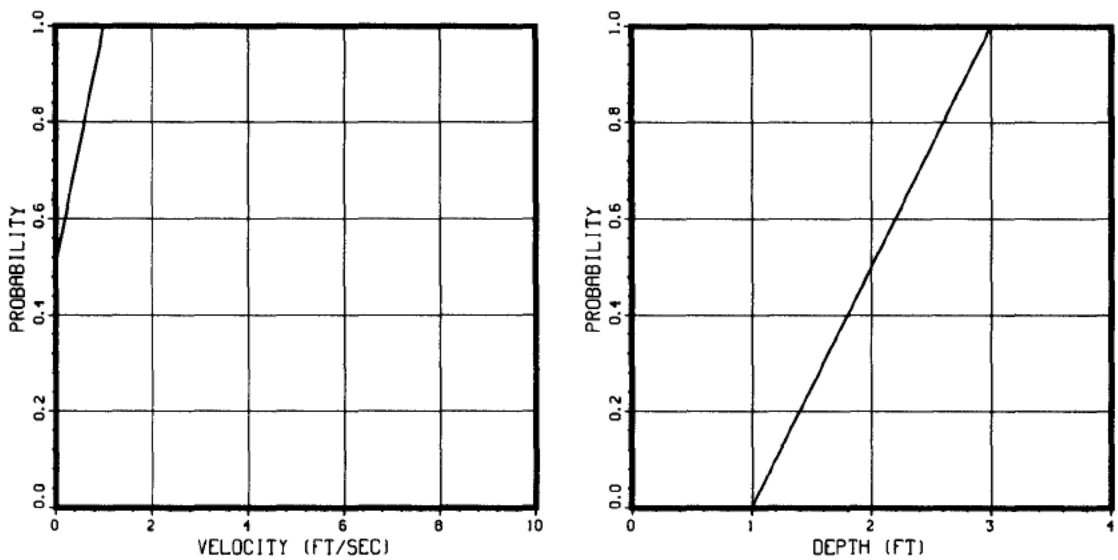
720300 78/06/26.





BOATING ROWING RAFTING DRIFTING

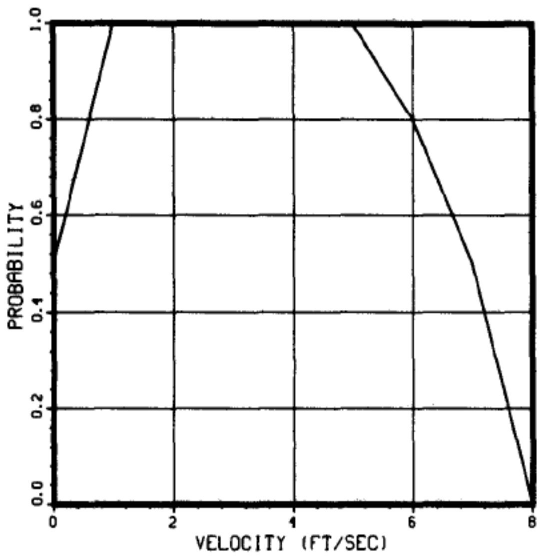
720400 78/06/26.

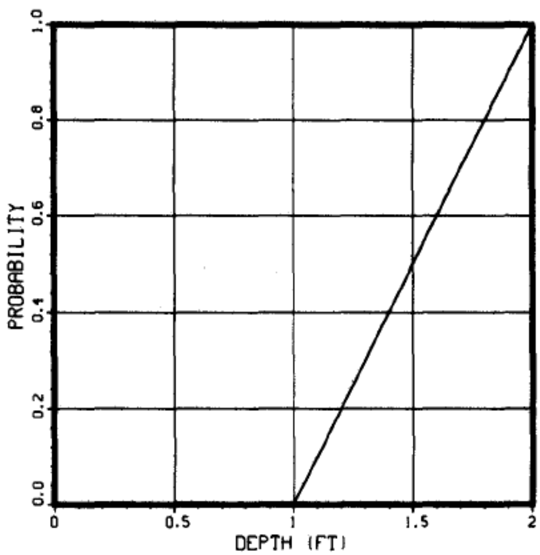


NOTE: Velocity plots have a maximum of 10 fps. The curve for the velocity for this activity is at a probability of 1.0 at 10 fps, a 0.5 probability at 12 fps, and a 0.0 probability at 14 fps.

BOATING TUBING FLOATING

720500 78/06/26.





U. S. Department of the Interior **Fish and Wildlife Service**

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

IN THE DISTRICT COURT OF THE THIRD JUDICIAL DISTRICT
OF THE TERRITORY OF ARIZONA, IN AND
FOR THE COUNTY OF MARICOPA.

PATRICK T. HURLEY, *Plaintiff*, THE UNITED STATES OF AMERICA, *Intervenor*, Against CHARLES F. ABBOTT and Four Thousand Eight Hundred Others, *Defendants*.	**ORIGINAL** **No. 4564** **DECREE**

Before CHIEF JUSTICE KENT,
Sitting as DISTRICT JUDGE.

Decision and Decree

Filed March 10, 1910
at 9:35 A.M.
Elias F. Dunleavy, Clerk
By E. S. Curtis, Deputy Clerk

HURLEY

propriate water, important, and that question is the subject matter of this suit."

In that case Judge Kibbey, after setting forth at length the facts in the case, in an exhaustive and able opinion covering the questions of law that arose therein, held that, as the parties to the suit, as was disclosed by their pleadings, had proceeded on the theory that an association of individuals or a corporation may become entitled to divert from a natural water course a definite quantity of water, and that this right depended, not on the fact that the constituent members of an association or corporation had for the water a beneficial use, and applied it to that use, but that the right and title to divert depended on the amount that they had been actually accustomed to divert, there was an omission to make that particular proof of the rights of individual appropriators upon which the right of diversion necessarily depended; and that under the pleadings and evidence in the case no attempt could be made to define the rights of individual appropriators, since an attempt to define in such suit the rights of individual irrigators would not operate as an adjudication thereof. The findings of fact in the case were therefore confined to a determination of the amount of land from time to time brought under cultivation and supplied by the various canals and ditches, and a table was prepared showing the number of quarter sections of land brought into cultivation under the various canals from time to time from the year 1868 to and including the year 1889, the determination in the case being expressly confined to the rights of the several owners of the canals and not to a determination of the rights of individual customers of such canal companies. The Court decreed that the amount of water which the various canal companies were entitled in each year to divert from the Salt river by means of their several canals and dams, was the amounts necessary under proper methods of irrigation to cultivate and irrigate the number of quarter sections set forth in such table, but did not find the amount of water actually necessary for such cultivation.

Whatever may have been the legal effect of the decree entered in the Wormser suit, there was no effective attempt to enforce it or to distribute water according to its terms. Even prior to its rendition an agreement was entered into by the various canal companies whereby the parcels of land as found by such decree to be entitled to water lying under the Tempe and San Francisco canals should receive water for their irrigation to be diverted from the river by the Tempe canal according to the dates of the reclamation thereof, and in the amount of sixty-four miners' inches to the quarter section measured at the head of the canal. The balance of the normal flow of water in the river at its various stages was divided among the various canal companies in accordance with the terms of the agreement entered into by them independent of the various dates of reclamation of the land lying under the canals as such dates were found in the Wormser decree. Since such agreement the water in the river at its various stages up to 60,000 miners' inches has been distributed theoretically under the provisions of this decree, but practically and actually under the agreement entered into by the canal companies as just stated.

To this agreement and to this distribution of the water protest has been made from time to time since the rendition of the Wormser decree, by individual land owners not content with the action of the canal company serving them with water in that regard, and various suits have been instituted from time to time in this Court to test the validity of such distribution of the water under such arrangement, none of which suits have ever come to final judgment, and one of which, at least, is still pending awaiting the determination of this proceeding.

TABLE No. 10.

"A table of acres and miners' inches for Class A land, showing the total acreage year by year and water for the same at 48 miners' inches per quarter section or one miners' inch for every three and one-third acres.

YEARS	Total acreage and miners' inches	Total on North Side	Total on South Side	Broadway Canal	San Francisco Canal	Tempe Canal	Utah Canal	Mesa Canal	Consolidated Canal	Highland Canal
Indian	2,333 700	2,333 700								
1869	5,543 1,663	5,543 1,663								
1870	7,363 2,209	6,998 2,099	365 110	365 110						
1871	11,528 3,459	10,293 3,088	1,235 371	365 110		820 246	50 15			
1872	18,228 5,469	12,163 3,649	6,065 1,820	365 110		5,650 1,695	50 15			
1873	20,623 6,187	12,623 3,787	8,000 2,400	365 110	1,625 487	5,960 1,788	50 15			
1874	21,028 6,308	13,028 3,908	8,000 2,400	365 110	1.625 487	5,960 1,788	50 15			
1875	21,908 6,572	13,088 3,926	8,820 2,646	365 110	1,945 583	6,460 1,938	50 15			
1876	24,568 7,370	14,788 4,436	9,780 2,934	365 110	1,945 583	7,420 2,226	50 15			
1877	29,718 8,915	16,548 4.964	13,170 3,951	365 110	1,945 583	9,270 2,781	1,590 477			
1878	39,053 11,716	20,453 6,136	18,600 5,580	365 110	2,710 813	10,300 3,090	2,900 870	2,325 697		
1879	45,238 13,571	23 888 7,166	21,350 6,405	365 110	2,805 842	11,115 3,334	2,955 886	4,110 1,233		
1880	55,663 16,699	31,913 9,574	23,750 7,125	365 110	2,885 866	11,175 3,352	2,995 898	6,330 1,899		
1881	62,338 18,701	36,878 11 063	25,460 7,638	365 110	2,885 866	12,265 3,679	2,995 898	6,950 2,085		
1882	70,938 21,282	44,623 13,387	26,315 7,895	365 110	2,885 866	12,265 3,679	3,315 995	7,485 2.245		
1883	74,133 22,240	45,878 13,763	28,255 8,477	405 122	3,625 1,087	12,705 3,812	3,315 995	8,205 2,461		
1884	77,298 23,189	47,368 14,210	29,930 8,979	405 122	3,625 1,087	13,740 4,122	3,635 1,091	8,525 2,557		
1885	79,698 23,909	47,938 14,381	31,760 9,528	405 122	3 625 1,087	14,540 4,362	4,385 1,316	8,805 2,641		
1886	83,603 25,081	50,438 15,131	33,165 9,950	405 122	3,625 1,087	15,300 4,590	4,750 1,425	9,085 2,726		
1887	89,483 26,845	52,513 15,754	36,970 11,091	405 122	3,720 1,116	17,585 5,275	5,390 1,617	9,870 2,961		
1888	99,588 29,877	56,793 17,038	42,795 12,839	405 122	3,720 1,116	19,525 5,857	8,955 2,687	10,190 3,057		
1889	107,118 32,136	62,053 18,616	45,065 13,520	405 122	3,720 1,116	20,005 6,002	9,275 2,782	11,660 3,498		
1890	111,483 33,445	64,393 19,318	47,090 14,127	405 122	3.720 1,116	21,295 6,388	9,530 2,859	12,140 3,642		

TABLE No. 10—(Continued)

YEARS	Total acreage and miners' inches......	Total on North Side...	Total on South Side...	Broadway Canal......	San Francisco Canal......	Tempe Canal....	Utah Canal....	Mesa Canal....	Consolidated Canal......	Highland Canal......
1891	114,008	65,283	48,725	405	3,720	22,440	9,530	12,630	....	....
	34,203	19,585	14,618	122	1,116	6,732	2,859	3,789	....	....
1892	121,098	68,468	52,630	405	3,720	22,740	9,960	14,285	1,280	240
	36,329	20,540	15,789	122	1,116	6,822	2,988	4,285	384	72
1893	123,813	69,598	54,215	405	3,720	22,740	10,645	14,545	1,920	240
	37,144	20,879	16,265	122	1,116	6,822	3,193	4,364	576	72
1894	124,843	70,493	54,350	405	3,720	22,740	10,765	14,560	1,920	240
	37,453	21,148	16,305	122	1,116	6,822	3,229	4,368	576	72
1895	126,773	72,183	54,590	405	3,720	22,980	10,765	14,560	1,920	240
	38,032	21,655	16,377	122	1,116	6,894	3,229	4,368	576	72
1896	127,743	72,653	55,090	445	3,720	23,360	10,765	14,640	1,920	240
	38,323	21,796	16,527	134	1,116	7,008	3,229	4,392	576	72
1897	129,098	73,463	55,635	445	3,720	23,520	10,765	14,745	2,200	240
	38,730	22,039	16,691	134	1,116	7,056	3,229	4,424	660	72
1898	129,678	73,678	56,000	445	3,720	23,520	10,800	15,075	2,200	240
	38,903	22,103	16,800	134	1,116	7,056	3,240	4,522	660	72
1899	129,878	73,878	56,000	445	3,720	23,520	10,800	15,075	2,200	240
	38,963	22,163	16,800	134	1,116	7,056	3,240	4,522	660	72
1900	130,583	74,248	56,335	445	3,720	23,520	10,865	15,345	2,200	240
	39,175	22,274	16,901	134	1,116	7.056	3,260	4,603	660	72
1901	131,273	74,778	56,495	445	3,720	23,520	10,865	15,345	2,200	400
	39,382	22,433	16,949	134	1,116	7,056	3,260	4,603	660	120
1902	131,653	75,158	56,495	445	3,720	23,520	10,865	15,345	2,200	400
	39,496	22,547	16,949	134	1,116	7,056	3,260	4,603	660	120
1903	132,133	75,438	56,695	445	3,920	23,520	10,865	15,345	2,200	400
	39,640	22,631	17,009	134	1,176	7,056	3,260	4,603	660	120
1904	132,838	76,033	56,805	445	4,030	23,520	10,865	15,345	2,200	400
	39,852	22,810	17,042	134	1,209	7.056	3,240	4,603	660	120
1905	134,213	76,333	57,880	465	4,030	23,520	11,135	16,105	2,200	425
	40,264	22,900	17,364	140	1,209	7,056	3,340	4,832	660	127
1906	135,228	77,108	58,120	465	4,030	23,740	11,135	16,125	2,200	425
	40,568	23,132	17,436	140	1,209	7,122	3,340	4,838	660	127
1907	139,823	80,773	59,050	465	4,030	24,380	11,135	16,305	2,310	425
	41,947	24,232	17,715	140	1,209	7,314	3,340	4,892	693	127
1908	146,748	87,508	59,240	465	4,030	24,380	11,135	16,475	2,330	425
	44,024	26,252	17,772	140	1,209	7,314	3,340	4,943	699	127
1909	151,083	91,813	59,270	465	4,030	24,380	11,165	16,475	2,330	425
	45,325	27,544	17,781	140	1,209	7,314	3.349	4,943	699	127

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Statistical Summaries of Streamflow Data and Characteristics of Drainage Basins for Selected Streamflow-Gaging Stations in Arizona Through Water Year 1996

By G.L. POPE, P.D. RIGAS, *and* C.F. SMITH

Water-Resources Investigations Report 98–4225

Prepared in cooperation with
Arizona Department of Water Resources,
Bureau of Reclamation,
Pima County Board of Supervisors,
Flood Control District of Maricopa County, and
Salt River Project

Tucson, Arizona
1998

09508500 VERDE RIVER BELOW TANGLE CREEK, ABOVE HORSESHOE DAM, AZ

Annual peak discharges

Water year	Date	Annual peak discharge (ft^3/s)	Discharge codes	Water year	Date	Annual peak discharge (ft^3/s)	Discharge codes
1000	00-00-00	[1]180,000	ES,PF	1958	03-23-58	21,100	
1760	00-00-00	[1]130,000	ES,PF	1959	08-17-59	6,060	
1891	02-24 91	[2]150,000	ES,HP	1960	12-26-59	23,400	
1906	11-27-05	[3]96,000	ES,HP	1961	08-23-61	2,800	
1916	01-20-16	68,900	ES,HP	1962	02-13-62	13,300	
1920	02-22-20	[4]95,000	ES,HP	1963	08-22-63	18,900	
1925	09-17-25	20,000	ES	1964	08-27-64	6,910	
1926	04-06-26	32,000	ES	1965	01-07-65	25,700	
1927	02-17-27	70,000	ES	1966	12-22-65	39,300	
1928	02-05-28	14,000	ES	1967	12-07-66	53,000	
1929	04-05-29	26,000	ES	1968	12-19-67	32,600	
1930	08-09-30	8,100	ES	1969	01-26-69	45,800	
1931	02-14-31	34,000	ES	1970	09-06-70	61,900	
1932	02-09-32	53,000	ES	1971	08-03-71	3,030	
1933	03-13-33	1,660	ES	1972	12-27-71	21,100	
1934	08-25-34	3,300	ES	1973	10-20-72	63,400	
1935	02-07-35	14,300	ES	1974	08-02-74	1500	
1936	02-24-36	12,000	ES	1975	04-15-75	5,420	
1937	02-07-37	63,000	ES	1976	02-10-76	39,900	
1938	03-04-38	100,000	ES	1977	08-24-77	1,620	
1939	09-14-39	17,700	ES	1978	03-01-78	91,400	
1940	02-27-40	5,020	ES	1979	12-19-78	94,000	
1941	03-14-41	43,800	ES	1980	02-15-80	94,800	
1942	10-14-41	3,510	ES	1981	04-06-81	2,030	
1943	08-14-43	16,600	ES	1982	03-12-82	42,100	
1944	03-14-44	7,530	ES	1983	12-23-82	22,400	
1945	03-16-45	9,710	ES	1984	10-01-83	27,200	
1946	04-08-46	8,660		1985	12-28-84	19,300	
1947	09-19-47	11,500		1986	11-30-85	10,300	
1948	03-25-48	2,560		1987	03-10-87	5,000	
1949	01-13-49	11,000		1988	02-03-88	19,800	
1950	10-19-49	9,330		1989	02-05-89	2,670	
1951	08-30-51	16,400		1990	09-03-90	2,790	
1952	12-31-51	81,600		1991	03-02-91	34,300	
1953	08-29-53	6,390		1992	08-23-92	27,200	
1954	03-23-54	19,700		1993	01-08-93	145,000	
1955	08-23-55	11,600		1994	02-08-94	4,770	
1956	07-31-56	12,800		1995	02-15-95	[5]108,000	
1957	01-10-57	14,500		1996	08-03-96	2,450	

... and Baker (1985).

...ghest since 1888.

...ghest since 1891.

[4]Highest since 1906.

[5]Highest since 1920.

09508500 VERDE RIVER BELOW TANGLE CREEK, ABOVE HORSESHOE DAM, AZ--Continued

MEAN MONTHLY AND ANNUAL DISCHARGES 1946-96

MONTH	MAXIMUM (FT3/S)	MINIMUM (FT3/S)	MEAN (FT3/S)	STANDARD DEVIATION (FT3/S)	COEFFICIENT OF VARIATION	PERCENT OF ANNUAL RUNOFF
OCTOBER	4,190	155	333	579	1.7	4.7
NOVEMBER	1,380	192	370	297	0.80	5.2
DECEMBER	4,640	227	754	1,010	1.3	10.6
JANUARY	12,400	224	879	1,760	2.0	12.3
FEBRUARY	11,000	220	1,250	2,000	1.6	17.5
MARCH	10,400	194	1,560	1,810	1.2	21.8
APRIL	5,640	155	849	1,030	1.2	11.9
MAY	1,320	113	218	173	0.80	3.1
JUNE	316	83	135	42	0.31	1.9
JULY	430	76	179	71	0.40	2.5
AUGUST	1,180	127	334	232	0.70	4.7
SEPTEMBER	1,460	99	273	211	0.77	3.8
ANNUAL	2,230	189	591	437	0.74	100

MAGNITUDE AND PROBABILITY OF ANNUAL LOW FLOW BASED ON PERIOD OF RECORD 1947-96

PERIOD (CONSECUTIVE DAYS)	DISCHARGE, IN FT3/S, FOR INDICATED RECURRENCE INTERVAL, IN YEARS, AND NON-EXCEEDANCE PROBABILITY, IN PERCENT					
	2 50%	5 20%	10 10%	20 5%	50 2%	[illegible] 1%
1	91	76	70	65	61	[illegible]
3	94	79	72	68	63	[illegible]
7	98	82	75	70	65	[illegible]
14	103	86	79	73	68	[illegible]
30	111	93	85	79	72	[illegible]
60	128	107	98	91	83	[illegible]
90	146	123	112	104	96	[illegible]
120	173	147	133	122	109	[illegible]
183	198	171	163	158	154	[illegible]

MAGNITUDE AND PROBABILITY OF INSTANTANEOUS PEAK FLOW BASED ON PERIOD OF RECORD 1000, 1925-96

DISCHARGE, IN FT3/S, FOR INDICATED RECURRENCE INTERVAL IN YEARS, AND EXCEEDANCE PROBABILITY, IN PERCENT					
2 50%	5 20%	10 10%	25 4%	50 2%	100 1%
16,000	41,600	67,300	110,800	151,700	200,300

WEIGHTED SKEW (LOGS) = -0.18
MEAN (LOGS) = 4.19
STANDARD DEV. (LOGS) = 0.51

MAGNITUDE AND PROBABILITY OF ANNUAL HIGH FLOW BASED ON PERIOD OF RECORD 1946-96

PERIOD (CONSECUTIVE DAYS)	DISCHARGE, IN FT3/S, FOR INDICATED RECURRENCE INTERVAL, IN YEARS, AND EXCEEDANCE PROBABILITY, IN PERCENT					
	2 50%	5 20%	10 10%	25 4%	50 2%	[illegible] 1%
1	8,220	25,200	44,600	81,600	120,000	[illegible]
3	5,660	16,000	27,000	46,900	66,400	[illegible]
7	3,640	9,510	15,500	25,600	35,300	[illegible]
15	2,430	5,890	9,320	15,100	20,700	[illegible]
30	1,710	3,950	6,130	9,830	13,400	[illegible]
60	1,190	2,690	4,200	6,840	9,460	[illegible]
90	976	2,130	3,260	5,230	7,150	[illegible]

DURATION TABLE OF DAILY MEAN FLOW FOR PERIOD OF RECORD 1946-96

DISCHARGE, IN FT3/S, WHICH WAS EQUALED OR EXCEEDED FOR INDICATED PERCENT OF TIME																
1%	5%	10%	15%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%	99%	99.5%	[illegible]
6,330	2,130	942	561	412	310	267	240	212	182	153	123	104	89	81	76	[illegible]

THE PIMA INDIANS

FRANK RUSSELL

Re-edition
with Introduction,
Citation Sources, and Bibliography
by BERNARD L. FONTANA

The University of Arizona Press
Tucson, Arizona

About the Author . . .

FRANK RUSSELL was an early and dedicated member of the anthropological profession whose detailed work on the material culture of the Piman people was accomplished in Arizona virtually on the eve of his death from tuberculosis. A member of the Harvard Faculty of Arts and Sciences, in 1900 Russell was given leave of absence for field work on the Gila River Reservation for the Bureau of American Ethnology. By contrast, his previous investigations had been among the tribes around Great Slave Lake and Herschel Island in the Arctic Sea. Russell's distinction as researcher and author is relatively little known to modern students of anthropology because his career was cut short at age 35. By that time he had completed this standard reference work on the Gila River Pimas, originally published as part of the *Twenty-sixth Annual Report of the Bureau of American Ethnology, 1904–1905.*

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divisions of the same linguistic stock they add the word Á'kimûlt, "river." "River people" is indeed an apt designation, as evidenced by their dependence on the Gila.

Gatschet has thus defined the Pima linguistic stock in an article entitled "The Indian languages of the Pacific," which was published in the Magazine of American History:[a]

Pima. Dialects of this stock are spoken on the middle course of the Gila river, and south of it on the elevated plains of southern Arizona and northern Sonora (Pimería alta, Pimería baja). The Pima does not extend into California unless the extinct, historical Cajuenches, mentioned in Mexican annals, spoke one of the Pima (or Pijmo, Pimo) dialects. Pima, on Pima reserve, Gila river, a sonorous, root-duplicating idiom; Névome, a dialect probably spoken in Sonora, of which we possess a reliable Spanish grammar, published in Shea's Linguistics;[b] Papago, on Papago reserve, in southwestern Arizona.

Villages

During the early part of the nineteenth century there were eight Pima villages on the Gila, according to statements made by Ká'mâl tkâk and other old men of the tribe. The numerous accounts by travelers and explorers contain mention of from five to ten pueblos or villages. The names are usually those bestowed by the Spanish missionaries or unrecognizable renderings of the native terms. The villages were principally upon the south bank of the river, along which they extended for a distance of about 30 miles.[c] Some have been abandoned; in other cases the name has been retained, but the site has been moved. The first villages named by Kino were Equituni, Uturituc, and Sutaquison. The last two were situated near the present agency of Sacaton (pl. I). The first may have been the village of Pimas and Kwahadk's, which was situated west of Picacho on the border of the sink of the Santa Cruz river (fig. 1), which was abandoned about a century ago and was known as Akûtcíny, Creek

[a] Vol. I, 156.

[b] The most valuable publication relating to the Pima language is the "Grammar of the Pima or Névome, a language of Sonora, from a manuscript of the XVIII Century." This was edited by Buckingham Smith, and 160 copies were issued in 1862. It is in Spanish-Névome, the latter differing slightly from the true Pima. The grammar has 97 octavo pages with 32 additional pages devoted to a "Doctrina Cristiana y Confesionario en Lengua Névome, ó sea la Pima."

[c] The Rudo Ensayo states that "between these Casas Grandes, the Pimas, called Gileños, inhabit both banks of the river Gila, occupying ranches on beautiful bottom land for 10 leagues farther down, which, as well as some islands, are fruitful and suitable for wheat, Indian corn, etc." Records of the American Catholic Historical Society, v, 128.

"The most important of these ranches are, on this side, Tusonimó, and on the other, Sudacson or the Incarnation, where the principal of their chiefs, called Tavanimó, lived, and farther down, Santa Theresa, where there is a very copious spring." (Ibid., 129.) This "spring" was probably above the present Gila Crossing where the river, after running for many miles underground in the dry season, rises with a strong flow of water that supplies extensive irrigating ditches.

Whipple, Ewbank, and Turner, writing in 1855, enumerate the following Pima villages: San Juan Capistrano, Sutaquison, Atison, Tubuscabor, and San Seferino de Napgub (see Pacific Railroad Reports, III, pt. 3, 123).

In 1858 Lieut. A. B. Chapman, First Dragoons, U. S. Army, completed a census of the Pimas and Maricopas. The names of the villages, leaders, and the population of both tribes are here reprinted

Mouth. The site of this settlement was visited by the writer in April, 1902. It is marked by several acres of potsherds that are scattered about the sand dunes on the south side of the dry river bottom that is scarcely lower than the level of the plain. A few Mexican families have lived in the vicinity for many years, pumping water from a depth of a hundred feet and depending upon crops of corn and beans raised in the summer when a few showers fall upon their fields. These Mexicans plow out stone implements and bits of pottery, but have never found any burial places.[a] There are two medium-sized adobe ruins on the flat river bottom; one of these has walls of the same pisé type that is exhibited by the Casa Grande ruin (pl. III), situated 25 miles to the northward.

from S. Ex. Doc. 1, pt. 1, 559, 35th Cong., 2d sess., 1859. The number of Maricopas is included that the comparatively small importance of that tribe may be appreciated.

MARICOPAS

[Head chief, Juan Chevereah.]

Villages.	Chiefs.	Warriors.	Women and children.	Total.
El Juez Tarado	Juan Jose	116	198	314
Sacaton		76	128	204
		192	326	518

PIMAS

[Head chief, Antonio Soule [Azul].]

Buen Llano	Ojo de Buro and Yiela del Arispe	132	259	391
Ormejera No. 1	Miguel and Xavier	140	503	643
Ormejera No. 2	Cabeza del Aquila	37	175	212
Casa Blanca	Chelan	110	425	535
Chemisez	Tabacaro	102	210	312
El Juez Tarado	Cadrillo del Mundo and Ariba Aqua Bolando	105	158	263
Arizo del Aqua	Francisco	235	535	770
Aranca No. 1	La Mano del Mundo	291	700	991
Aranca No. 2	Boca Dulce			
		1,152	2,965	4,117

Mr Browne, a member of Commissioner Poston's party that visited the villages in January, 1864, wrote: "The number of Pima villages is 10; Maricopas, 2; separate inclosures, 1,000." (J. Ross Browne, Adventures in the Apache Country, 110.) On a later page (290) he gives the population by villages, of which he names but seven:

Aqua Baiz	533	Herringuen	514
Cerrito	259	Llano	392
Arenal	616		
Cachunilla	438	Total	3,067
Casa Blanca	315		

"There are 1,200 laboring Pimas and 1,000 warriors."

James F. Rusling (The Great West and the Pacific Coast, 369), who visited the Pimas in 1867, also states that there were then ten Pima villages.

[a] Font mentions a Pima-Papago village in this vicinity, called "Cuitoa." Manuscript Diary, 35.

At the Salt River settlement a Mexican under the influence of whisky killed a Pima, but the Indians "were good enough not to want to kill" the murderer.

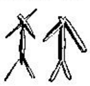
Gila Crossing (*a*), *Salt River, Blackwater* (*b*). In the spring of 1891 occurred the last and most disastrous of the Gila floods. The Maricopa and Phoenix Railroad bridge was swept away and the channels of both the Gila and Salt rivers were changed in many places. The destruction of cultivated lands led to the change of the Salt River Pimas from the low bottoms to the mesas.

1891–92

Gila Crossing. A boarding school[a] for Indian children was established at Phoenix.

Two men died at Gila Crossing during the autumn, and it was supposed that they were poisoned by the tizwin which they had been drinking.

In a tizwin drunk on the Salt River reservation a Papago shot a Pima and fled to escape the consequences, leaving his wife at the village.



Blackwater. The chief and one of the headmen at Blackwater died during the year.

1892–93

Gila Crossing. Two friends went to Maricopa and got drunk on whisky. One cut the other's throat; he then went to the villages on the river above Gila Crossing and in maudlin tones said he thought he saw himself striking someone under him.[b]

The schoolhouse was moved out of Phoenix to a point 3 miles north of the city during the summer of this year (1892).

A woman was struck by lightning at Hi'atam, the village above Gila Crossing.

A dance at Salt River occurred in which two men, drunk with whisky, killed each other.

In the spring of 1892 the Gila Crossing chief, Ato'wâkäm, died.

The Government issued barbed wire for fencing at Gila Crossing, and directed the people to make a road across the fields, which should be fenced to form a lane.

Blackwater. A woman was gored to death at Blackwater by a cow.

The chief, who had been bitten some years before by a rattlesnake but had recovered, died in the spring of 1893.

---

[a] It was opened in a leased hotel building in September, 1891. Owing to lack of facilities only boys, to the number of 42, were admitted.

[b] The passion for distilled liquor had arisen within the last quarter of a century. Lieutenant Emory wrote, in November, 1846, "Aguardiente (brandy) is known among their chief men only, and the abuse of this and the vices which it entails are yet unknown."

Estimated Manning's Roughness Coefficients for Stream Channels and Flood Plains in Maricopa County, Arizona

By B.W. Thomsen and H.W. Hjalmarson

Prepared by the
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Water Resources Division
375 South Euclid Avenue
Tucson, Arizona 85719

Prepared for the
Flood Control District
of Maricopa County
2801 West Durango Street
Phoenix, Arizona 85009

April 1991

GILA RIVER ABOVE BULLARD AVENUE NEAR AVONDALE--Continued

Table 4.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .028		
		n_1 = ----		
		n_2 = ----		
		n_3 = .027		
		n = .055		

Subsection B (main channel)

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .005		
		n_2 = ----		
		n_3 = .025		
.10	x	n = .055	=	.006
		n_b = .025		
		n_1 = .002		
		n_2 = ----		
		n_3 = .003		
.55	x	n = .030	=	.017
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .055		
.05	x	n = .080	=	.004
		n_b = .020		
		n_1 = ----		
		n_2 = ----		
		n_3 = ----		
.15	x	n = .020	=	.003
		n_b = ----		
		n_1 = ----		
		n_2 = ----		
		*n_3 = .200		
.15	x	n = .200	=	.030
1.00				.060

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .028		
		n_1 = ----		
		n_2 = ----		
		n_3 = .017		
		n = .045		

Subsection B (main channel)

Portion of area or wetted perimeter of subsection from left end		Components		Weighted and composite values
		n_b = .025		
		n_1 = .003		
		n_2 = ----		
		n_3 = .017		
.10	x	n = .045	=	.004
		n_b = .025		
		n_1 = .001		
		n_2 = ----		
		n_3 = .002		
.55	x	n = .028	=	.015
		n_b = .025		
		n_1 = ----		
		n_2 = ----		
		n_3 = .040		
.05	x	n = .065	=	.003
		n_b = .020		
		n_1 = ----		
		n_2 = ----		
		n_3 = ----		
.15	x	n = .020	=	.003
		n_b = ----		
		n_1 = ----		
		n_2 = ----		
		*n_3 = .150		
.15	x	n = .150	=	.022
1.00				.047

*Only value of n_3 of consequence.

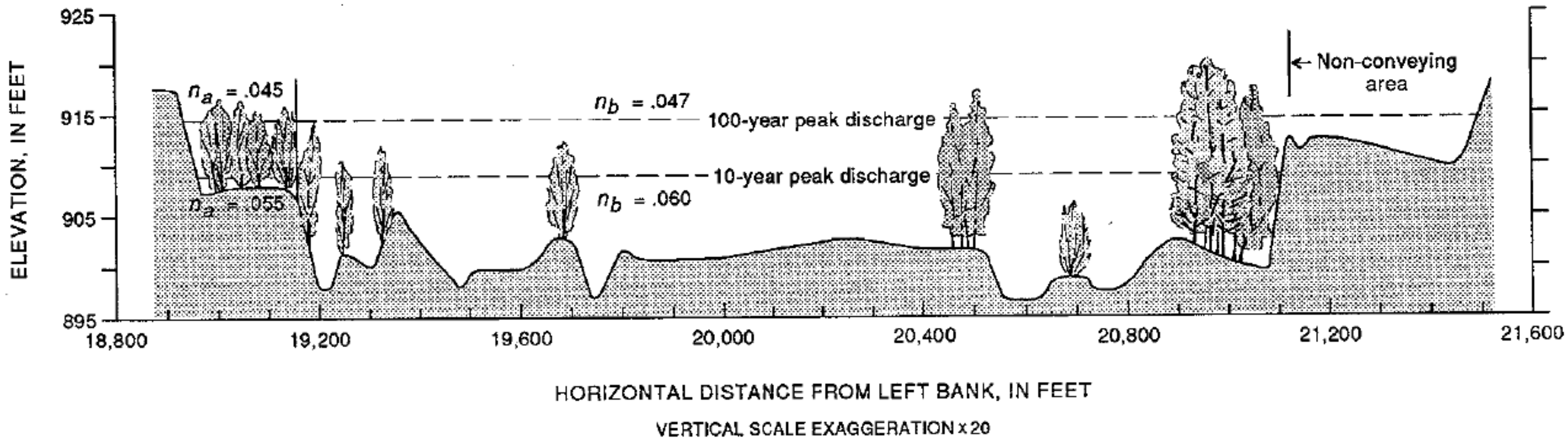

Figure 4.--Cross section of Gila River above Bullard Avenue near Avondale.

HASSAYAMPA RIVER BELOW OLD U.S. HIGHWAY 80--Continued

Table 10.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = .003	
	n = .028	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

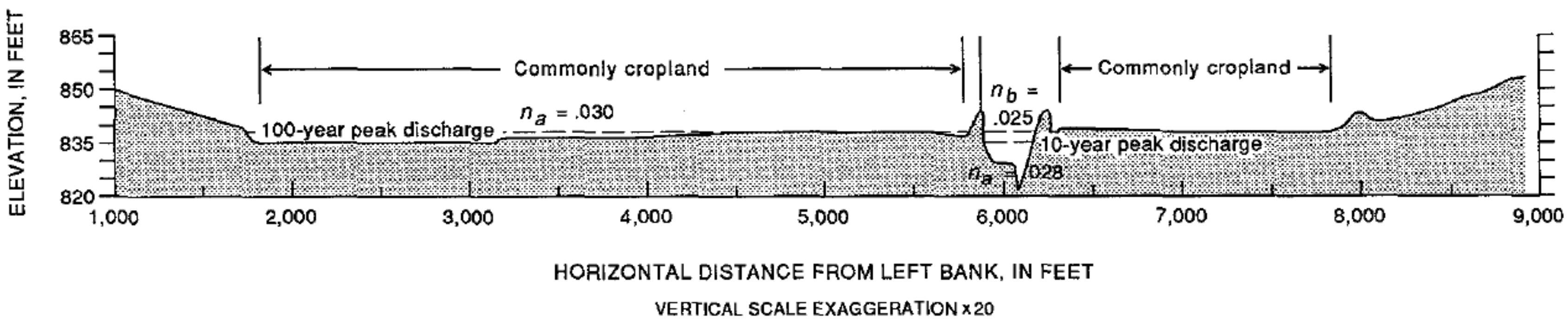

Figure 16.--Cross section of Hassayampa River below old U.S. Highway 80.

CENTENNIAL WASH BELOW SOUTHERN PACIFIC RAILROAD--Continued

Table 14.--Components and weighted and composite values of Manning's n

[Dashes indicate a roughness coefficient of zero]

10-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .030	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .030	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .005	
	n_2 = ----	
	n_3 = .030	
	n = .060	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

100-Year Flood

Subsection A

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

Subsection B

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .005	
	n_2 = ----	
	n_3 = .030	
	n = .060	

Subsection C

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = ----	
	n_2 = ----	
	n_3 = ----	
	n = .025	

Subsection D

Portion of area or wetted perimeter of subsection from left end	Components	Weighted and composite values
	n_b = .025	
	n_1 = .010	
	n_2 = ----	
	n_3 = .065	
	n = .100	

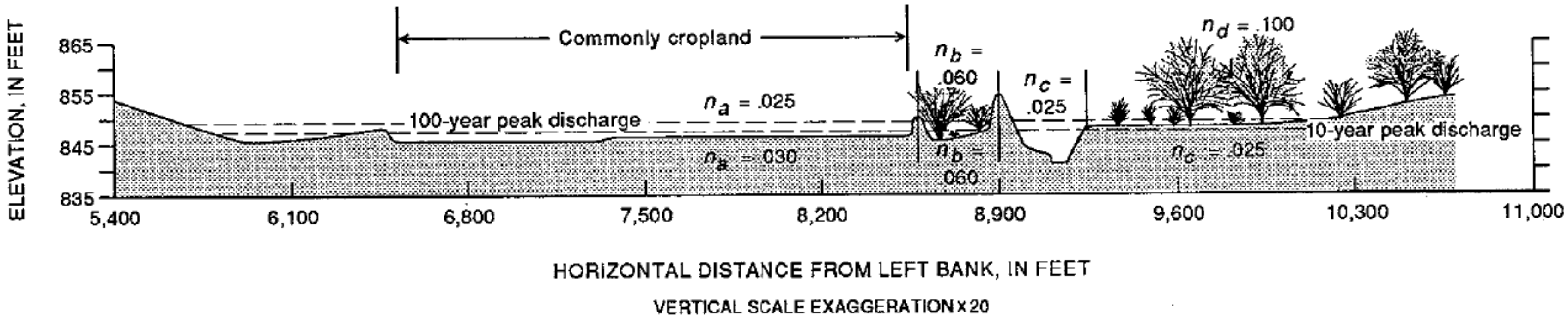

Figure 24.--Cross section of Centennial Wash below Southern Pacific Railroad.

PREDEVELOPMENT HYDROLOGY OF THE SALT RIVER INDIAN RESERVATION, EAST SALT RIVER VALLEY, ARIZONA

By B.W. Thomsen and J.J. Porcello

U.S. GEOLOGICAL SURVEY
Water–Resources Investigations Report 91–4132

Prepared in cooperation with the
U.S. BUREAU OF INDIAN AFFAIRS

Tucson, Arizona
November 1991

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
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ILLUSTRATIONS

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	*By*	*To obtain*
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
mile per hour (mi/h)	1.609	kilometer per hour
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per acre (acre-ft/acre)	0.3047	cubic meter per square meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
foot squared per day (ft^2/d)	0.0929	meter squared per day
foot per mile (ft/mi)	0.1894	meter per kilometer
degree Fahrenheit (°F)	(temp °F-32)/1.8	degree Celsius

Sea level: In this report *"sea level"* refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called *"Sea Level Datum of 1929."*

PREDEVELOPMENT HYDROLOGY OF THE SALT RIVER INDIAN RESERVATION, EAST SALT RIVER VALLEY, ARIZONA

By

B.W. Thomsen and J.J. Porcello

ABSTRACT

Predevelopment hydrologic conditions in the Salt River Valley were investigated to provide information for the adjudication of water rights of users in the Gila River basin. Prior to development by non-Indian settlers, the Salt River was perennial through the Salt River Indian Reservation. The ground-water reservoir was filled to capacity or nearly so and was sustained mainly by infiltration of water from the Salt River. Water levels generally were 10 to 70 feet below the land surface. The direction of ground-water flow was from north to south in Paradise Valley and from east to west along the flood plain of the Salt River and in the area south of the river.

The average annual discharge of the Salt River before development was estimated to be 1,250,000 acre-feet and the median annual discharge 950,000 acre-feet. These estimates are based on recorded data with adjustments for results of tree-ring studies and estimates of upstream diversions and reservoir evaporation.

A ground-water flow model was developed to simulate ground-water flow, riverbed infiltration, mountain-front recharge, and evapotranspiration for purposes of evaluating predevelopment ground-water conditions. The model represents average conditions in the ground-water system before the system was affected by storage and diversion of streamflow upstream from the reservation. Average values for components of ground-water flow determined from the model for the study area include recharge by infiltration from the Salt River, 19,700 acre-feet per year; mountain-front recharge and subsurface inflow, 10,700 acre-feet per year; discharge to the Salt River near Tempe, 9,800 acre-feet per year; evapotranspiration from ground water, 13,300 acre-feet per year; and subsurface outflow, 7,300 acre-feet per year.

INTRODUCTION

In the 1860's and 1870's, non-Indian settlers arrived in Arizona in large numbers and began to divert water from the Salt River near the area that became the Salt River Indian Reservation. The Salt River Indian Reservation was established in 1879 along the Salt River in the eastern part of the Salt River Valley. The development and activities since that time have significantly changed the hydrology of the area. The flow of the Salt River and the recharge to the ground-water system on the reservation have been greatly diminished as a result of upstream storage and diversions. Water levels in wells have declined, and the direction of ground-water flow has changed as a result of pumping for irrigation in areas adjacent to the reservation. General adjudication to determine water rights of users in the Gila River watershed is being conducted in the superior courts of Arizona under authority established by Arizona Revised Statutes Title 45, Chapter 1, Article 6. To develop data pertinent to the adjudication process, the U.S. Bureau of Indian Affairs entered into a cooperative agreement with the U.S. Geological Survey to evaluate the hydrologic conditions that existed prior to the development of the area by non-Indian settlers.

Purpose and Scope

The purpose of this report is to describe the hydrologic conditions that existed in the area of the Salt River Indian Reservation prior to development by non-Indian settlers. Non-Indian settlers were diverting significant quantities of water from the Salt River near the reservation in the 1870's (Davis, 1897). Hydrologic data do not exist for the period prior to 1870; therefore, data collected since 1870 were used to evaluate predevelopment conditions, as described in the section entitled "Approach." The results of the evaluation represent long-term average hydrologic conditions.

Approach

The evaluation of the hydrologic conditions that existed prior to 1870 required estimating the surface flow of the Salt River upstream from the Salt River Indian Reservation and defining the ground-water system in and adjacent to the reservation. Estimates of average flow of the Salt River were based on recorded data with adjustments to represent predevelopment conditions. The adjustments were based on the recorded effects of development on river flows and mathematical evaluations of climatic trends. Studies of relations between streamflow and tree rings were used to help substantiate estimates of the predevelopment flow of the Salt River.

The ground-water system was evaluated by using a mathematical model. The model covers an area larger than the reservation (fig. 1) in order to encompass parts of the mountain ranges that form physical boundaries to much of the ground-water system. The model parameters were estimated from published values and recorded field data; each parameter was estimated independently. Evapotranspiration was calculated by using the oldest maps and photographs available to determine areas and types of vegetation and applying evapotranspiration rates determined in recent studies.

Location, Physiography, and Climate

The study area includes about 950 mi^2 in south-central Arizona, of which about 77 mi^2 is in the Salt River Indian Reservation (fig. 1). The area is characterized by broad desert plains dissected by many arroyos and separated by rugged relatively low mountains. The altitude of the

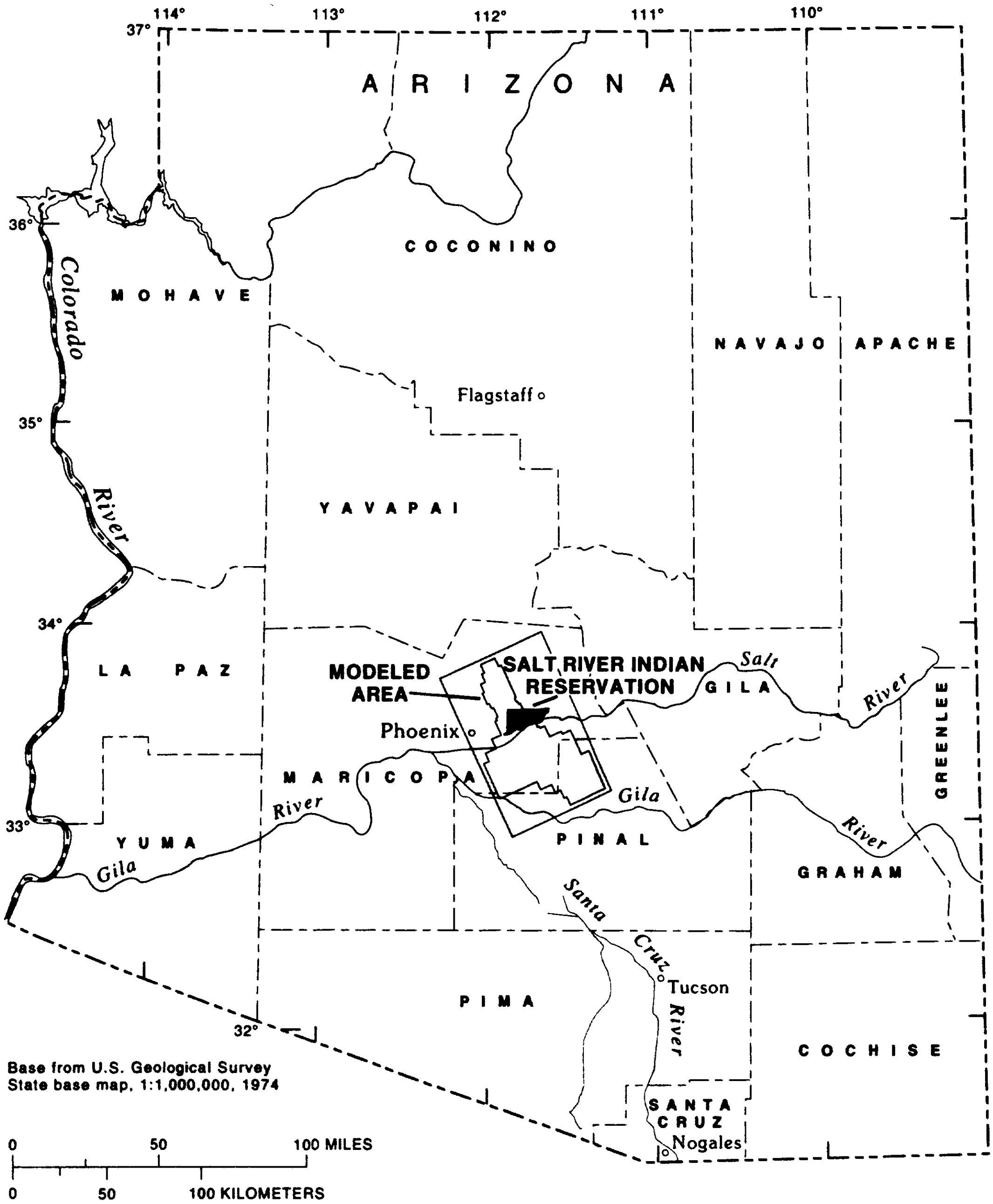


Figure 1.--Location of study area (shaded).

desert plains ranges from 2,200 ft above sea level north of the reservation to less than 1,200 ft at the southwest corner. The Phoenix and South Mountains, which are on the west side of the study area, reach altitudes of 2,500 ft. The McDowell and Superstition Mountains, which are on the east side, are at altitudes of about 4,000 and 5,000 ft, respectively. The major streams in the area are the Salt and Gila Rivers and Queen and Cave Creeks. The Salt River drains the northern part of the area, and the Gila River drains the southwestern part. Queen Creek, a tributary to the Gila River, drains the southeastern part, and Cave Creek crosses the northwest corner of the study area (fig. 2). The Salt River and its major tributary, the Verde River, drains more than 12,000 mi^2 north and northeast of the reservation (fig. 1) and, prior to the activities of the non-Indian settlers, contributed perennial flow through the study area.

The dominant native vegetation types are mesquite and saltbush along the washes and palo verde and cacti on the hills. Creosote bush covers most of the desert floor except where it has been replaced by cultivated farmland. Mesquite, cottonwood, and willow trees grew in places along the river when non-Indian settlers arrived (Lee, 1904) but most have been removed.

The climate is dry and incapable of supporting more than a minimum vegetative growth without irrigation. Summers are hot, and daily temperatures usually exceed 100°F from mid-June through August. Mean daily temperatures range from about 64°F to 105°F. The relative humidity generally is low, ranging from about 20 to 50 percent (Sellers and others, 1985).

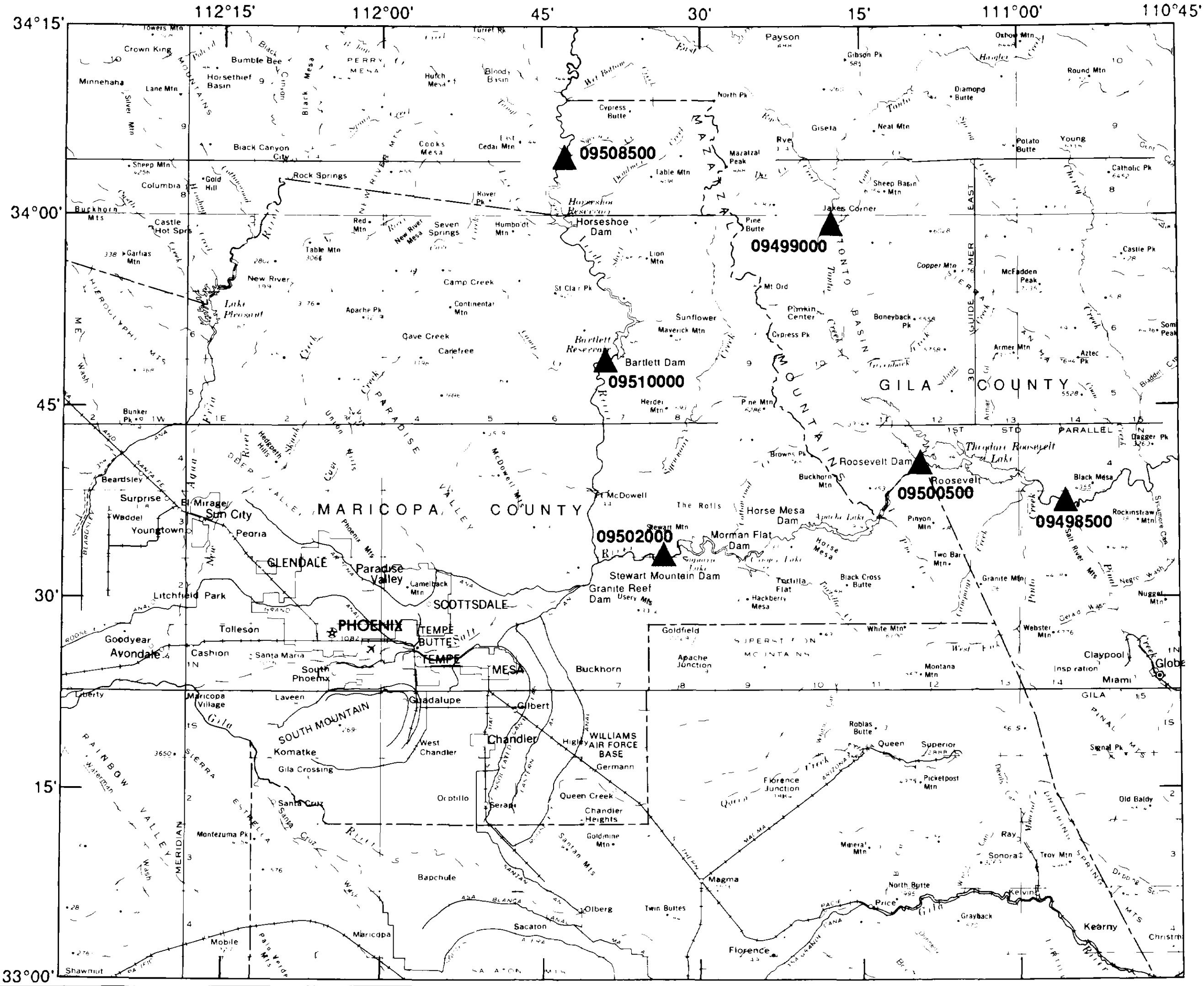
Winters are mild, and average temperatures range from 30°F to 40°F in early morning and from 60°F to 80°F in the afternoons. Subfreezing temperatures occur on only a few days during an average year (Sellers and others, 1985). Mean daily temperatures range from about 33°F to 70°F.

Annual precipitation averages about 8 in. and results mainly from two types of storms. Summer thunderstorms, which develop as a result of the flow of moist-tropical air from the Gulf of Mexico, make July and August the wettest months. Regional storms from the Pacific Ocean produce gentle widespread showers during the fall and winter months.

Wind movement in the area is relatively light. In 1895, the monthly average was about 5 mi/h at Phoenix (Davis, 1897, p. 31). U.S. Weather Bureau records for January 1948 through December 1955 show that average wind speeds do not exceed 8.3 mi/h at Phoenix (Sellers and Hill, 1974, p. 30).

Previous Investigations

An investigation of the water supplies available for irrigation in the Salt and Gila Valleys near Phoenix, Arizona, was made in 1896 by Authur P. Davis (1897). This investigation dealt mainly with surface-water supplies. W.T. Lee (1905) investigated the underground waters of the Salt River Valley; his report presents tabulations of well records, water levels, and chemical quality of ground water and includes descriptions of geology, physiography, and the economics of pumping ground water. Ground



Base from U.S. Geological Survey
State base map, 1:500,000, 1972

0 20 MILES
0 20 KILOMETERS
SCALE 1:1,000,000

EXPLANATION

▲ 09499000 STREAMFLOW-GAGING STATION AND NUMBER

Figure 2.--Location of streamflow-gaging stations.

water of the Arizona territory was examined to determine its suitability for sanitary, irrigation, and technical uses (Skinner, 1903).

A study of Paradise Valley was made to evaluate the possibility of developing a ground-water supply for irrigation (Meinzer and Ellis, 1915). McDonald and others (1947) collected information on the availability of ground water in Paradise Valley as a possible source of municipal supply for the City of Phoenix. Arteaga and others (1968) updated knowledge of ground-water conditions in Paradise Valley. Two reports present records of wells and related ground-water data in the Queen Creek area (Babcock and Halpenny, 1942; Skibitzke and others, 1950).

An electrical-analog model of the ground-water system in central Arizona was used to determine the probable future effects of continued ground-water withdrawal (Anderson, 1968). The model was constructed by using the known hydrologic characteristics of the water-bearing rocks and the pumping history through 1964. Ross (1980) developed a digital model to evaluate the effects of a proposed well field on water levels in wells on the Salt River Indian Reservation.

Maps showing water-level altitudes for 1976 and water-level changes for 1923-76 in the eastern part of the Salt River Valley were prepared by Laney and others (1978). Maps showing ground-water conditions in the Salt River Valley as of 1983 were prepared by Reeter and Remick (1986). Geologic and hydrologic characteristics of the water-bearing units in the eastern part of the Salt River Valley were described by Laney and Hahn (1986). Description of hydrologic conditions and distribution of aquifer materials in alluvial basins (Freethey and others, 1986) are pertinent to the study area. Ground-water conditions for 1900 and 1986 and changes in ground-water conditions were described by Thomsen and Miller (1991).

HISTORY OF WATER DEVELOPMENT

Most of the Salt River Valley was occupied and irrigated by the Hohokam Indians from about 300 B.C. to A.D. 1450 (Masse, 1981). Remnants of prehistoric villages and canal systems were noted by archeologists in 1887, but by 1903, most of the surface evidence of these villages and canal systems had been obliterated by farming and construction. On the basis of the remains of extensive irrigation works, the amount of land irrigated under the prehistoric system was estimated to have been at least 250,000 acres (Hodge, 1893). Recent archeological studies of the Hohokam irrigation system have recorded more than 300 mi of main canals and 1,000 mi of smaller canals in the Salt River Valley (Masse, 1981).

Modern irrigation in the Salt River Valley was begun by John W. Swilling in 1867 (Salt River Project, 1970). The Swilling Ditch, as it was originally called, was on the north side of the river about 5 mi east of Phoenix. In 1868 the canal became known as the Salt River Valley Canal (Davis, 1897). In 1870 the Tempe Canal was constructed on the south side of the river about 7 mi upstream from the Salt River Valley Canal. Other canals constructed on the south side of the river included the San Francisco, Utah, Mesa, and Consolidated Canals built in the 1870's and the

Highland Canal built in 1889. On the north side of the river, the Grand Canal was built in 1878 and the Arizona Canal in 1883-84 (Davis, 1897).

Reliable figures on the amount of land irrigated in the late 1800's were difficult to obtain. The farmers did not keep good records, and in many cases the amount of land claimed as irrigated was that "under ditch" (land to which water might be taken). According to the Eleventh Census, the total area irrigated in Maricopa County during 1889 was 35,212 acres (Davis, 1897). Water was claimed, however, for 151,360 acres in 1889, according to records compiled under the orders of Judge Kibbey. The average water use on 60,000 acres irrigated in 1895 was 4.6 acre-ft/acre (Davis, 1897).

The need for a dependable supply of water for irrigation led to the construction of reservoirs to store excess runoff and to regulate the flow of the river. The first structure on the Salt River, Roosevelt Dam, was completed in 1911, followed by Mormon Flat Dam in 1925, Horse Mesa Dam in 1927, and Stewart Mountain Dam in 1930. On the Verde River, Bartlett Dam was completed in 1939 and Horseshoe Dam in 1946. The six reservoirs have a combined storage capacity of more than 2 million acre-ft of water, of which about 85 percent is stored on the Salt River.

Many wells were dug or drilled to provide domestic water supplies, but only small quantities of ground water were withdrawn for irrigation in the late 1800's. The use of ground water for irrigation was hampered by the scarcity and cost of suitable power for pumping (Davis, 1897). The quantities of ground water pumped remained relatively small, less than 100,000 acre-ft/yr in the entire Salt River Valley until the early 1920's. Ground-water withdrawals in the Salt River Valley increased gradually and exceeded 1 million acre-ft in 1942 and 2 million acre-ft in 1952 (U.S. Geological Survey, 1986).

GEOLOGY

The study area is in the Basin and Range physiographic province (Fenneman, 1931), which is characterized by broad alluvial valleys separated by rugged mountains. The mountains are composed mainly of granitic, volcanic, and metamorphic rocks that yield little water. The valley floors are underlain by a wide variety of sedimentary deposits that constitute the main ground-water reservoirs. Deposits consist of unconsolidated to variably consolidated sediments that are several thousand feet thick in places. The sediments include unconsolidated clay, silt, sand and gravel, caliche, gypsum, mudstone, siltstone, sandstone, conglomerate, and anhydrite. The degree of sorting and cementation and the distribution of the different materials varies areally and with depth. Interbedding and lensing are common, and lateral discontinuities caused by high-angle faults could be present in some older units (Laney and Hahn, 1986).

On the basis of geologic and hydrologic properties, the sediments have been divided into four units—red, lower, middle, and upper (Laney and Hahn, 1986). The following description of the sedimentary units is summarized from Laney and Hahn (1986). The red unit was deposited before the period of block faulting associated with the Basin and Range structural disturbance. The red unit consists of well-cemented breccia, conglomerate, sandstone, and siltstone. As a result of faulting, the red unit is exposed locally along the mountain fronts, mainly north of the Salt River along the east and west boundaries of the study area; the thickness of the unit is unknown. The lower, middle, and upper units were deposited during and after the period of block faulting. The lower unit consists of clay, silt, mudstone, and evaporite with interbedded sand, gravel, conglomerate, and basalt. The unit is at least 600 ft thick near the mountains and could be as much as 10,000 ft thick southeast of Chandler and in the center of Paradise Valley. The middle unit consists of silt, siltstone, and silty sand and gravel and ranges in thickness from less than 100 ft near the mountains to about 1,000 ft near Williams Air Force Base; the unit is about 800 ft thick in Paradise Valley. The upper unit consists of gravel, sand, and silt and underlies most of the valley floor; most of the unit is unconsolidated, but locally the deposits are strongly cemented by caliche. The upper unit is more than 300 ft thick south and southwest of Mesa and 200 ft thick in Paradise Valley.

HYDROLOGY

Hydrologic cycle is a term used to denote the circulation of water from the ocean, through the atmosphere, to the land, and back to the ocean. The movement of water over and through the land enroute back to the ocean is the main concern of this study.

Water that moves over the land surface tends to collect and become streamflow. The quantity and duration of streamflow depends, in general, on the quantity, intensity, and type of precipitation and on the nature of the material over which the water passes. As streamflow moves along natural channels, some water might evaporate and thus be lost from the local system, or a part or all of it might percolate into porous materials and become either soil moisture or ground water.

Water that percolates into the earth from either precipitation or streamflow and reaches the water table, or the zone of saturation, is called ground water. Water that is retained in the unsaturated zone above the water table is called soil moisture. Water in the subsurface might return to the land surface and become streamflow where the water table intersects the land surface. The water might move into the unsaturated zone to become soil moisture or it could be removed from the local system by evapotranspiration or by pumping.

Precipitation

Precipitation is the initial source of water, but not all the precipitation that reaches the land surface is available for man's use. Water that reaches the land surface as precipitation probably proceeds along any of three general paths. The water might evaporate soon after contact with the land surface, move across the land as surface runoff, or penetrate the earth to become either soil moisture or ground water. Recorded precipitation data indicate that the quantity of precipitation can be extremely different from year to year, and studies of past climates show long-term changes in precipitation quantities (Sellers, 1965).

Precipitation in the study area averages about 8 in./yr and occurs mainly as rain. Snow falls in the upper reaches of the rivers that affect the study area. Total precipitation in the study area averages more than 300,000 acre-ft/yr, of which 30,000 acre-ft/yr falls on the reservation. Most of the rainfall on the flatlands of the study area evaporates or is used by vegetation, and virtually none reaches the ground-water reservoir. Precipitation on the mountains tends to collect in channels and run off and can be sufficient in quantity at times to provide recharge to the ground-water system along the mountain fronts.

For 1931-72, annual precipitation averaged 7.60 in. at Scottsdale and 7.57 in. at Mesa and ranged from 3.04 to 13.84 in. at Scottsdale and 2.83 in. to 16.64 in. at Mesa (Sellers and Hill, 1974). Precipitation is less than the potential evapotranspiration in all months, but particularly so in April, May, and June.

Most long-term precipitation records in Arizona began between 1895 and 1915, at least 25 years after the period of interest for this study. The longest continuous precipitation record in Arizona is for Tucson at and near the University of Arizona. During 109 years, annual precipitation averaged 11.41 in. and ranged from 5.07 to 24.17 in.; the median value was 10.94 in. A statistical analysis of the Tucson data indicates no trend in precipitation (Thomsen and Eychaner, 1991).

Fritts and others (1979) used tree-ring data to evaluate climatic variations over a longer time period (1602-1970) and showed that average winter precipitation during 50-year intervals can vary by 20 percent over much of the United States. The percentage of agreement, however, between reconstructed and observed precipitation was greatest in the southwestern United States, including Arizona.

Each line of evidence suggests that the precipitation regime before 1870 was similar to the current regime; therefore, precipitation estimates using recent data are considered to be representative of predevelopment time. Precipitation records at Phoenix date back to 1877 but records for 7 years between 1886 and 1896 are missing. The average annual precipitation was 7.54 in. at the Phoenix post office for 1877 to 1967 and 7.26 in. at the Phoenix airport for 1938 to 1983. Annual precipitation ranged from 2.85 to 19.73 in. at the post office and 2.82 to 16.26 in. at the airport, and median values were 6.85 in. at the post office and 7.09 in. at the airport.

Streamflow

The Salt River was a perennial stream and the main source of water in the study area when the non-Indian settlers arrived (Davis, 1897). The Verde River, which joins the Salt River near the east boundary of the Salt River Indian Reservation, was also a perennial stream. Upstream from the confluence of the two rivers, each river drains an area of more than 6,000 mi^2. The Gila River, Cave Creek, and Queen Creek are related to the hydrology of the study area because of their role in recharging the ground-water system.

Records of discharge of the Salt and Verde Rivers have been kept since 1888. The early estimates of discharge were provided by the Arizona Canal Company and the Hudson Reservoir and Canal Company (Davis, 1897). Subsequently, estimates of daily or monthly discharge were compiled by the U.S. Bureau of Reclamation and the Salt River Valley Water Users' Association (U.S. Geological Survey, 1954). Early estimates of discharge were made on the Verde River near Fort McDowell and on the Salt River at two sites—one called "at McDowell," which was upstream from the confluence with the Verde River, and one called "at Arizona Dam," which was downstream from the confluence with the Verde River. Arizona Dam was about 2.5 mi upstream from the present site of Granite Reef Dam. Water-stage recorders were installed on the Verde River above Camp Creek (equivalent to present site below Bartlett Dam, 09510000) in 1925, on the Salt River below Stewart Mountain Dam (09502000) in 1930, and on the Salt River near Roosevelt (09498500) in 1935 (fig. 2). Before the installation of water-stage recorders, discharge of the Verde River was related to staff gages at several sites near the mouth of the river, and discharge of the Salt River near Roosevelt was related to staff gages 1 mi downstream from the recorder site. Records for the Salt River at Roosevelt, just upstream from the site of Roosevelt Dam, include the discharge of Tonto Creek (fig. 2). Although the discharge of the Verde River was measured or estimated at several sites over the years, the records are considered to be equivalent; hence, continuous records are available from 1888 to 1986 (table 1). The longest record of discharge for the Salt River is for the site near Roosevelt, which dates from 1913. Discharge records for the Salt River below Stewart Mountain Dam began with the 1931 water year (table 1).

The two gaging stations nearest the confluence of the Salt and Verde Rivers are on the Salt River below Stewart Mountain Dam and the Verde River below Bartlett Dam. Records for these two stations were combined to determine the flow of the Salt River through the study area, and discharge values have been adjusted for storage in reservoirs. On the basis of available records, the combined average discharge of the Salt and Verde Rivers is 1,223,000 acre-ft/yr; the median discharge is 889,000 acre-ft/yr. Records for the Verde River date back to 1888 and those for the Salt River to 1931. For the common period of record, 1931-86, the combined average discharge is 1,151,000 acre-ft/yr, the median discharge is 873,000 acre-ft/yr, and the annual discharge ranged from 282,000 to 3,832,000 acre-ft. The recorded values reflect the effect of upstream diversions and reservoir evaporation on the discharge at the confluence of the Salt and Verde Rivers.

Diversions for irrigation in the upper Verde River area average 31,000 acre-ft/yr (Owen-Joyce and Bell, 1983). Additional small diversions for irrigation in the upper Salt River basin bring the total quantity of water diverted for irrigation upstream from the reservoirs to about 40,000 acre-ft/yr. Evaporation from the reservoirs on the Salt and Verde Rivers is estimated to average 110,000 acre-ft/yr. Estimates are based on pan-evaporation data collected by the Salt River Project since 1954 at Roosevelt and Bartlett Lakes (Dallas Reigle, Hydrologist, Salt River Project, Phoenix, written commun., 1988). Diversions for powerplant operations, storage in stockponds and recreational lakes, and transbasin

Table 1.--*Streamflow data at selected streamflow-gaging stations*

Station number[1]	Station name	Drainage area, in square miles	Water years	Annual runoff		
				Mean		Median
				Acre-feet	Inches[2]	Acre-feet
09500500	Salt River at Roosevelt	5,830	1888-1907 1910-13	756,000	2.44	491,000
09498500	Salt River near Roosevelt	4,306	1913-86	653,000	2.84	514,000
09502000	Salt River below Stewart Mountain Dam[3]	6,232	1931-86	730,000	2.20	498,000
09508500	Verde River below Tangle Creek	5,872	1945-86	411,000	1.40	319,000
09510000	Verde River below Bartlett Dam[3]	6,188	1888-1986	493,000	1.49	391,000
09499000	Tonto Creek above Gun Creek	675	1942-86	114,000	3.16	66,700

[1]The complete 8-digit station number for each station, such as 09498500, includes the 2-digit part number "09" plus the 6-digit downstream order number "498500."

[2]One inch of runoff is the volume equivalent to a layer of water 1 inch deep over the entire basin.

[3]Data adjusted for changes in storage in major upstream reservoirs.

diversions are considered to have a negligible effect on the average discharge of the basin.

The total reduction in the natural discharge of the Salt and Verde River basins as a result of evaporation from reservoirs and diversions for irrigation in the upper reaches cannot be accurately determined but is estimated to average 150,000 acre-ft/yr. Much of the reduction in discharge was occurring in 1931 when discharge records began on the Salt River below Stewart Mountain Dam. A trend analysis using Kendall's tau-b statistic indicated no trend in the combined discharge data for 1931-86.

Tree-ring data provide evidence of past climatic variations. Long-term-growth records of trees and a shorter term streamflow record can be used to estimate streamflow for the longer period using statistical multiple regression (Fritts, 1976). Tree-ring data were used to extend the annual- and seasonal-discharge records of the Salt and Verde Rivers back to A.D. 1580 (Smith and Stockton, 1981). The extended records were for the gaging stations on the Salt River near Roosevelt and the Verde River below Tangle Creek. The 400 years of reconstructed discharge records were divided into five 80-year periods, and the average discharge for four of the five periods was less than for the period of record for each basin. When the reconstructed discharge records for the two basins were combined, the average discharge for the five 80-year periods ranged from 83 to 99 percent of the average discharge for the period of record. The average discharge for the entire 400 years was 91 percent of the average for the period of record.

The annual discharge of the natural (predevelopment) Salt-Verde drainage basin into the study area is estimated to average 1,250,000 acre-ft. This estimate is based on the recorded data with adjustment for the results of the tree-ring study and the estimates of upstream diversions and reservoir evaporation. The median annual discharge is estimated to be 950,000 acre-ft.

The Salt River undoubtedly was a constant source of recharge to the ground-water system in the study area before the arrival of non-Indian settlers. Water-level data compiled by Lee (1905) showed that water moved from the Salt River to the aquifer in the first 10 mi downstream from Granite Reef Dam, but about 3 mi farther downstream, water moved from the aquifer back to the Salt River. Flow of the Gila River was also a source of recharge to the ground-water system in the southern part of the study area (Thomsen and Eychaner, 1991).

Queen Creek, which heads in the mountain area south of the Salt River and east of the study area, is tributary to the Gila River. The average discharge of Queen Creek was about 5,000 acre-ft/yr, and most of the water infiltrated into the alluvium near the contact with the mountain area. Flood-control structures have changed the flow pattern of Queen Creek.

Cave Creek drains the mountain area north of Paradise Valley and flows across the northwest corner of the study area where its channel is in coarse alluvium. The channel is dry most of the time but carries water occasionally in response to intense rainfall. Flow is perennial in the upper reaches of Cave Creek, but the water generally infiltrates into the alluvium several miles upstream from the study area. The average discharge of Cave Creek is estimated to be 5,000 to 10,000 acre-ft/yr.

Ground Water

Ground water occurs mainly under water-table or unconfined conditions in the sedimentary material that underlies much of the Salt River Indian Reservation and the surrounding area. The water table is that surface in an unconfined water body at which the pressure is atmospheric. The water table is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water. When Lee (1905) investigated the underground waters of the Salt River Valley, water levels were from 10 to 70 ft below the land surface in the developed area. These water levels could have been higher than the predevelopment level owing to infiltration of diverted irrigation water. Seepage losses were large in the many long ditches required to carry water to scattered tracts of land, and irrigators applied water very lavishly in early spring when water was abundant (Davis, 1897, p. 43). However, water levels reportedly had declined "in the past few years," and the decline was attributed to the drought that prevailed during those years and to the increasing number of wells in use (Lee, 1905, p. 120-121). The effects of irrigation seepage and drought conditions on the ground-water levels of the early 1900's are unknown but probably are minimal. Thus, the water levels measured by Lee (1905) are considered to adequately represent predevelopment conditions. Lee (1905, p. 119) described the water table as "a comparatively regular plain, sloping in general with the grade of the river." The direction of ground-water movement in 1900 was from east to west along the flood plain of the Salt River and in the area south of the river and from north to south in Paradise Valley. The ground-water reservoir apparently was filled to capacity or nearly so and was sustained mainly by the infiltration of water from the Salt River.

Mountain ranges that border much of the area impede the movement of ground water. The rocks that form the mountains generally are not water bearing but might, where fractured, yield as much as a few tens of gallons per minute of water to wells. On the valley floor, the upper unit has excellent water-bearing characteristics and, where saturated, could yield as much as 4,500 gal/min of water to wells. During floods on the Salt River and Queen Creek, the upper unit readily accepts large volumes of recharge. In the south-central part of the area where deposits are cemented by caliche, ground water is perched in the upper unit (Laney and Hahn, 1986). The middle unit generally will yield as much as 1,000 gal/min of water to wells; however, north of Mesa, the unit yields about 4,000 gal/min of water locally to wells. The lower unit yields 50 gal/min or less of water to wells in many areas; however, the conglomerate and the sand and gravel components of the unit could yield as much as 3,500 gal/min of water to wells. The red unit yields as much as 1,000 gal/min of water to wells near Scottsdale (Laney and Hahn, 1986).

Recharge to the ground-water system occurs mainly from infiltration of streamflow. Prior to development, the Salt River was the main source of recharge. Queen Creek, Cave Creek, and the Gila River contrib- uted small quantities of recharge on the periphery of the study area. Mountain-front runoff from the McDowell and Superstition Mountains contributed small quantities of recharge in the Paradise Valley and Queen Creek areas.

Water is discharged from the ground-water system by surface flow and underflow from the area and by evapotranspiration. Discharge of ground water in the Salt River near Tempe occurred regularly prior to development and probably averaged about 25,000 acre-ft/yr (Lee, 1905, p. 151).

Underflow and Mountain-Front Recharge

Underflow through permeable materials that underlie the surface drainages helps to recharge the ground-water system. The Salt River and

Queen Creek enter the study area from areas underlain by crystalline rocks of low permeability; hence, the underflow from these drainages probably was negligible. The Gila River and Cave Creek are underlain by alluvium and are potential sources of underflow into the study area. Underflow from the Gila River and mountain-front recharge from the Superstition Mountains are indicated by predevelopment water levels (Thomsen and Baldys, 1985; Thomsen and Miller, 1991). The quantity of underflow was about 6,000 acre-ft/yr on the basis of hydraulic- conductivity data and estimates of the cross-sectional area. Underflow through Paradise Valley was principally from Cave Creek and was calculated to be 6,700 acre-ft/yr (McDonald and others, 1947, p. 11). Freethey and Anderson (1986) estimated the predevelopment underflow from Cave Creek and the mountain-front recharge from the McDowell Mountains to be 4,000 acre-ft/yr, and this value was used in the ground-water budget. Total underflow into the area was estimated to be 10,000 acre-ft/yr.

Underflow southwestward from the area is indicated by predevelopment water levels (Thomsen and Baldys, 1985; Thomsen and Miller, 1991). The quantity of underflow could have been as much as 7,000 acre-ft/yr on the basis of transmissivity data and estimates of the cross-sectional area. Underflow along the Salt River between Tempe Butte and South Mountain was estimated to be 1,000 acre-ft/yr. Total underflow from the area probably was about 8,000 acre-ft/yr.

Hydraulic Characteristics of the Ground-Water Reservoir

The hydraulic characteristics of the ground-water reservoir are the physical properties that control the ability of the material to store and transmit water. These properties depend mainly on the size of openings or interstices and their shape, arrangement, and interconnection. The hydraulic characteristics commonly used to describe ground-water reservoirs are storage coefficient and transmissivity, which provide a measure of the quantity of water stored in the reservoir and the rate at which the reservoir will transmit water. The movement of ground water through a section of aquifer can be expressed by the equation:

$$Q = TIW, \tag{1}$$

where

Q = flow, in cubic feet per day;
T = transmissivity, in feet squared per day;
I = hydraulic gradient (dimensionless); and
W = width of section, in feet.

Transmissivity is a function of the hydraulic conductivity and saturated thickness of the reservoir and can be expressed by the equation:

$$T = KM, \tag{2}$$

where

K - hydraulic conductivity, in feet per day, and
M - saturated thickness, in feet.

Hydraulic conductivity is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Lohman and others, 1972). Hydraulic conductivity is expressed in units of length per unit time, such as feet per day.

Transmissivity is the rate at which water at the existing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient. Transmissivity is expressed in consistent units of volume (L^3) per unit time (T) per unit width (L), which reduces to L^2T^{-1}. In the English system, transmissivity is expressed in cubic feet per day per foot, which reduces to feet squared per day.

The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Lohman and others, 1972). In an unconfined water body, it is virtually equal to the "specific yield," which is the ratio of the volume of water that saturated material will yield by gravity drainage to the volume of the material drained. The storage coefficient is expressed as volume (L^3) per unit area (L^2) per unit length (L) and is, therefore, dimensionless. Specific storage is the volume of water released from or taken into storage per unit volume of the porous medium per unit change in head (Lohman and others, 1972).

Quantitative data on the hydraulic characteristics of ground-water reservoirs are obtained from field data on water levels, water-level fluctuations, and natural or artificial discharges (Ferris and others, 1962; Bentall, 1963). Aquifer-test data indicate that transmissivity values in the study area range from about 2,500 to 50,000 ft^2/d and values as great as 75,000 ft^2/d have been estimated for some local areas (Laney and Hahn, 1986). Most of the aquifer tests were made after the upper part of the aquifer, which in many areas is the most transmissive, had been at least partly dewatered; hence, the transmissivity values are less than they would have been when the aquifer was full. The greatest values of transmissivity occur south of the Salt River in the Mesa area (Anderson, 1968; Laney and Hahn, 1986). In general, transmissivity values range from 20,000 to 40,000 ft^2/d north of the Salt River and decrease northward into Paradise Valley. Stratification in alluvial material causes transmissivity values to be much larger parallel to the bedding plane than perpendicular to the bedding plane.

The average storage coefficients for sedimentary deposits in central Arizona range from 15 to 20 percent (Anderson, 1968). In simulating the effects of a proposed well field on the ground-water system in the Salt River Indian Reservation, Ross (1980) used a storage coefficient of 0.12.

The hydraulic gradient averaged about 0.001 and ranged from 0.0006 to 0.004 prior to ground-water withdrawals by the non-Indian settlers. At the present time (1986), hydraulic gradients range from about 0.002 to 0.03 in most of the area.

Evapotranspiration

Evapotranspiration is defined as "water withdrawn from a land area by *evaporation* from water surfaces and moist soil and plant *transpiration*" (Langbein and Iseri, 1960). Evaporation is commonly measured by noting the change in water level in an open pan during a given time period. Such measurements do not accurately reflect evaporation from natural water bodies because of difference in water temperature, vapor pressure, and water-surface roughness. The rate of evaporation from a small pan usually far exceeds that from a large reservoir or lake. The ratio of lake to pan evaporation is referred to as the pan coefficient. Annual evaporation from a U.S. Weather Bureau Class A pan at Mesa during 1963-73 averaged 106.31 in. (Sellers and Hill, 1974). The pan coefficient is about 0.67, and the average annual lake evaporation is about 70 to 75 in. (U.S. Department of Commerce, 1968). Annual lake evaporation, in feet, multiplied by an area of water surface, in acres, would give the volume of water evaporated, in acre-feet per year. Plants obtain water from precipitation and soil moisture, and deep-rooted plants called phreatophytes obtain much of their water from the capillary fringe and the saturated zone. The rate of transpiration by phreatophytes depends on the availability of water and on the species, cover density and size, and stage of maturity of the plants. The quantity of water withdrawn from the ground-water reservoir by phreatophytes depends on the depth to ground water. The use of water by phreatophytes is greatest when ground water is shallow and decreases as depth to water increases (fig. 3). The relation between water use and depth to water is not well defined for all phreatophyte species but is fairly well defined for mesquite (Anderson, 1976).

The most common species of phreatophytes indigenous to southern Arizona are cottonwood, willow, baccharis (seepwillow), and mesquite (Gatewood and others, 1950). These species probably were the main woodland types of vegetation along the Salt River near the Salt River Indian Reservation prior to the arrival of non-Indian settlers. The area of potential phreatophytic growth was 18,500 acres as determined from topographic maps published in the early 1900's and aerial photographs taken in 1936. Probably only about half the area contained phreatophytes. According to early photographs and descriptions (Davis, 1897; Lee, 1905; Salt River Project, 1970), most of the flood plain and low terraces along the Salt River were covered with grass and were scattered with phreatophytes that were light in density.

An investigation of the consumptive use of water by phreatophytes was made in 1963-71 to determine evapotranspiration before and after clearing phreatophytes on 15 mi of the Gila River flood plain (Culler and others, 1982). Results of the study showed that the annual evapotranspiration averaged 3.7 ft and ranged from 4.7 ft for dense stands of phreatophytes to 2.1 ft for areas of no phreatophytes. Vegetation consisted mainly of saltcedar and mesquite with scattered cottonwood, seepwillow, seepweed, and arrowweed. Depth to ground water on the flood plain ranged from 5 ft near the river to 20 ft near the outer boundaries of the flood plain. Removal of the phreatophytes resulted in a reduction in evapotranspiration that averaged 1.6 ft/yr and ranged from 1.2 to 2.2 ft/yr owing to the differences in the density of phreatophytes. Evapotranspiration after the removal of phreatophytes consisted of

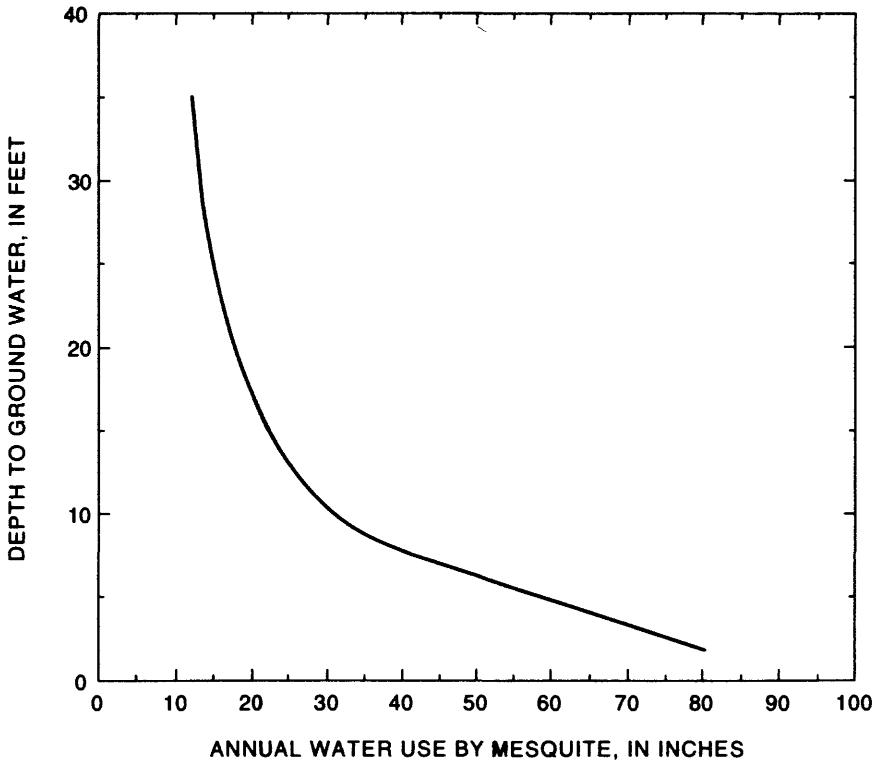


Figure 3.—Relation between depth to ground water and annual water use by mesquite (From Anderson, 1976, fig. 10, p. 46).

evaporation from bare ground and transpiration from annual vegetation. Because phreatophytes obtain their water supply primarily from ground water, the reduction in evapotranspiration that resulted from removal of the phreatophytes is considered to represent a measure of ground water withdrawal by phreatophytes. Precipitation and soil moisture provide a significant part of the evapotranspiration during the period of high potential evapotranspiration (Culler and others, 1982).

Ground-water withdrawal by phreatophytes was estimated to average 15,000 acre-ft/yr on the basis of an evapotranspiration rate of 1.6 ft/yr and the assumption that phreatophytic growth covered half the potential growth area. Because phreatophytes were scattered and their distribution unknown, the evapotranspiration rate was halved and applied to the entire area of potential phreatophytic growth for modeling purposes.

Ground-Water Budget

A water budget that accounts for all inflows and outflows was prepared for the ground-water reservoir underlying the study area. Because aquifers were in equilibrium prior to development by non-Indian settlers, the average long-term change in ground-water storage prior to 1870 was considered to be zero. Hence, the sum of all inflows must have equaled the sum of all outflows.

The average annual water budget for the ground-water reservoir under predevelopment conditions is expressed by the equation:

$$G_i + Q_r = G_o + Q_d + ET_g, \qquad (3)$$

where

G_i = subsurface inflow,
Q_r = recharge to the aquifer from the Salt River,
G_o = subsurface outflow,
Q_d = discharge to the Salt River from the aquifer, and
ET_g = evapotranspiration from the ground-water reservoir.

All components were evaluated independently except Q_r, which was computed as a residual. Average values were as follows:

G_i = 10,000 acre-ft/yr,
Q_r = 38,000 acre-ft/yr,
G_o = 8,000 acre-ft/yr,
Q_d = 25,000 acre-ft/yr, and
ET_g = 15,000 acre-ft/yr.

The net flux from the Salt River to the aquifer, Q_n, is expressed by the equation:

$$Q_n = Q_r - Q_d. \qquad (4)$$

Using the above values, Q_n is 13,000 acre-ft/yr.

SIMULATION OF GROUND-WATER FLOW

The modular three-dimensional, finite-difference ground-water flow model of the U.S. Geological Survey (McDonald and Harbaugh, 1991) was used in the simulation of the predevelopment ground-water flow regime. A two-dimensional application of the model was used because regional flow in the upper and middle lithologic units was predominantly horizontal. The aquifer was simulated as a steady-state flow system because all available data suggest that annual ground-water inflows and outflows were about equal (Anderson, 1968; Thomsen and Baldys, 1985). The model was calibrated mainly to the earliest available well data and was constructed to reflect steady-state ground-water flow conditions that existed before settlement of the East Salt River Valley.

The model solves the following partial-differential equation for three-dimensional flow in a saturated medium (McDonald and Harbaugh, 1988):

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) - W = S_s\frac{\partial h}{\partial t}, \qquad (5)$$

where

x, y, z = cartesian coordinates, aligned along the major axes of the hydraulic-conductivity tensor [L],
K_{xx}, K_{yy}, K_{zz} = principal components of the hydraulic-conductivity tensor [LT^{-1}],
h = hydraulic head [L],
W = volumetric flux per unit volume of sources and (or) sinks of water [T^{-1}],
S_s = specific storage of aquifer material [L^{-1}], and
t = time [T].

A two-dimensional model simulates no vertical flows except for those embodied in the term, W; therefore, head is invariant with respect to altitude, and the vertical-flow term drops out of the equation. Because a steady-state condition implies that inflows and outflows to the aquifer are equal, heads throughout the aquifer also are steady over time. The two-dimensional steady-state flow equation, therefore, is expressed as

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) - W = 0. \qquad (6)$$

The required input data for a two-dimensional steady-state model are the grid and cell dimensions, boundary conditions, and parameter values relating to the hydraulic conductivity, and various components of the term W. For this study, the term W includes the processes of evapotranspiration, riverbed infiltration, and mountain-front recharge. For unconfined aquifers, such as is present in East Salt River Valley, the model allows the user to specify either transmissivity values or hydraulic conductivities and layer thicknesses.

Model Construction

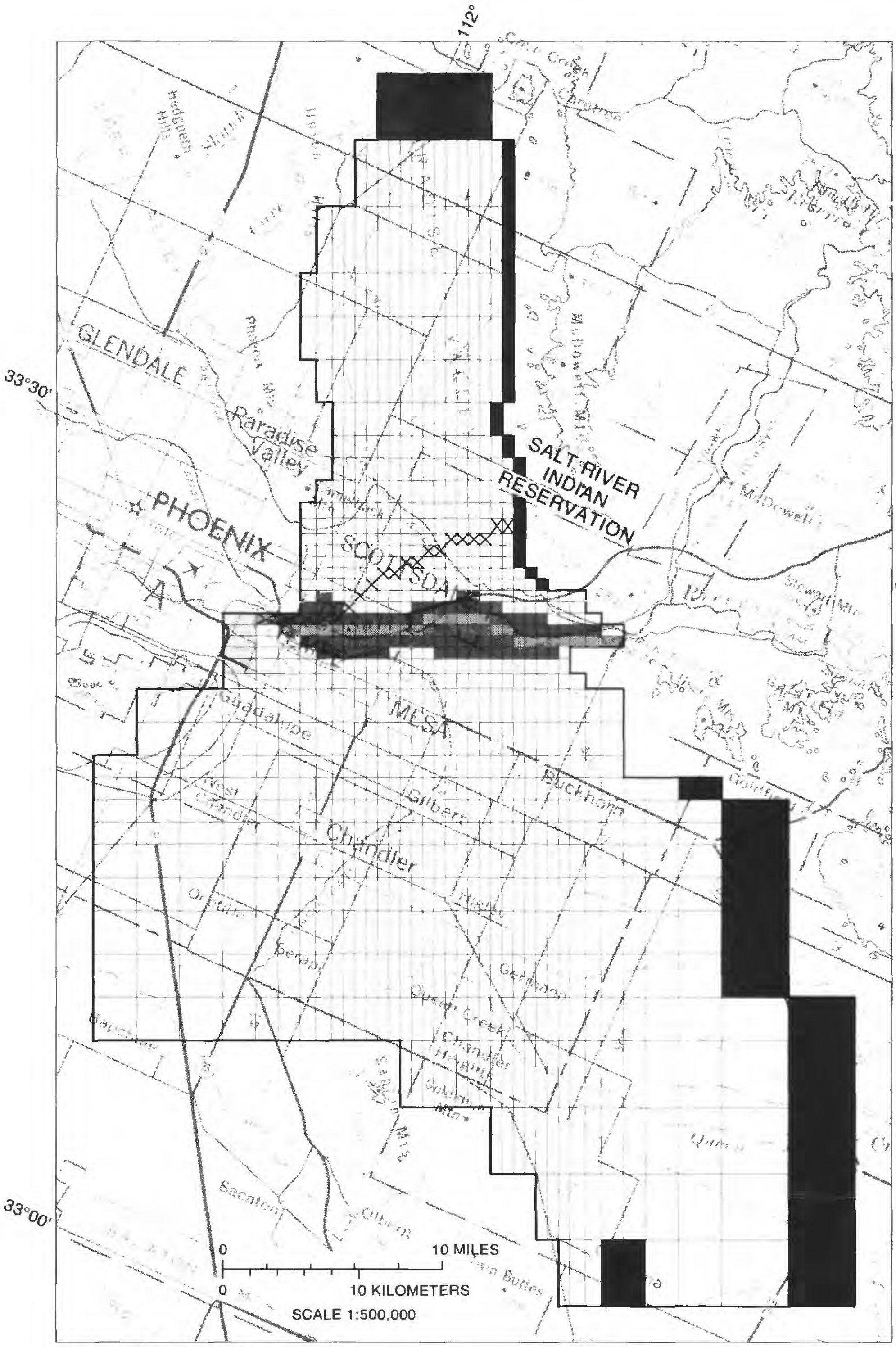
The finite-difference technique used by the ground-water flow model requires the subdivision of the active ground-water flow region into a grid of rectangular cells, which can be identically sized or variably sized. The aquifer was modeled with a grid dimension of 44 rows by 39 columns (fig. 4). The cells were variable in size. The grid was designed to place the smallest cells along the channel of the Salt River and the largest cells along the model boundaries. The grid was oriented 24.7° west of true north so that the cells would be in close alignment with the path of the Salt River because the ground-water budget indicated that the river was the dominant source and sink for subsurface waters under predevelopment conditions. The solution of the steady-state heads at each cell was obtained using the strongly implicit solution procedure of the model with a head-closure criterion of 0.01 ft.

Model boundaries were based on previously mapped boundaries between alluvial deposits and crystalline rocks except in the Gila River area where an artificial boundary was established for modeling convenience. The simulation used specified-flux, specified-head, and head-dependent boundaries. Areas of mountain-front recharge were simulated as specified-flux boundaries. Subsurface outflow at Tempe Butte and the Gila River was simulated with specified-head boundaries. The head altitudes were selected from measurements at nearby wells and from the predevelopment water-level contours. The Salt River was treated as a head-dependent flux boundary; values of head and vertical flux at each river node were computed as a function of the specified stage of the river and the head in the aquifer.

An underflow of 3,300 acre-ft/yr from Cave Creek was distributed evenly over all specified-flux nodes in the northernmost row of the model, and 700 acre-ft/yr of mountain-front recharge from the McDowell Mountains was distributed evenly along the mountain range. An underflow of 500 acre-ft/yr from the Gila River was applied to two nodes in the southernmost row of the model, and mountain-front recharge of 5,200 acre-ft/yr from the Superstition Mountains was distributed along the mountain range.

Perennial streamflow from the Salt River watershed was simulated as flow in the present (1986) channel of the river. A total of 28 cells were specified as river reaches. The river stages in the upper 10 reaches were set to altitudes that were 2 ft above the average channel-floor altitudes in each cell. River stages in the lower 18 reaches were set equal to water-table altitudes suggested by regional-predevelopment contours (Thomsen and Baldys, 1985). Riverbed altitudes were determined from recent (1973-82) topographic maps and differ by as much as 15 ft in places from altitudes determined from topographic maps published in the early 1900's (fig. 5). The differences might result in part from mapping variations but probably result mainly from channel changes.

Although the flood plain of the Salt River was more than one model-cell wide in much of the valley, only a single cell within appropriate grid columns was selected because mean annual widths of channel flow probably were no greater than a few hundred feet (Hodge, 1877). Riverbed conductance was estimated initially from channel geometry and a vertical-hydraulic conductivity of 5 ft/d was assumed. Riverbed conductance is the product of vertical hydraulic conductivity and area of riverbed sediments in a model cell, divided by the thickness of the riverbed sediments. For simulation purposes, the riverbed thickness for each reach was set arbitrarily at 100 ft except at the edges of the valley where simulated thicknesses ranged from 50 to 90 ft.



Base from U.S. Geological Survey
State base map, 1:500,000, 1972

EXPLANATION

SPECIFIED-HEAD CELL

SPECIFIED-FLUX CELL

EVAPOTRANSPIRATION CELL

RIVER AND EVAPOTRANSPIRATION CELL

STREAM-LINE CELL IN CALIBRATED MODEL—Studied in the sensitivity analysis

BOUNDARY OF MODEL

Figure 4.—Finite-difference grid and boundary conditions used in ground-water flow model.

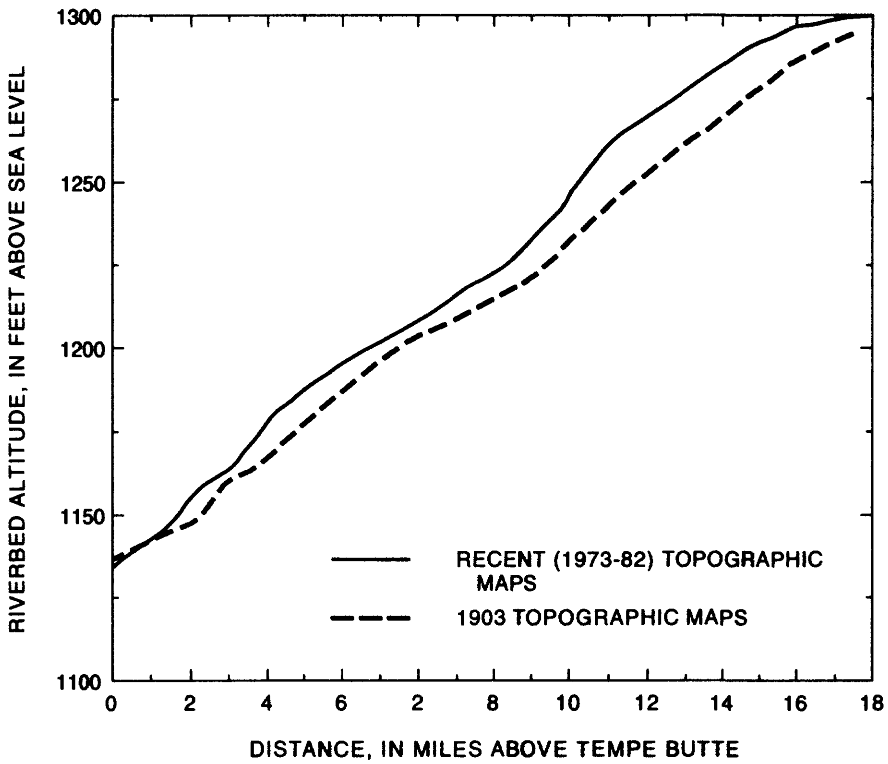


Figure 5.--Recent (1973-82) and 1903 profiles of the Salt River bed.

Evapotranspiration cells were restricted mainly to the flood plain of the Salt River (fig. 4). River cells also were simulated as evapotranspiration cells because of the growth of phreatophytes in the river channel. The evapotranspiration surface, defined as the aquifer-head altitude above which maximum evapotranspiration occurs, was set equal to the altitude of the land surface at most evapotranspiration cells. Within river cells, this surface was set 5 ft above the channel-floor altitude to account for the perennial nature of the river, as well as the topographic relief between the channel floor and banks. The simulated evapotranspiration extinction depth, defined as the depth below which phreatophytes are unable to withdraw ground water, was 30 ft.

Simulated transmissivities were selected to reflect the dominant role of the upper unit in the two-dimensional predevelopment ground-water flow system. Estimates of transmissivity for the upper unit were derived from Anderson (1968) and from Laney and Hahn (1986), and the unit was simulated as an isotropic medium. Initial approximations of transmissivity in Paradise Valley were derived mainly from upper-unit contour maps of thickness and percent sand and gravel (Laney and Hahn, 1986). Transmissivities that ranged from 2,000 to 75,000 ft^2/d and transmissivity-distribution patterns suggested by Anderson (1968) and Laney and Hahn (1986) were used as a guide for changes in transmissivity during the calibration process.

Calibration

The principal goal of the calibration process was to match simulated-head contours with heads measured at 121 wells while maintaining the various ground-water flow components within reasonable limits of their independent estimates. The calibration was followed by a sensitivity analysis in which variations in model parameters were examined for their relative effects on head configuration and magnitudes of the flow components. The sensitivity analysis was vital in assessing the credibility of the calibrated model because the two-dimensional nature of the model prevented evaluation of how well it would reproduce historical patterns of pumping over the past 50 years.

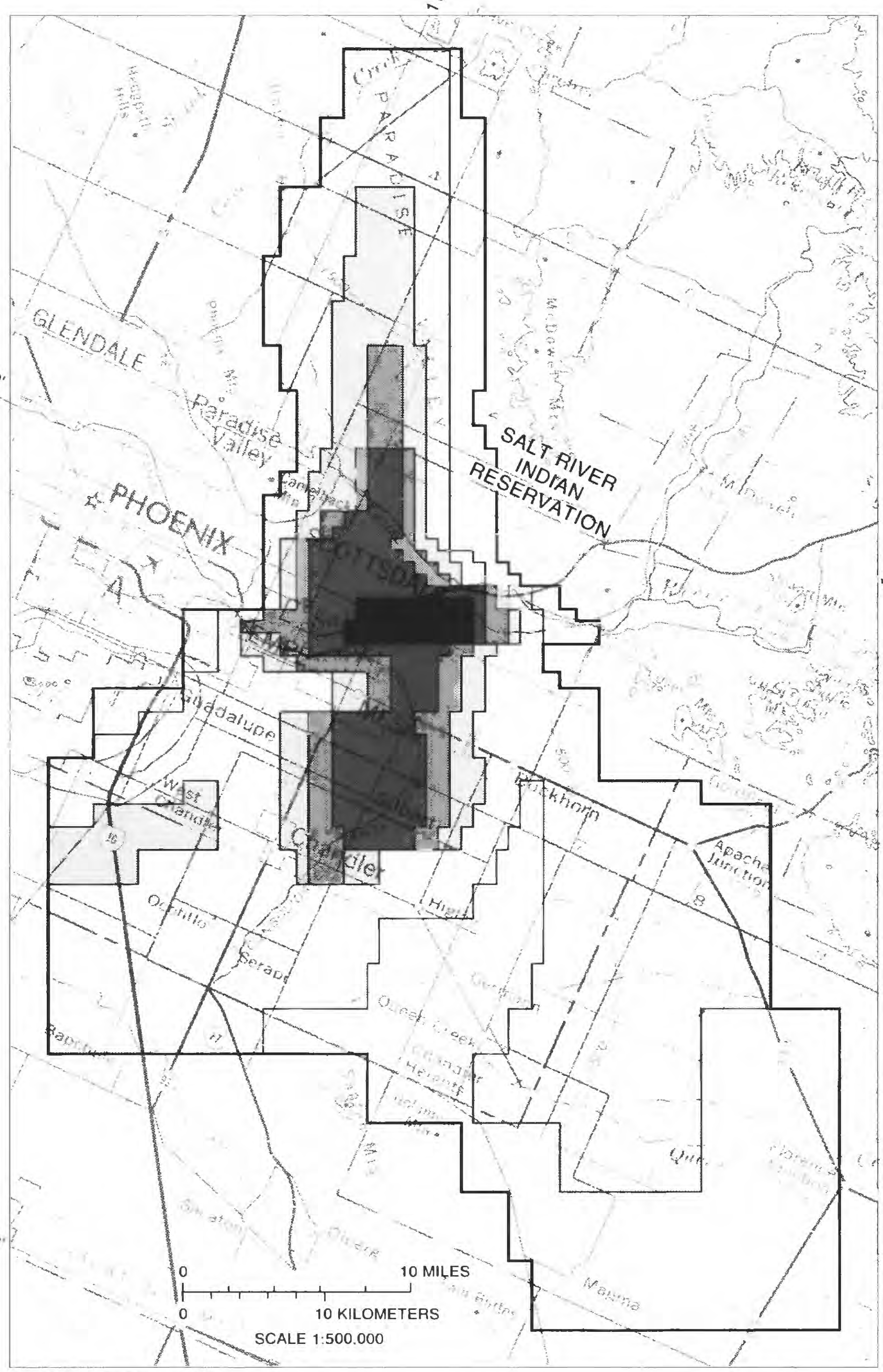
Many ground-water models are calibrated in a manner that lends more credence to independent estimates of the transmissivity distribution and the ground-water flow budget than to the estimated-head distribution. In this study, the well data provided more information about the flow system than did the transmissivity and budget estimates because only depths to water were directly measured before much of the upper unit was dewatered. Because the transmissivity distribution and the flow components were estimates, rather than measured values, they were considered less reliable than the measured water levels.

Initial estimates of riverbed conductance were based on channel geometries and an assumed vertical hydraulic conductivity of 5 ft/d. These estimates, however, produced an unrealistic distribution of gaining and losing reaches of the Salt River. A reduction of all riverbed conductances by two orders of magnitude produced more reasonable distributions of fluxes with little change in the total volume of flow exchanged between the river and the aquifer. This change reflected adjustments of the estimates of channel geometry and vertical hydraulic conductivity that were used in the original computations of riverbed conductance. Riverbed conductance was reduced because vertical fluxes in the river are proportional to the difference between river and aquifer heads, and that difference was much smaller under predevelopment conditions than under present (1986) conditions.

Simulation Results

Simulated transmissivities within the Salt River Indian Reservation ranged from 2,000 ft^2/d along the margins of the aquifer to 40,000 ft^2/d near the river (fig. 6). The same range of transmissivities was simulated throughout the study area. Simulated transmissivities were intermediate in magnitude between those given by Anderson (1968) and Laney and Hahn (1986) and exhibited similar spatial trends. The simulation displayed a high-transmissivity zone from central Paradise Valley southwestward toward the Gila River and a low-permeability zone near the town of Queen Creek. Simulated values of evapotranspiration along the Salt River flood plain were in close agreement with initial estimates of evapotranspiration.

Simulated water-level contours generally compared well with the independent estimates of Thomsen and Baldys (1985) and contours derived



Base from U.S. Geological Survey
State base map, 1:500,000, 1972

EXPLANATION

TRANSMISSIVITY, IN FEET SQUARED PER DAY

2,000	20,000	30,000
10,000	25,000	40,000

BOUNDARY OF MODEL

Figure 6.—Simulated transmissivity distribution.

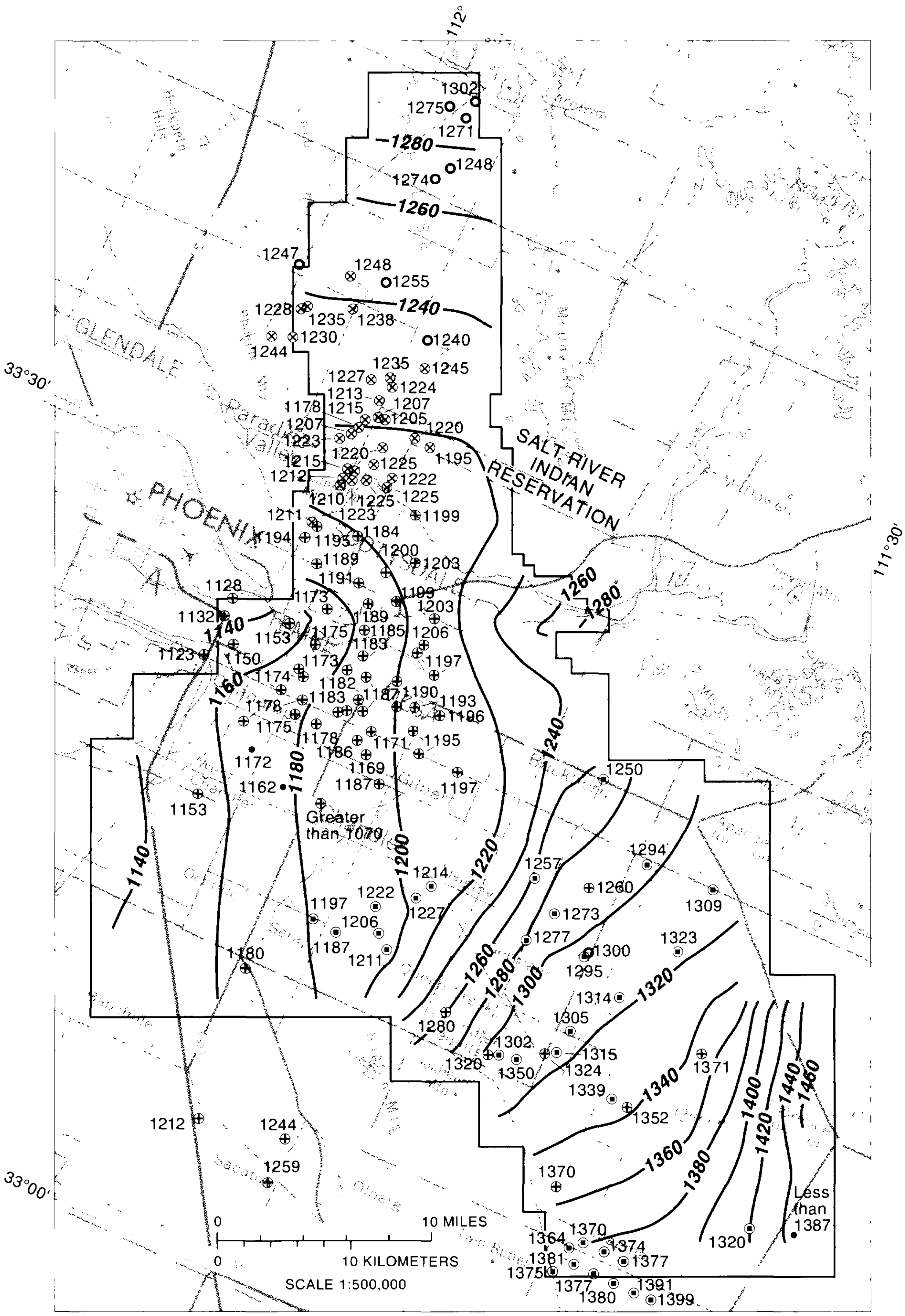
from water-level measurements shown by Meinzer and Ellis (1915). Contours indicate that the Salt River was a predominantly losing stream in the east half of the study area and a predominantly gaining stream in the west half of the area (fig. 7). This result agrees with maps and descriptions given by Lee (1905). Heads computed at river cells generally were a few tenths of a foot within the specified river stages. Similar heads and stages of the river cells and the shapes of the contours crossing the river indicate that the river was the dominant hydrologic feature of the valley.

The shapes of the 1,220-foot and 1,240-foot contours south of the Salt River indicated that some of the predevelopment riverbed recharge flowed southwestward toward the Gila River and the rest followed the general path of the river. The ground-water divide was poorly defined. Mountain-front recharge from the Superstition Mountains and underflow from the Gila River in the southeast corner of the study area flowed westward and then southwestward toward the Gila River in the southwest corner of the study area.

Simulated water-level contours within the Salt River Indian Reservation ranged from 1,160 ft to 1,260 ft along the Salt River (fig. 7). The simulated flow north of the reservation and along its west boundary was derived from underflow from Cave Creek and mountain-front recharge. The shapes of the contours reflect the assumption that mountain-front recharge from the McDowell Mountains was a minor source of ground water to the reservation.

Differences between simulated and measured water levels (herein called residuals) were generally less than ±20 ft. Residuals ranged from 0 to 96 ft, but only 4 of the 121 values were greater than ±30 ft. The average-absolute value of the residuals was 10 ft, and the standard deviation was 15 ft. The root-mean-square average of the residuals also was 15 ft. The residual population appeared normally distributed as a group, but slight spatial trends were evident. A zone of negative residuals immediately downgradient from a zone of positive residuals in the Tempe-Mesa area indicates that the water table in this area in 1903 could have been flatter than the predevelopment water table because of the combined effects of drought and recharge from irrigation. A zone of negative residuals immediately north of the Arizona Canal suggests that McDonald and others (1947) were correct in their assumption that the water levels measured by Meinzer and Ellis (1915) in this area were influenced by leakage from the canal. The distribution of head residuals suggests that any temporal trends inherent in the water-level data used were minimal in comparison to the spatial trends.

The simulated predevelopment ground-water inflow to the Salt River Indian Reservation was 26,700 acre-ft/yr; 19,700 acre-ft/yr occurred as infiltration of Salt River flows, and 7,000 acre-ft/yr occurred as underflow from Cave Creek and mountain-front recharge (table 2). About 51 percent of ground-water discharge from the reservation occurred as subsurface outflow along the south and west boundaries of the reservation, and evapotranspiration and discharge to the bed of the Salt River constituted 30 and 19 percent of the discharge, respectively. The net flux of 14,700 acre-ft/yr from the river to the aquifer was slightly greater than the subsurface outflow from the reservation.



Base from U.S. Geological Survey
State base map, 1:500,000, 1972

EXPLANATION

WELL—Number, 1172, indicates altitude of the water level in feet above sea level. Sources of water-level data:

1172 Davis (1897)

1191 Lee (1905)

1225 Meinzer and Ellis (1915)

1314 Babcock and Halpenny (1942)

1271 McDonald and others (1947)

—1320— SIMULATED WATER-LEVEL CONTOUR—Shows altitude of the water level as estimated by the model, in feet above sea level. Contour interval 20 feet

BOUNDARY OF MODEL

Figure 7.—Simulated predevelopment water levels and measured water levels.

Table 2.--*Estimated and simulated values of ground-water flow components*

[Flow is in acre-feet per year]

Flow component	Estimated flow in the modeled area[1]	Simulated flow in the modeled area[1]	Simulated flow in the Salt River Indian Reservation
INFLOW			
Recharge from Salt River	38,000	19,700	19,700
Mountain-front recharge and subsurface inflow	10,000	10,700	[2]7,000
Total aquifer recharge	48,000	30,400	26,700
OUTFLOW			
Discharge to Salt River	25,000	9,800	5,000
Evapotranspiration	15,000	13,300	8,100
Subsurface outflow			
At Tempe Butte	1,000	800	------
At Gila River	7,000	6,500	------
Total	8,000	7,300	13,600
Total aquifer discharge	48,000	30,400	26,700
NET FLUX FROM SALT RIVER[3]	13,000	9,900	14,700

[1]The modeled area includes the Salt River Indian Reservation.
[2]Subsurface inflow to the reservation from Cave Creek is 6,700 acre-feet and mountain-front recharge within the reservation is 300 acre-feet per year.
[3]Recharge from the Salt River minus discharge to the Salt River equals net flux.

The simulated predevelopment ground-water flow budget indicated that the Salt River was the dominant source of recharge to the regional aquifer, and evapotranspiration was the dominant sink. The net flux from the river was 9,900 acre-ft/yr. The simulated and estimated magnitudes of evapotranspiration were nearly identical, but the simulated discharge to the Salt River was much less than was estimated. The large difference between the simulated and estimated values of the discharge to the Salt River suggests that the estimated value was corrupted by irrigation return flow resulting from canal leakage and irrigation techniques. Most simulated regional ground-water flow components were less than initial estimates. The difference between estimated and simulated values ranged from about 10 percent for evapotranspiration to about 60 percent for discharge to the Salt River.

Sensitivity Analysis

The sensitivity analysis, which is the principal means of assessing the credibility of the calibrated model, was designed to illustrate the changes in head profiles and flow components that result from variations of parameter values. The analysis was done by performing a series of simulations in which all parameters were held constant except the one being analyzed, and that parameter was varied over a broad range of values that were considered reasonable. Transmissivity, mountain-front recharge, riverbed conductance, evapotranspiration-extinction depths, and evapotranspiration rates were all varied independently. Simulated heads within the Salt River Indian Reservation were evaluated in each sensitivity simulation by constructing head profiles along a stream line through the middle of the reservation extending from the base of the McDowell Mountains westward and southwestward toward the Salt River (fig. 4). This profile represented the head distribution along a stream line in the calibrated model but not necessarily along a stream line in the sensitivity runs. The sensitivity of heads along the profile may not be indicative of sensitivity everywhere in the model. The average-absolute and root-mean-square values of head residuals of each simulation were compared in order to assess the sensitivity of heads throughout the valley (table 3).

Sensitivity of Heads

Heads along the stream line were sensitive to all parameters except the two evapotranspiration parameters. Head changes were negatively correlated to changes in transmissivity along the east 7 mi of the profile, insensitive along a 3-mile reach above the river, and positively correlated to transmissivity changes at Tempe Butte (fig. 8). Heads generally were insensitive to riverbed-conductance values greater than the calibrated values indicating that the river was acting nearly as a constant-head boundary because of the high riverbed-conductance values. Lower conductances flattened the head gradient noticeably (fig. 9). Changes in head were positively correlated to changes in simulated boundary flux; the degree of sensitivity decreased steadily downgradient toward Tempe Butte where heads in the lower 4 mi of the profile were insensitive to boundary-flux changes (fig. 10).

Head-residual statistics followed the same general sensitivity trends as the head profile; however, decreases in riverbed conductance had little influence on the residuals (table 3) in comparison with the noticeable influence on the slope of the profile (fig. 9). The head-residual statistics were insensitive to variations in most parameters because the residual values were distributed throughout the entire study area; whereas, the sensitivity of the head profile resulted from its representation of a single stream line.

Table 3.--*Sensitivity of head-residual statistics to model parameters*

Multiplier of calibrated value	Percent change in average-absolute head	Percent change in root-mean-square value
	Transmissivity	
0.50	387	416
.75	104	111
1.00	0	0
1.25	31	18
1.50	73	63
2.00	137	133
	Evapotranspiration extinction depth	
0.33	0	0
.67	0	0
1.00	0	0
1.33	0	0
1.67	0	0
	Evapotranspiration rate	
0.20	0	0
.50	0	0
1.00	0	0
1.50	0	0
2.00	0	0
	Riverbed conductance	
0.01	-5	-3
.10	-1	0
1.00	0	0
10.00	0	0
100.00	0	0
	Mountain-front recharge	
0.50	138	133
.75	46	33
.90	7	-1
1.00	0	0
1.10	19	22
1.25	72	77
1.50	174	185
2.00	391	418

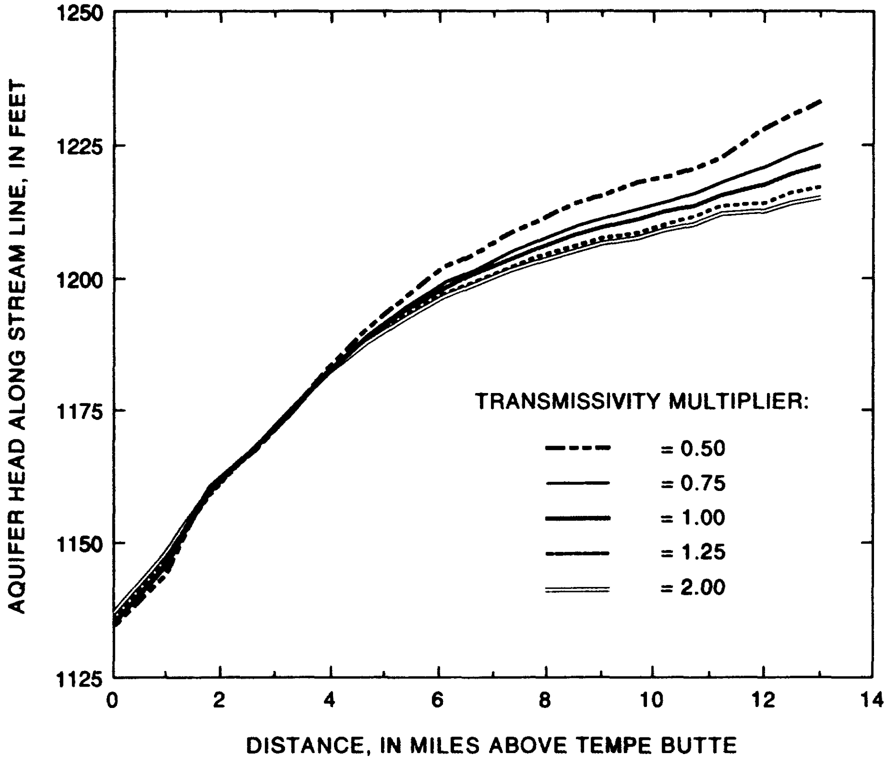


Figure 8.--Sensitivity of stream-line profile to changes in transmissivity values.

Sensitivity of Flow Components

Flow components generally were sensitive to changes in model parameters (fig. 11). Changes in transmissivity produced the greatest changes in the ground-water budget, whereas changes in riverbed conductance produced the least.

The net flux from the Salt River to the aquifer was insensitive to changes in riverbed conductance but highly sensitive to changes in boundary fluxes and evapotranspiration parameters (extinction depth and ground-water withdrawal rate). The net flux was negatively correlated to changes in boundary fluxes and positively correlated to changes in evapotranspiration parameters. Variations in transmissivity produced variations in the net river flux that appeared as equivalent changes in subsurface outflow. Evapotranspiration was completely unresponsive to changes in transmissivity. Changes in net river flux produced by variations in evapotranspiration parameters caused equivalent changes in the evapotranspiration component. Subsurface outflow was completely insensitive to changes in net river flux induced by variations in evapotranspiration parameters. Changes in riverbed conductance had little effect on net river flux, subsurface outflow, and evapotranspiration. Variations in mountain-front recharge (boundary flux) had a negative correlation to net river flux and had only a slight positive correlation to subsurface outflow and evapotranspiration.

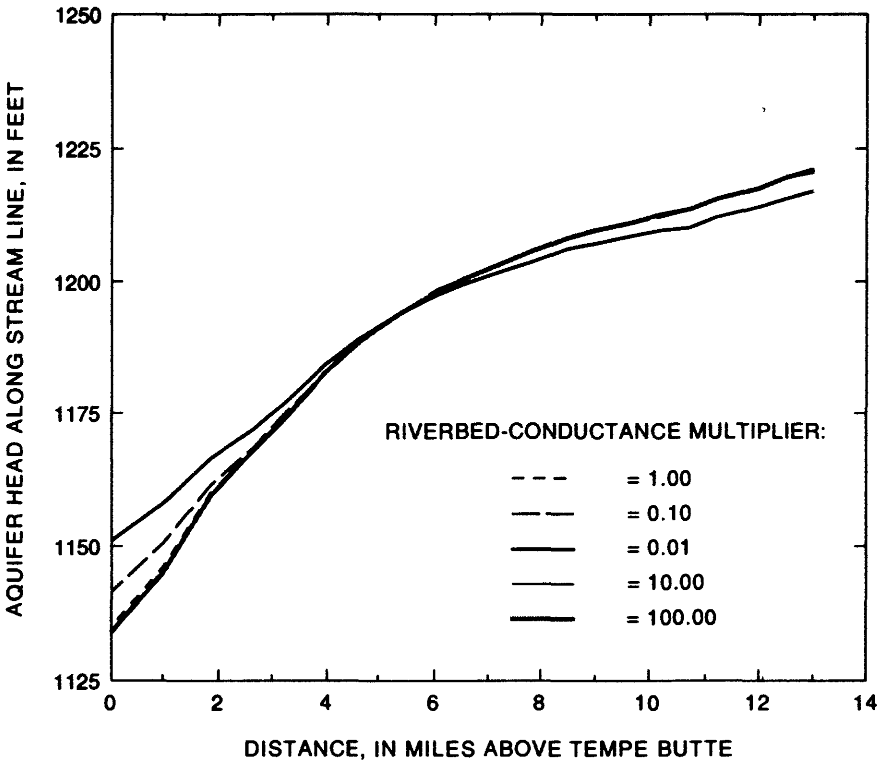


Figure 9.--Sensitivity of stream-line profile to changes in riverbed conductance.

Total recharge from and discharge to the river exhibited strong positive correlations to transmissivity changes. These fluxes, however, were sensitive to decreases and insensitive to increases in riverbed conductances. Increases in evapotranspiration rates and extinction depths reduced the discharge to the river and increased the recharge from the river and the net-river flux.

The flow-component sensitivity results are compatible with the head-sensitivity results and suggest that the simulated predevelopment scenario was reasonable and that the emphasis placed on the well data during the calibration process was appropriate. Net river flux and evapotranspiration along the flood plain had little influence on regional-head configurations outside the flood plain, as suggested by the insensitivity of the head profile and head residuals to most variations in evapotranspiration parameters and riverbed conductance. Head configurations were most sensitive to changes in boundary fluxes and regional variations in transmissivity.

SUMMARY

The Salt River Indian Reservation is in an area of broad desert plains separated by rugged mountains and is transected by the Salt River. Ground water occurs mainly under unconfined conditions in unconsolidated to

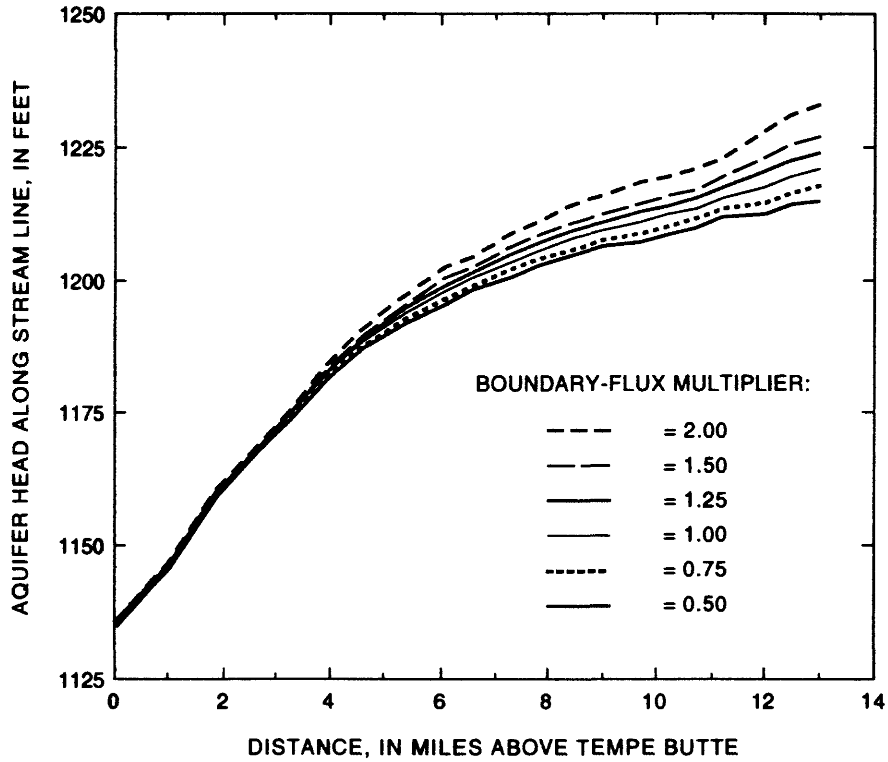


Figure 10.—Sensitivity of stream-line profile to changes in boundary-flux values.

variably consolidated sedimentary material that underlies the desert plains. Hydrologic conditions that existed in and near the Salt River Indian Reservation prior to development by non-Indian settlers were investigated. Prior to the 1860's, when modern irrigation began in the Salt River Valley, flow was perennial in the Salt River. The median annual flow at Granite Reef Dam was estimated to be 950,000 acre-ft, and the average annual flow was estimated to be 1,250,000 acre-ft. Ground water was 10 to 70 ft below the land surface in areas developed before 1900. Infiltration from the Salt River maintained water levels at shallow depths, and ground water was discharged into the Salt River near Tempe.

Simulation of the predevelopment ground-water flow indicates that average recharge to the aquifer by infiltration from the Salt River was 19,700 acre-ft/yr. Mountain-front recharge and subsurface inflow was 10,700 acre-ft/yr. Discharge from the aquifer to the Salt River was 9,800 acre-ft/yr, subsurface outflow was 7,300 acre-ft/yr, and evapotranspiration from ground water was 13,300 acre-ft/yr.

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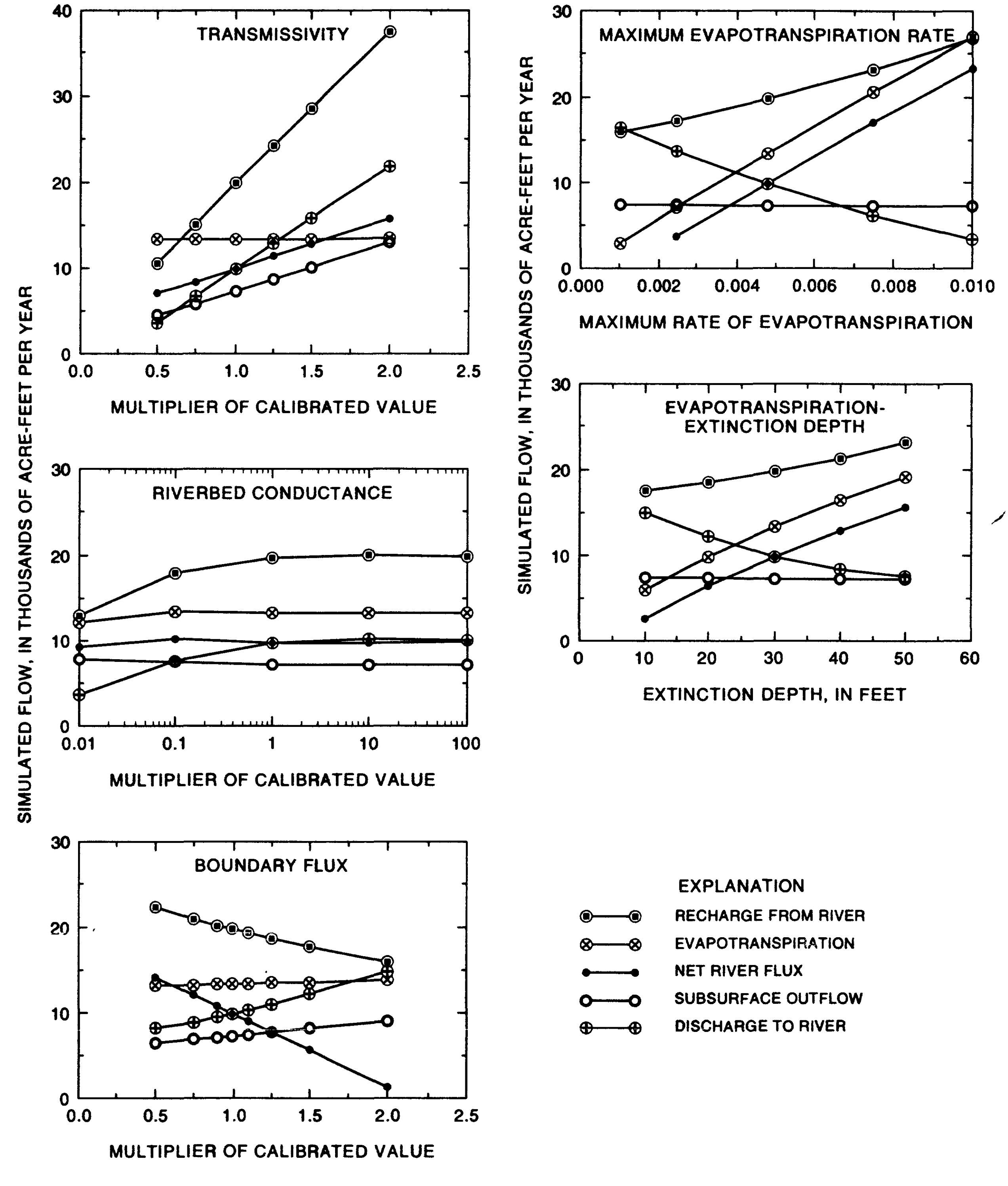

Figure 11.--Model sensitivity to changes in transmissivity, riverbed conductance, boundary-flux values, evapotranspiration rate, and evapotranspiration-extinction depth.

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Second Edition

By Henry P. Walker and Don Bufkin

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The Wagonmasters: High Plains Freighting from the Earliest Days of the Santa Fe Trail to 1880 (Norman, 1966)
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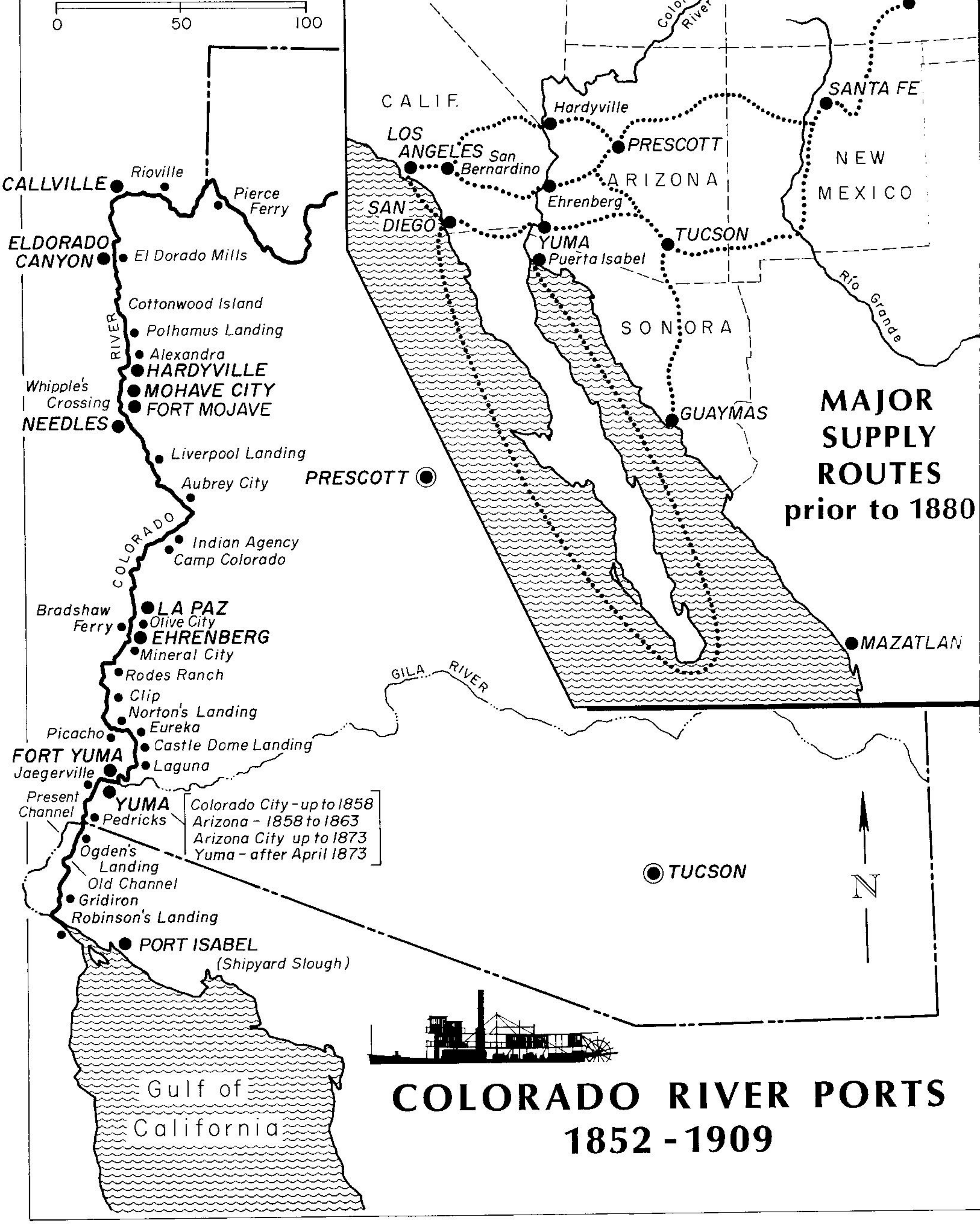

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CALLVILLE
Rioville
Pierce Ferry
ELDORADO CANYON
El Dorado Mills
Cottonwood Island
Polhamus Landing
Alexandra
HARDYVILLE
MOHAVE CITY
FORT MOJAVE
Whipple's Crossing
NEEDLES
RIVER
Liverpool Landing
Aubrey City
PRESCOTT
COLORADO
Indian Agency
Camp Colorado
Bradshaw Ferry
LA PAZ
Olive City
EHRENBERG
Mineral City
Rodes Ranch
Clip
Norton's Landing
Eureka
Picacho
Castle Dome Landing
FORT YUMA
Laguna
Jaegerville
Present Channel
YUMA
Pedricks
Colorado City - up to 1858
Arizona - 1858 to 1863
Arizona City up to 1873
Yuma - after April 1873
Ogden's Landing
Old Channel
Gridiron
Robinson's Landing
PORT ISABEL
(Shipyard Slough)
Gulf of California
GILA RIVER
TUCSON
N
CALIF.
Hardyville
LOS ANGELES
San Bernardino
PRESCOTT
ARIZONA
Ehrenberg
SAN DIEGO
YUMA
Puerta Isabel
TUCSON
SANTA FE
NEW MEXICO
Río Grande
SONORA
GUAYMAS
MAZATLAN
MAJOR SUPPLY ROUTES prior to 1880
COLORADO RIVER PORTS
1852 - 1909

39. COLORADO RIVER PORTS AND MAJOR SUPPLY ROUTES

ARIZONA WAS FORTUNATE in that before the arrival of the Southern Pacific Railroad in 1877 it had several routes over which supplies and machinery could be brought in by wagon or river steamer.

By far the most important line of supply was the Colorado River. Under the Treaty of Guadalupe Hidalgo, American vessels could ply the river without interference by Mexican authorities. Thus, goods imported via the river avoided the ruinously high Mexican import duties. Goods were brought to the mouth of the river in ocean-going ships and were transferred to shallow-draft river steamers. These steamers varied from the *Uncle Sam*, with a capacity of thirty-five tons, to the *Mohave II* at over one hundred tons. The steamers often towed one-hundred-ton barges. In the 1870's six steamers and five barges were in operation. Repair shops and a dry dock were built at Port Isabel at the mouth of the river.

The practical head of navigation was at Hardyville. In seasons of high water, steamers reached Callville, at the mouth of the Vegas Wash, or even Rioville, near the mouth of the Virgin.

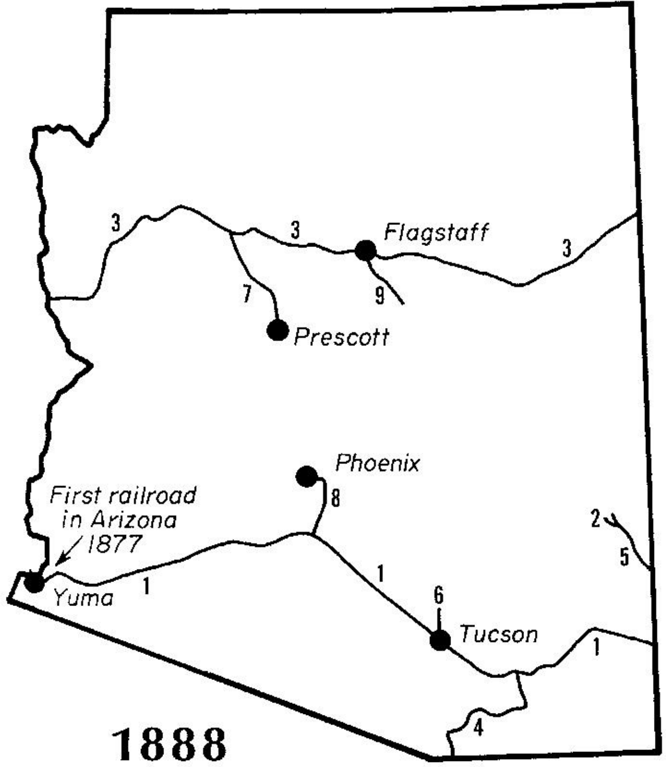
Yuma was the chief port from which supplies were hauled by wagon to all of Arizona south of the Gila and Salt rivers. Although it was only 80 air-line miles from the river's mouth, the meandering of the stream made the distance some 170 miles by steamer. About seventy miles north of Yuma, La Paz was the port for central Arizona. In 1869 a shift of the river channel left La Paz high and dry, and Ehrenberg, about three miles to the south, took its place. Hardyville, some three hundred miles upstream from Yuma, was the distribution point for the mines of the northwest and was connected to Prescott by a toll road.

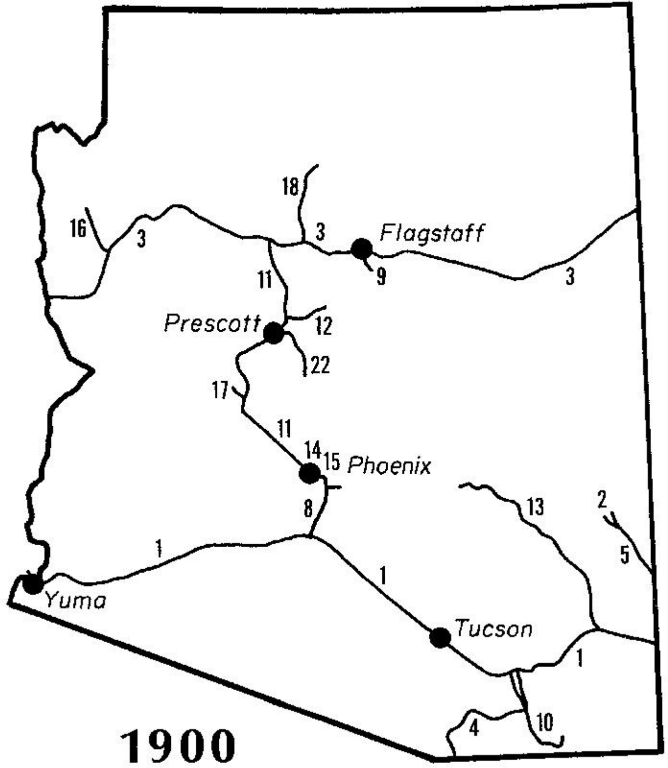
In addition, there were numerous landing places on both banks of the river that served single mines or groups of mines, some as far back as twenty miles from the river. Throughout most of the territorial period the legislature memorialized Congress for money for the improvement of navigation on the Colorado River.

From the east a small trickle of supplies came from the Texas coast as early as 1856, when Charles D. Poston imported mining machinery and supplies for the mines near Tubac. Other merchandise came from the Missouri Valley over the Santa Fe Trail. These routes both involved distances of over one thousand miles. As the railroads pushed west after the Civil War, goods were brought by wagon from successive railheads, and crudely smelted copper and lead were shipped east.

A natural road led northward from the port of Guaymas, Sonora, on the Gulf of California. Before the Civil War the Tubac mines were given permission to ship their silver through Guaymas duty free, but political strife in northwestern Mexico discouraged much use of this route. During the Civil War arrangements were made with Governor Ignacio Pesqueira of Sonora to move government supplies from Guaymas to Tucson without payment of import duties. Until 1877 civilian goods came in over the same route at only 5 per cent of the usual Mexican duties. When the central government took full control of the Guaymas customs house, the red tape involved in getting permits from Mexico City discouraged use of this route.

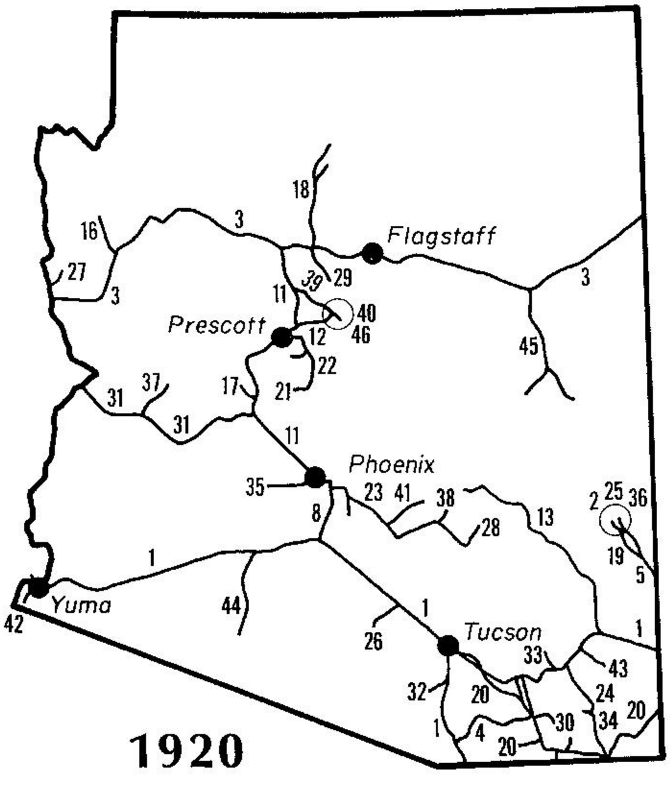
There were also routes leading from the Pacific Coast. The citizens of San Diego County, which reached east to the Colorado River, raised several thousand dollars to improve the road to Yuma. Another wagon route ran from San Bernardino to either Ehrenberg or Fort Mohave. The great drawback of these routes was that about one-half of the weight capacity of the teams had to be devoted to carrying water and forage for the animals while crossing the California desert.

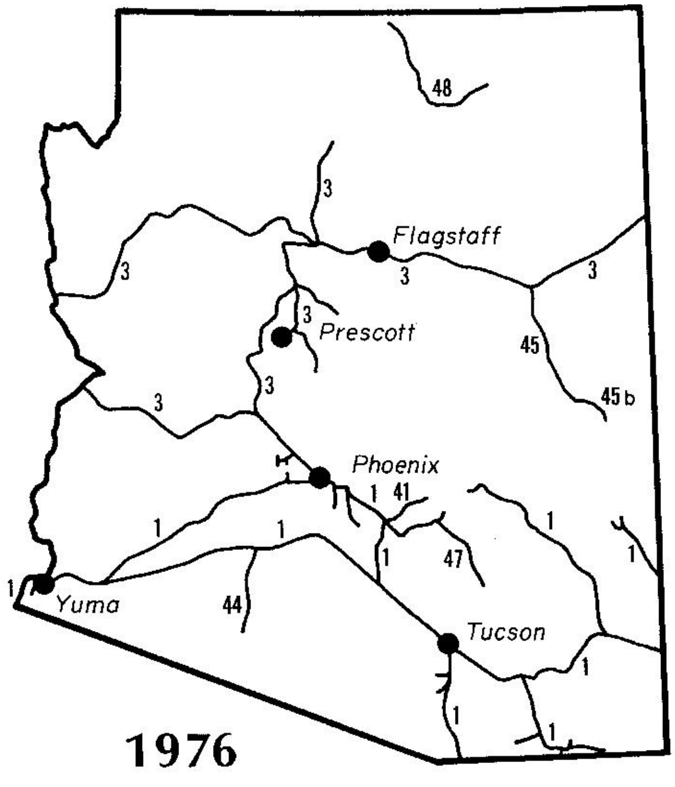




Refer to numbered table for key to maps

1888, 1900 & 1920 maps show existence of railroads by their initial corporate names. The 1972 map indicates current operating company.





RAILROAD DEVELOPMENT

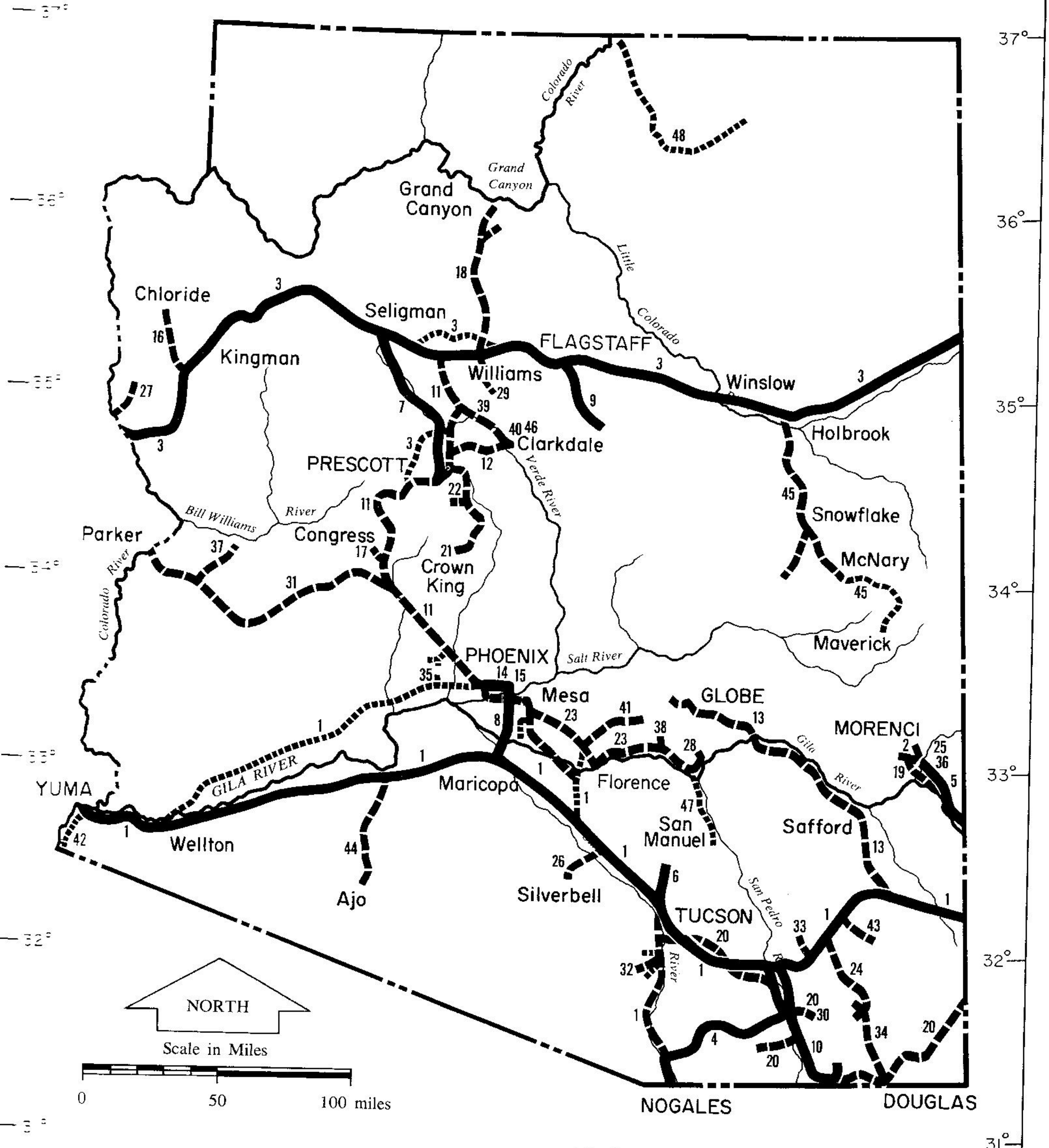
46. RAILROAD DEVELOPMENT

Much of the early exploration and mapping of Arizona was done in anticipation of building a railroad from the Mississippi River to California (Map 23). However, it was not until 1877 that the Southern Pacific Railroad reached the western border at Yuma and four years later that it connected with the Texas Pacific east of El Paso. The second line to cross the territory was the Atlantic & Pacific (later the Atchison, Topeka & Santa Fe), which built west from Albuquerque in 1880 and reached the Colorado in 1883.

The four decades between 1880 and 1920 was a period of great activity in railroad building. Lines were projected, and some were built to provide north-south links between the two major lines, but most of the new roads were designed to serve the mining industry.

Number on Map	Company Name	Year of First Service to Any Part of Arizona
1	Southern Pacific	1877
2	Coronado	1879–80
3	Atlantic & Pacific	1881–83
	3a Santa Fe Pacific	1897
	3b Atchison, Topeka & Santa Fe	1902
4	New Mexico & Arizona	1881–82
5	Arizona and New Mexico	1883–84
	5a Clifton & Southern Pacific (New Mexico)	
	5b Clifton & Lordsburg (Arizona)	
6	Arizona Narrow Gauge	1886
	6a Tucson, Globe & Northern	
7	Prescott & Arizona Central	1886
8	Maricopa & Phoenix	1887
9	Arizona Mineral Belt	1887
	9a Central Arizona	
10	Arizona Southeastern	1888–89
11	Santa Fe, Prescott & Phoenix	1893
12	United Verde & Pacific	1894
13	Gila Valley, Globe & Northern	1894–98
14	Maricopa and Phoenix and Salt River Valley	1895
15	Phoenix, Tempe and Mesa	1895
16	Arizona and Utah	1899
17	Congress Consolidated	1899
18	Santa Fe & Grand Canyon	1901
	18a Grand Canyon Railway	
19	Morenci Southern	1901
20	El Paso & Southwestern	1901
21	Bradshaw Mountain	1902–1904
22	Prescott & Eastern	1898
23	Phoenix and Eastern	1903
24	Arizona & Colorado	1903–1909
25	Clifton & Northern Railroad	1903
26	Arizona Southern	1904
27	Mohave & Milltown	1904
28	Arizona Eastern	1910
29	Saginaw Southern	1904
30	Tombstone & Southern	1905
31	Arizona & California	1905
32	Twin Buttes	1906
33	Johnson, Dragoon & Northern	1908
34	Mexico & Colorado	1909
35	Phoenix and Buckeye	1910
36	Shannon-Arizona	1909
37	Arizona & Swansea	1910
38	Ray & Gila Valley	1900, 1910
39	Verde Valley	1913
40	Verde Tunnel & Smelter	1914
41	Magma Arizona	1915
42	Yuma Valley	1914
43	Mascot & Western	1915
44	Tucson Cornelia & Gila Bend	1916
45	Apache Railway	1918–1919
	45a Southwest Forest Industries	
	45b White Mountain Scenic (operated on lumber railroad connecting with the Apache Railway)	
46	Arizona Extension	1918
47	San Manuel & Arizona	1955
48	Black Mesa & Lake Powell	1971–72

NOTE: The complete story of railroads in Arizona is quite complex. The purpose of this listing is to provide a chronology of railroads based on their original corporate names. The date given is for the year of first service in Arizona. No attempt has been made to indicate acquisition and consolidation of the initial lines into the larger roads, nor has any attempt been made to provide dates of abandonment for those routes no longer in existence.



RAILROADS

Legend

CONSTRUCTED 1877 to 1890 — CONSTRUCTED 1891 to 1920 — CONSTRUCTED 1921 to 1970

47. RAILROADS

Following the completion of the two transcontinental railroads, several connecting links were built by local businessmen. The Maricopa & Phoenix was built in 1887 to connect Phoenix to the Southern Pacific. In the preceding year Prescott was tied in to the Atlantic & Pacific at Seligman by the Prescott & Arizona Central Railway.

An attempt was made to connect Flagstaff on the Atlantic & Pacific with the mineral district around Globe. The Arizona Mineral Belt laid about thirty-six miles of track and started a tunnel through the Mogollon Rim, but then funds ran out. Another attempt to reach Globe was the Arizona Narrow Gauge, which laid about ten miles of track out of Tucson before the company went bankrupt. Changing the name to the Tucson, Globe & Northern Railroad did not help.

Possibly the most interesting railroad in Arizona was the Coronado, a twenty-inch narrow-gauge line built in 1879 from the Longfellow Mine to the smelter at Clifton. The empty cars were hauled up to the mine by mules and were run down to the smelter by gravity with the mules riding on platforms on the cars. Then a steam locomotive was built in Baltimore, shipped by rail to Las Animas, Colorado, and thence by ox-wagon to Clifton. A second locomotive made the trip around the Horn to San Francisco, thence in another ship to the mouth of the Colorado River, up to Yuma by river steamer, and finally to Clifton by wagon.

Most of the trackage in the complexes east of Prescott, east of Phoenix, and southeast of Tucson was laid to provide cheap transportation for the big mining districts. In fact, the real development of Arizona's mining industry had to await the arrival of the railroads.

There were some exceptions. The Apache Railroad was designed primarily to haul lumber out of the forests of the Mogollon Rim country. The Santa Fe & Grand Canyon provided transportation for tourists visiting the Grand Canyon. The newest line in the state is the Black Mesa & Lake Powell, which carries coal from the Black Mesa coal fields to an electric power generated plant.

In 1881–82 the Atchison, Topeka & Santa Fe built the New Mexico & Arizona from Benson to Nogales, connecting with the Sonora Railway to Guaymas on the Gulf of California.

The Southern Pacific laid a new line from Wellton to Phoenix in 1926, thus finally putting the state capitol on a main line. A few short spurs have been built in recent years to provide access to new mines such as the Twin Buttes Mine some twenty-five miles south of Tucson.

When Arizona became a state in 1912 it had 1,675 miles of railroad track, and by 1930 the total had grown to 2,524 miles. Since then there has been a steady decline as a result of the development of the automobile and truck as well as the closing of a number of mines because the ore had been mined out. A number of short-line railroads have been closed down as common carriers but continue to operate as "factory facilities" to move ore from mine to concentrator or smelter.

The Ribbon of Green

Change in Riparian Vegetation in the Southwestern United States

Robert H. Webb, Stanley A. Leake, Raymond M. Turner
Principal photography by Dominic Oldershaw

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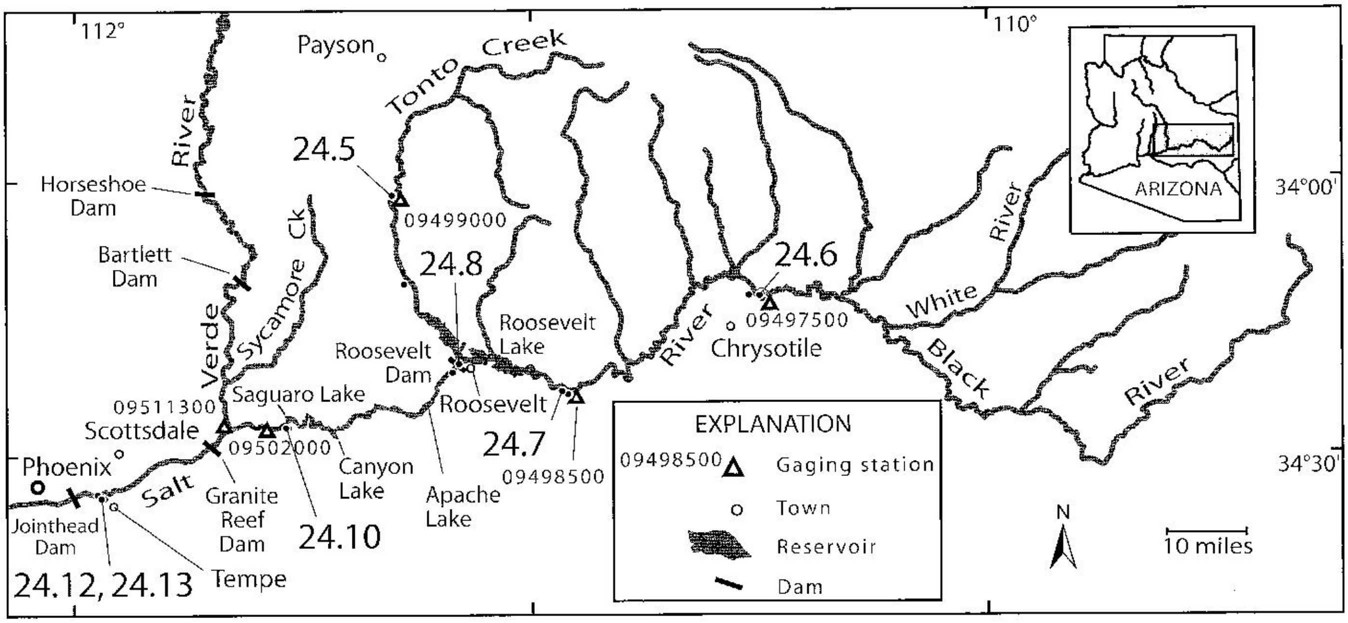

Figure 24.1 Map of the Salt River in central Arizona.

1976 exceeded a bankfull discharge threshold of 175,000 ft^3/s on the Salt River upstream from Tempe.[10] In A.D. 899, the Salt River reportedly yielded 2.5 million acre-feet of runoff, based on tree-ring reconstructions,[11] and a flood with a peak discharge of 420,000 ft^3/s occurred at about this time.[12] The long-term average flow volume of the Salt and Verde Rivers at gaging stations upstream from the Salt River Valley is 1.2 million acre-feet per year,[13] and the largest measured flood, in February 1891, had a peak discharge of about 300,000 ft^3/s (see the next section).

The combined flow of the Salt and Verde Rivers has created some of the most devastating floods in Arizona history. For example, in February 1890, the Salt River rose 17 feet, washing out the bridge at Tempe and damaging floodplain structures all the way to Yuma.[14] In February 1891, the river rose one foot higher than this and flooded a swath of the valley up to 8 miles wide. The 1891 flood on the Salt River, with a peak discharge estimated to be 300,000 ft^3/s,[15] had serious consequences for the fledgling town of Phoenix; the floodwaters reportedly destroyed one-third of the town.[16] Floods that caused inundation or other damage occurred in September 1897, January 1905, March 1905, January 1916, November 1919, and March 1938.[17]

Despite the presence of dams upstream on both the Salt and the Verde Rivers, floods in the last quarter of the twentieth century were severe through Phoenix. Generated mostly upstream in the Salt River (fig. 24.2), these floodwaters combined with waters pouring down the Verde River to create truly awesome floods through the urban area. In March 1978, floodwaters peaked at 125,000 ft^3/s through Phoenix, and on January 8, 1993, the peak discharge was 129,000 ft^3/s (see fig. 24.11). The need to protect floodplain structures, such as bridge abutments, and to increase the area for development next to the river drove channelization of the river and the installation of soil cements on its banks.

Flow Regulation and Groundwater Development

The first diversion of the Salt River for irrigation purposes occurred in 1885.[18] This structure paled in comparison to what came next: Granite Reef Dam (1908), Roosevelt Dam (1911), Mormon Flat Dam (1926), Horse Mesa Dam (1927), and Stewart Mountain Dam (1930). Other dams on the Verde River (see chapter 23) completed the full regulation of the Salt River by 1946. Roosevelt Dam, originally called Tonto Dam because it was built at the mouth of Tonto Creek, impounds Theodore Roosevelt Lake and flooded the town of Roosevelt. In 1959, the dam was renamed for President Theodore Roosevelt. The original dam, 284 feet high, was raised to a height of 357 feet in a project completed in 1996.[19] Downstream from the former town of Roosevelt, the Salt River is completely regulated for the purposes of flood control, irrigation, and domestic water supply for the Salt River Valley.

The SRP, which began in 1903 as part of the Salt River Valley Water Users Association,[20] delivers a little less than one million acre-feet per year of water to central Arizona, primarily to Phoenix and its suburban satellite communities.[21] It also produces hydroelectric power from the dams it manages: potential power production of 36 megawatts (MW) from Roosevelt Dam; 129 MW from Horse Mesa Dam and its pumped storage unit; 60 MW from Mormon Flat Dam and its pumped storage unit; 13 MW from Stewart Mountain Dam;, and a combined output of less than 5 MW from several small structures on canals. The combination of flood control, water storage, and power generation makes this complex of dams on the Salt River extremely important to Arizona's development and economy.

Despite the abundance of surface-water diversion for irrigation, groundwater pumping in Arizona began to