Navigability of the Santa Cruz River

by

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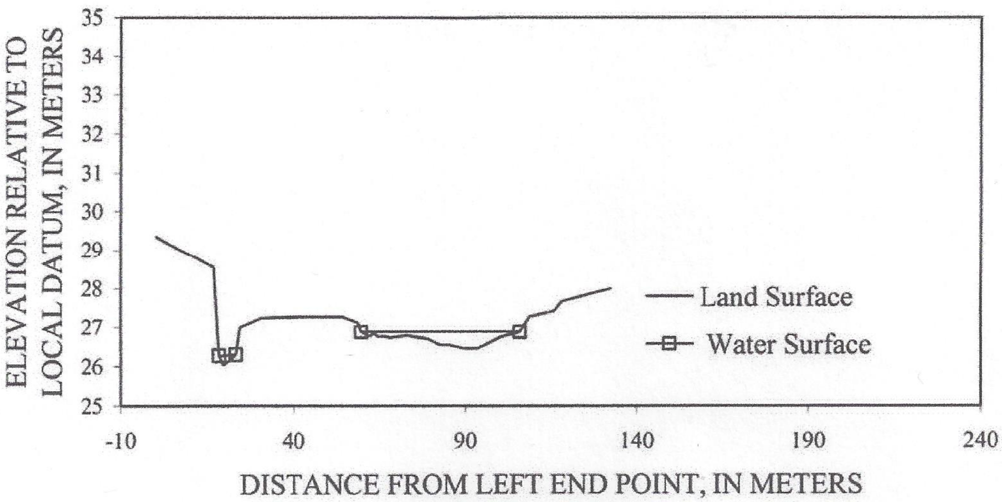

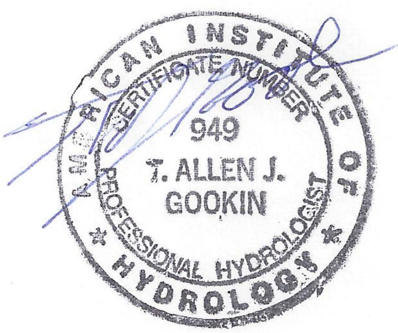

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I. INTRODUCTION

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 main stem of the Santa Cruz River. The purpose of this report is to review the report by Hjalmarson entitled "Navigability Along the Natural Channel of the Santa Cruz River" ("Report") and the "Declaration of Rich Burtell" ("Declaration").

This report addresses the following:

- **History of Navigation** on the Santa Cruz River (Chapter II)
- Was there a **Need for Navigation** (Chapter III)
- Determination of **Virgin Flows** (Chapter IV)
- Determination of the river's **Width** (Chapter V)
- Determination of the river's **Depth** (Chapter VI)
- Determination of whether navigability **Criteria** are met (Chapter VII)

A. LEGAL CRITERIA

Several court cases are of importance in determining the navigability of the Santa Cruz River. The three primary cases are *State v. Arizona Navigable Stream Adjudication*

Commission[1] ("Arizona Appellate Decision"), *PPL Montana, LLC v. Montana*[2] ("Montana Decision"), and the *United States v. Utah*[3] ("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, suggests 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 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. This topic of "ordinary" will be addressed in chapter IV which deals with the hydrology of the Santa Cruz River. "Natural" has more to do with the channel itself. What is the channel in its natural condition? This topic of "natural" is addressed in chapters V and VI.

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

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[1] 224 Ariz. 230.
[2] 132 S.Ct. 1215.
[3] 284 U.S. 64.

particularly important for the Santa Cruz River. However, the Santa Cruz River does have, based on the basic geomorphology and political boundaries of the River, three very clear and distinct reaches that probably should be considered separately. These are the Upper, Middle, and Lower Reaches. This report will deal primarily with the Middle Reach because it is obvious that, and everybody agrees that, the Upper or Lower Reaches are not navigable.

The Upper Reach of the Santa Cruz River begins at its headwaters, goes into Mexico, and ends at the United States/Mexican border. The flows in the Arizona segment of the Upper Reach are very small and as such are clearly non-navigable. The flows in the Mexico segment of the Upper Reach are beyond the jurisdiction of this Commission and are ignored in this report.

The Middle Reach of the Santa Cruz River is the primary point of controversy regarding navigability. Based on the volume of flow, the manner in which the Santa Cruz channel handles the flow varies on the location along the Middle Reach. The Middle Reach of the Santa Cruz was perennial in some segments and intermittent/ephemeral in other segments. The beginnings and ends of these segments are not exact but are based on the characteristics of flow in that segment. The segments are:

- The Nogales Segment: the perennial portion that begins at the U.S./Mexican border and goes to roughly the Santa Cruz County/Pima County border.

- The Continental Segment: the intermittent/ephemeral section that goes from the end of the Nogales Segment to San Xavier.
- The Tucson Segment: the perennial section that picks up at the end of the Continental Segment and continues through Tucson to Marana.
- The Picacho Segment: The intermittent/ephemeral section that goes from Marana to near Picacho Peak.

The Lower Reach of the Santa Cruz River is the rest of the river from near Picacho Peak to its junction with the Gila River. In predevelopment times, this reach of the Santa Cruz was ephemeral with the exception of the portion of the Santa Cruz on the Gila River Indian Reservation. This wet area on the Reservation was a combination of cienega and a dense thicket of mesquite known as the "New York Thicket". During a period known as the "Starving Decade", due to upstream diversions causing a failure of farm crops on the Reservation, the Pimas were forced to destroy the mesquite thicket by cutting and selling the mesquite wood to non-Indians in order to eat.

II. NAVIGABLE IN FACT

The primary facts normally used by the Courts to determine navigability are whether or not the river has actually been navigated for commercial purposes historically. If the river has been successfully navigated under the correct legal conditions, 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. 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.

There seems to be little disagreement that there is no history of commercial navigation on the Santa Cruz River.

A. THE HOKOKAM

Virtually anybody who has lived in Arizona for an extended period of time has heard of the Hohokam. 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 an analysis of the evidence concerning the Hohokam.[1] Most importantly, ANSAC found that no evidence was presented that the Hohokam traveled by water.[2] I am unaware of any additional materials that have been submitted

[1] ANSAC 2006 pg 19-20.
[2] ANSAC 2006 pg 20.

recently that suggest otherwise. Neither Hjalmarson nor Burtell address this period as it relates to the Santa Cruz River.

One additional piece of evidence regarding navigability of the Santa Cruz River comes from the University of Arizona in discussing the pottery of the Hohokam:

> A common Hohokam design painted on pottery depicts a walking figure with a hiking staff, carrying a bundle on his back. This figure is often referred to as the "burden basket carrier" and may be a trader. Since earliest times, the Hohokam were active traders. They received goods from western New Mexico, most of Arizona, and the coasts of California and Mexico, as well as from the more advanced cultures of west-central Mexico.[3]

The concept that the traders were recorded on the pottery, but boats were not, is an additional indication of the Hohokam reliance on trade by walking.

The Hohokam irrigation development was substantial, which leads to the question; did the Hohokam ruin the river in their time so as to preclude navigation? It is almost certain that there would have been times during the period of the Hohokam development that the irrigation would have negated the ability of traders to use the water for navigation up and down the Santa Cruz River. However, the Hohokam period lasted between 1,000 and 1,700 years. The Hohokam canal system did not occur overnight. It was not like modern day irrigation projects today where the farmers get a loan from the federal government and ten years later the project is fully built. These Hohokam canals were dug by hand and started from scratch. There would have been lengthy periods where the rivers would have been virtually unaffected by

[3] Gregonis and Reinhard no page.

diversions due to the small amount of those diversions. If the Hohokam could have navigated they would have, but they did not; the Hohokam chose to walk.

Fuller documents that the Hohokam did not use boats when he states:

> Thus, the archaeological record suggests that the Santa Cruz River was marginal for irrigation agriculture using prehistoric agricultural technologies and that the most extensive use of the river for irrigation occurred in historic times. The prehistoric peoples of the Santa Cruz River valley traded in shell, ceramics, and presumably other items. The well-documented use of the river as a transportation and settlement corridor in historic times is materially manifest in the chain of missions, presidios, and other communities along the river that have been investigated by historical archaeologists. Despite all of this archaeological work, however, no archaeological evidence of navigation along the Santa Cruz River has been found.[4]

B. PIMA OCCUPATION

The Pimas lived in the Santa Cruz Valley when the Spaniards arrived. The Pimas believe they are descendants of the original Hohokam who survived whatever disaster collapsed the Hohokam civilization in the mid 1400s. Certainly much of the Pima culture mirrors the Hohokam culture. ANSAC correctly concludes that there were Pima survivors in the Santa Cruz area after the Hohokam.[5] In my research I could not find any reference to navigation of the Santa Cruz by the Pimas. Spanish explorers, while often traveling the Santa Cruz river also did not appear to use water craft.

C. ANGLO-AMERICAN IMPACT

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[4] Fuller et. al. 2004 Exhibit 019 Section 2 pg 32.

[5] ANSAC 2006 pg 20.

This section deals with the activities of pre-development conditions along the Santa Cruz River during the early 1800s. The Arizona Appellate Decision indicates that the river must be considered in its "ordinary and natural" condition. By 1912, the Santa Cruz River flow had been artificially depleted. But the channel, which did change dramatically due to the major flood in 1890, did so for natural reasons. As Hjalmarson correctly states: "The Santa Cruz River constructed its own geometry between river mile 78 in the Picacho area to river mile 180 at the Mexican border.".[6]

There was no successful boating along the Santa Cruz River in the pre-Statehood period, except on manmade lakes. There was one brief boating attempt on the Santa Cruz River during a flood in 1914.[7] The boating attempt successfully floated from Nogales to Tubac where the Santa Cruz River failed. As Fuller concluded: "The river was much too shallow most of the time for small boats, even in the perennial stretches."[8]

[6] Hjalmarson 2014 pg 4.
[7] Fuller 2004 pg 3-6.
[8] Fuller 2004 pg 12.

III. NEED FOR NAVIGATION

. Because the Santa Cruz River has not been successfully navigated, generally speaking, the river is not navigable. There are two components to the navigability doctrine (for title purposes), first whether the river in question was commercially navigated. As chapter II discussed there is no evidence that it was. 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 which to trade.

The need for navigation in the Santa Cruz River area cannot and has not been disputed. This is the first area of Arizona to develop. Humans occupied the area for many thousands of years. Irrigation in the Santa Cruz River area with villages and towns has existed for well over a thousand years. We are fairly certain that the Hohokam traded but not by boats on the Santa Cruz. We know the Pimas traded, but not by boats on the Santa Cruz. There are historical records dating back around 400 years. We know that a fortified area (Presidio) called Tucson and another fortified area called Tubac were established in the 1700s. Yet the records indicate that, not only did commercial navigation not occur, there was no use of the river for military navigation to provide supplies to the outposts. The United States established forts in the Santa Cruz River area in the 1800s. Again, there is no historical mention of commercial navigation or military navigation. These facts were decided in ANSAC's last Santa Cruz Decision.[1] Mr. Burtell's Declaration documents these points thoroughly.

[1] ANSAC 2006 pg 19-26.

IV. HYDROLOGY

As discussed in chapter III, the Santa Cruz River was not navigated despite an historic need to do so. This appears to meet the test required by the Utah Decision for the Santa Cruz River to be declared non-navigable. This chapter begins the process of answering the question of why the Middle Santa Cruz River was not navigated. In order to determine whether a river is susceptible of navigation, there are many factors that need to be considered, but two factors tend to overshadow the other factors. One factor is the amount of water in the river channel, and the second factor is the shape and size of the river channel. This chapter deals with how much water would have been in the Santa Cruz River channel under "ordinary and natural" conditions as of the date of Statehood.[1] There are three specific elements in Hjalmarson's discussion of available flow. Specifically, this chapter discusses what the natural average flow was, the natural base flow, and the natural flow-duration curve.

The Arizona Appellate Decision addressed the words "ordinary" and "natural" separately. "Ordinary" is defined as "occurring in the regular course of events; normal; usual".[2] The Arizona Appellate Court also defines "ordinary" as "customary".[3] The primary thrust of the definitions and the further explanation by the Arizona Appellate Court indicates that navigability is not prevented by unusual droughts, nor does

[1]224 Ariz. 230 pg 24.
[2]224 Ariz. 230 pg 24.
[3]224 Ariz. 230 pg 24.

boating in usually high river flows prove navigability. Normal, or "usual," means that most of the time, a percentage of the time far greater than 50%, but somewhat less than 100%, you would expect to have the conditions indicated. In hydrology, this would represent a range of values. The low end of the range would probably be what is called the base flow because the base flow is dependable and you would usually expect to see at least that much water on any but the driest of days. Baseflow is best shown by the flows, other than in direct response to rainfall or snowmelt, during the summer, usually in June.

The high end river flows are too fast to be navigable. There is no question that during high flows or flood flows there is plenty of depth and plenty of width in the river. The acceptable velocity of water for navigation is primarily dependent on two factors, safety and the ability to transport upstream.

The second term that the Arizona Appellate Court defined is "natural". In the case of river flows, natural flows are what the flows would have been if humans had not been in the region.[4] In hydrology, this is called "virgin flow".

A. AVERAGE VIRGIN FLOW

There are several sources of information that can be used to determine the virgin flow of a river in Arizona. Hjalmarson and I both relied upon the analysis of the so-called "White Book" published by the U. S. Bureau of Reclamation[5].

[4] 224 Ariz. 230.
[5] U. S. Bureau of Reclamation.

The numerous reasons why I prefer the "White Book" (the nickname for a Bureau of Reclamation Report) analysis to any others were presented in my testimony concerning the San Pedro River before ANSAC in August 2013[6] and apply equally to the Santa Cruz River. The "White Book" provides mean annual flow data for the Santa Cruz River at Rillito (aka Cortaro) and the Santa Cruz River at Nogales. Hjalmarson also uses the "White Book", and I agree with Hjalmarson's and the "White Book's" two average values of 29 cfs at Nogales and 60 cfs at Rillito (aka Cortaro).

Hjalmarson also uses the "White Book" and interpolates data using specific drainage areas from within the Central Arizona reach of the "White Book" to acquire the average flow at the mouth of the Lower Santa Cruz. Hjalmarson's technique for computing the average flow is certainly reasonable. However, Hjalmarson's technique is not the same as the one I have developed over the years based on drainage areas, river vegetation and channel lengths but that difference is not substantive in this context. Hjalmarson and I both conclude the Lower Santa Cruz is not navigable.

Hjalmarson uses the same procedure to interpolate the average flows between Nogales and Rillito (aka Cortaro). I have two problems with Hjalmarson's analysis in the Middle Santa Cruz. First, Hjalmarson's arithmetic is wrong (see Appendix A). Second, the proportioning of average flows should only be done, using the "White Book", at points where the Santa Cruz River was perennial or nearly so in the 1914 to

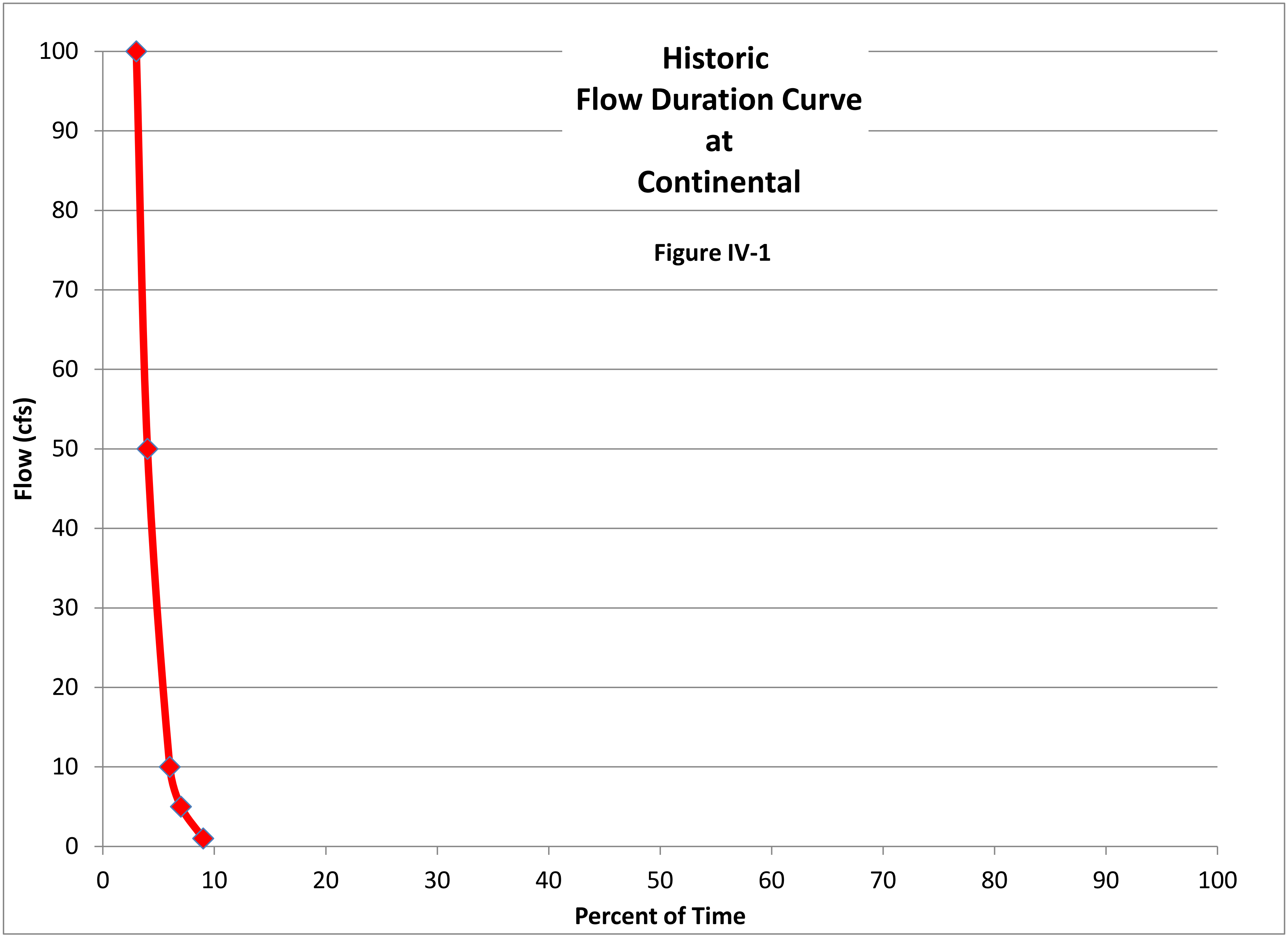
[6] Gookin slide 26-27.

1945 period. Otherwise significant parts of the depleted flow, if it had been present in the Santa Cruz River, could have been flowing underground through the sand. For example, the gage at Continental had an early historic flow of only 1 cfs or greater 9% of the time.[7] As can be seen on Figure IV-1, it does not take much imagination to realize that if the flow-duration curve at Continental is extended, about 90 percent of the time the Santa Cruz River is dry. If upstream depletions had not occurred, a large portion of the additional flow would have disappeared into the ground to wet the river. This water is not gone and, if vegetation or wells do not get the water, then the water will reappear at the next underground barrier. But for that spot in the river, the groundwater interaction with the surface throws the "White Book" values off. As will be discussed in some detail in this chapter's section on the flow curves, the quantities of water disappearing into the sand is greater in the dry sections of the Middle Santa Cruz.

B. BASE FLOW

Hjalmarson uses the Freethey and Anderson plates as a source for the base flow on the Santa Cruz. Freethey and Anderson warn in their document not to use their plates for this level of detail. Freethey and Anderson explain that their three plates are "a conceptual model" that only shows the "magnitude" of the values for base flow.[8]

[7]Hjalmarson 2014 Appendix pg C-7.
[8]Freethey and Anderson Plate 1.


Historic
Flow Duration Curve
at
Continental
Figure IV-1
Flow (cfs)
Percent of Time
0
10
20
30
40
50
60
70
80
90
100

Hjalmarson shows his work in his Appendix C for converting the Freethey and Anderson plates to numbers. Hjalmarson's work is wrong.[9] First, Hjalmarson's totals for the groundwater flows in and out of the various areas on the Freethey and Anderson plates are not equal to the same totals printed on the Freethey and Anderson plates. For example, the Freethey and Anderson plates say that 11,000 acre feet per year flow into and out of area 58. Hjalmarson says the flow in and out of the same area is 4,100 acre feet per year. Second Hjalmarson's proportioning of the Freethey and Anderson pie charts does not relate to the ones printed on the map. Hjalmarson also lists values[10] for baseflow at points that the Freethey and Anderson plates do not have data, specifically at Tubac and Tucson. Hjalmarson shows no baseflow at Rillito (aka Cortaro), even though Freethey and Anderson do show some baseflow at Rillito.

C. FLOW-DURATION CURVES

The key to Hjalmarson's analysis for the Santa Cruz are the flow-duration curves. In Hjalmarson's San Pedro and Lower Gila River reports, I had wondered how Hjalmarson got his values other than the mean, median, and base flow. In Hjalmarson's 2014 Santa Cruz report he assumes the Nogales curve is a typical curve and uses that curve for all locations on the Middle Santa Cruz. Hjalmarson then multiplies the values for the Nogales curve by the ratio of the computed average virgin

[9] See Appendix A (this report).
[10] Hjalmarson 2014 pg C-6.

flow to the average historic flow at Nogales from the "White Book". When Hjalmarson uses the Nogales' flow-duration curve multiplied by a constant to convert the curve to the Virgin flow at a different location, the result shows that there is a baseflow. The historic evidence says there was no baseflow. To fix this problem, Hjalmarson made arbitrary changes to the curve at the 80% and 90% values to get the flow down to zero or the computed baseflow. There are three problems with this process which are discussed below.

1. Plotting of the Nogales Curve

The Nogales Curve is plotted based on the data presented for Nogales by Hjalmarson[11] in his Santa Cruz report. It is obvious from Hjalmarson's figure 5 that the flow-duration curves are plotted by locating certain key values and drawing straight lines in between. The problem is the data[12] show values for 67%, 34%, 19%, 6% and 4% frequency. Ignoring the 6% and 4% points, which may be reflected in the curve (it is hard to tell), the points plotted are at 11%, 15%, 20%, 50%, 80%, and 90%. The 19% point from the data and the 20% point I measured from Hjalmarson's figure 5 are probably the same point (I am just scaling off an enlarged print of the figure 5 curves), but there is no indication as to where the data for the 11%, 15%, 50%, 80%, and 90% points on the graph come from or what happened to the 67% and 34% data

[11] Hjalmarson 2014 pg C-7
[12] Hjalmarson 2014 pg C-7

points that Hjalmarson claimed to use. These two data points are the most critical for the analysis.

If, as Hjalmarson states, [13] he uses the ratios of virgin flow to historic flow to multiply the historic curve, then you would expect the 34% data point, which had an historic value of 5 cfs, to have a virgin flow of 6.9 cfs.[14] Instead it is plotted as being 26 cfs.

It is certainly possible that instead of using the procedure that he explained[15], Hjalmarson just added the 8 cfs baseflow value that he calculated[16] (the difference between the "White Book" average virgin flow and average historic flow converted to cfs)[17] to all values, but then the 34% virgin flow values should be 13 cfs.[18] I cannot approximate the 26 cfs.

The 67% value showed 1 cfs in the source data, but is plotted as being about 12.5 cfs. If the multiplication procedure is used, the resulting value would only be about 1.3 cfs. If the addition procedure is used the resulting value is 9 cfs.

2 Applicability of the Nogales Curve to Other Locations

The Nogales Curve is presented as being a typical curve shape for the Santa Cruz River and was used for all the gaging sites. On many rivers, I would agree with

[13] Hjalmarson 2014 pg 17
[14] Virgin flow is 29 cfs at Nogales. Historic flow is 21 cfs at Nogales. Then 5cfs x (29/21)=6.9
[15] Hjalmarson 2014 pg 17
[16] Hjalmarson 2014 pg C-3
[17] Average Virgin Flow is 29 cfs. Average Historic Flow is 21 cfs.

the approach of using an upstream gage for the pattern to use at downstream locations. This approach does not work on the Santa Cruz from the Continental gage downstream. The reason is the dry reaches which cause the entire river to periodically go underground and reemerge in a totally different pattern.

Specifically, at Continental, Hjalmarson shows the river flow was intermittent. In its ordinary and natural condition, the Santa Cruz channel near Continental would have been dry about 90% of the time.[19] Sam Turner[20] did 12 seepage studies to see the rates at which water goes into the soils. Turner double-checked his results by measuring how fast pools of water left by floods sank into the ground. The results are astounding. Turner found that from Nogales to Chavez,[21]up to 300 cfs would sink into the riverbed.[22] Chavez is located in about the same spot that the early travelers observed the Santa Cruz River went into the sand.[23] From Chavez to Continental, an additional 700 cfs disappeared. This means that the flows at Nogales all disappeared over 90 percent of the time by the time it got to Chavez. This is consistent with Hjalmarson's data[24] that shows there was only more than 1 cfs nine percent of the time. These flows are generally not lost, except to riparian vegetation and groundwater pumping, and reemerge downstream near Tucson. But the reemerging flow will be in a differing pattern than that which flowed at Nogales. The important thing about the

[19] Condes pg A-16
[20] Turner, S.F. pg 50
[21] Chavez is or was about 2.5 to 3 miles north of Tubac.
[22] Turner, S.F. Figure 2
[23] Hjalmarson 2014 pg C-6
[24] Hjalmarson 2014 pg C-7

tremendous potential loss rates is that the upstream diversions were irrelevant to the flow in the dry reach. Ordinary Flows would disappear into the sand with or without upstream diversions. During the floods the diversion dams would wash out.[25] Diversions before the dry reach around Continental would impact the return flow at Tucson but not the Continental dry reach.

3. Artificial Curve Corrections

The curves presented by Hjalmarson have been artificially adjusted. If the reader looks at Figure 5 of Hjalmarson's report (reproduced here as Figure IV-2) and examines the lines at 80%, there is an artificial break at that point in all but the Tucson line. The Continental, Tubac, and Cortaro (aka Rillito) lines are extremely obvious. All three of the lines then head directly to 0 cfs, all at exactly the 90% probability. This adjustment allows the curve shapes to account for the historic observations of the Santa Cruz being dry without forcing the curves above the 80% to dip down to their correct levels. The Nogales and Tubac curves are more subtle and dip down to Hjalmarson's assumed base flow numbers at 90%.

Southern Arizona streams get their water from winter storms and monsoons. Snowmelt on the Santa Cruz is not significant. As we all know, it does not rain very often in Arizona. The base flow, which is the flow that occurs when it is not or has not recently rained, is the only flow for most of the time. Hjalmarson demonstrates his

[25] Hjalmarson 2005 pg 15

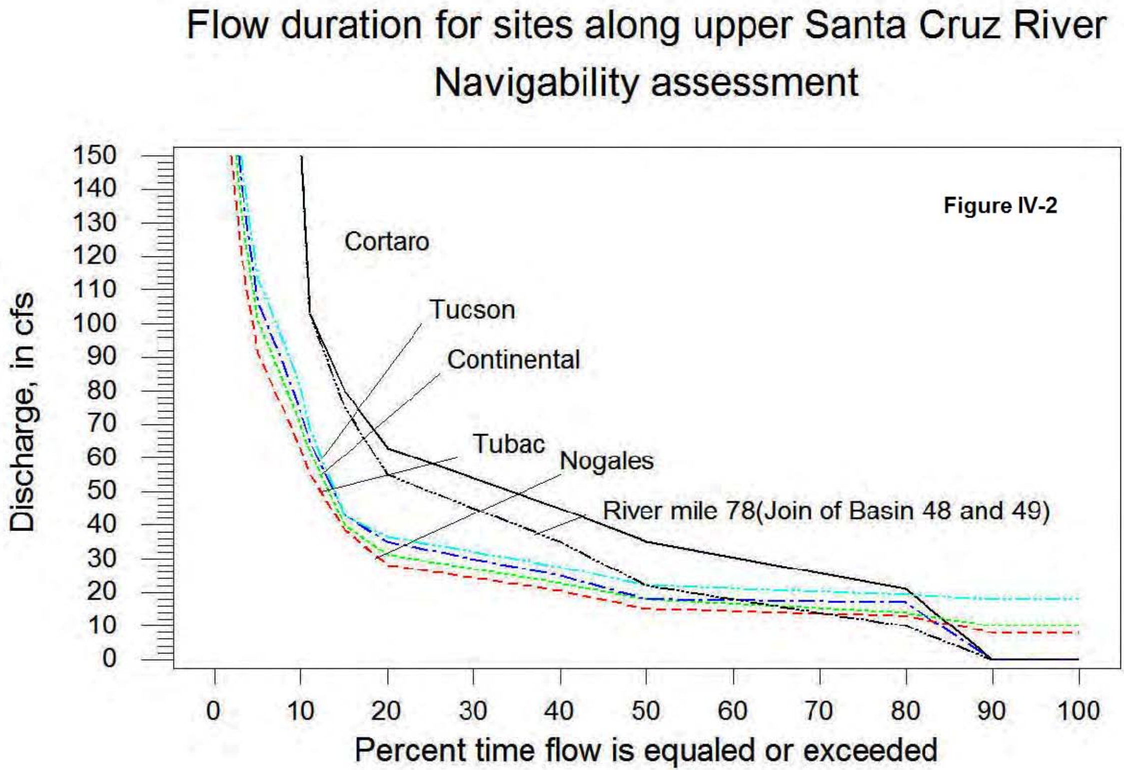


Figure 5. Flow duration relations for middle Santa Cruz River.

knowledge of this fact when he states[26]: "While base runoff is a rather small portion of the mean annual runoff, **base runoff is all or a large amount** of the total runoff **at least 50 percent of the time**."[Emphasis added] Making the artificial reductions at the 80 to 90 percent mark permits Hjalmarson to claim that 75% of the time the river was navigable[27] when the base runoff for the three gages that show zero flow was at or near zero "at least 50 percent of the time."

[26] Hjalmarson 2014 pg 20
[27] Hjalmarson 2014 pg. 5

V. WIDTH

Hjalmarson relies on the Hydraulic Geometry method to compute the widths of the Middle Santa Cruz River at different flows. In his analysis, Hjalmarson overgeneralizes the equation, which is meant to predict widths only at specific points, and uses it for the entire river. The Hydraulic Geometry method results are generally subject to a very large amount of error. Hjalmarson picks the wrong Hydraulic Geometry equations for the Middle Santa Cruz. As a result of the problems noted, the answers Hjalmarson generated for the Middle Santa Cruz do not replicate the channel widths found on the ground. Another way of saying it is that Hjalmarson's model is not calibrated for the Middle Santa Cruz. Each of these topics: Overgeneralization, Error, Wrong Equations, and Calibration are discussed below.

A. OVERGENERALIZATION

The Hydraulic Geometry equation was originally developed to allow a hydrologist to estimate the flow based on a river's width at specific spots on a river. These spots are at point bars. By using the equation to estimate the width, you are determining the widths at narrow points in the river.[1] The equation was never intended to provide widths for the entire river. What matters for navigability is the adverse conditions. While it may be worthwhile to use the equation to determine if the channel has the minimum width required, the equation does not tell you the maximum widths. Usually, the minimum

[1] Gookin 2013 slides 85, 86.

depths will occur where the river is wider. This makes this formula useless for determining minimum depth.

B. ERROR

In surveying, there is a distinction made between mistake and error. The concept of error is also taught in science or engineering classes. Error versus mistake is a valuable distinction in all these disciplines. Mistake is also referred to as blunder or often by less polite names. Error is an inherent part of any measurement. Error is the limitation on the accuracy of whatever measuring equipment or formula is being used. Error is usually expressed as being plus or minus a percentage or a specific value. In hydrology, an error of $\pm$ 10% on flow measurements is considered good.[2]

In some of Hjalmarson's referenced criteria for navigability, there are requirements of field inspection. It is not possible to expect that field investigations be made for periods back in time. This does make the use of available historical data very important.

Hjalmarson and I are both registered Professional Engineers. As engineers, we are often faced with dealing with uncertainty. The way uncertainty is normally handled is by safety factors. For example, in hydrology, when you are building a canal or computing a flood elevation you always should, and usually are required, to add freeboard[3]. Alternatively, you can use the error of the formula. The standard freeboard for a

[2]It is actually much more complicated but I know I found it boring and confusing when I had to learn it, so I am oversimplifying here.
[3]Freeboard is a hydraulic safety factor. It is additional depth built in to the canal or floodway.

constructed canal is less than would be appropriate for a natural channel. The freeboard standard for floods is too extreme for an ordinary flow. The best estimate for error, assuming the other problems did not exist, is the error of the formulae used by Hjalmarson.

Error is, by itself, a vague term. Error is usually accompanied by a term called the confidence interval. For example, a term used for a specific confidence interval that is often used by statisticians is "standard error". Standard error means that if you measure a lot of any physical phenomena, you expect 68.2% of those measurements to fall between the values of the mean – (minus) the standard error and mean + (plus) the standard error. In hydrology, standard error is not generally used. Hydrologists generally use a confidence interval that contains 90% or 95% of the measurements. To determine what the 90% confidence interval (which contains 90% of the values) is, you multiply the standard error by 1.45. Then you add the new value to the mean and subtract the new value from the mean. This result provides the range of values. If you use an interval of 95%, you go through the same process except you replace the 1.45 with 1.96. This all assumes a "normal" distribution.

The Hydraulic Geometry method has been used in many studies (?) with varying results. Unlike Hjalmarson's use of the Hydraulic Geometry method, the other Hydraulic Geometry users first calibrated their coefficients, a and b, to conform their equations to the local data. As Hjalmarson points out in an earlier joint report "[a]s of 1994 Arizona has never been calibrated".[4] In my research, I could not find any calibration for Arizona either. As a result, the following error discussion is from hydrologists who had calibrated their equation and should have less error than Hjalmarson's uncalibrated analysis.

In the State of Washington, an effort was made to calibrate the navigability of the rivers in the State. The level needed for navigability was determined by legislative fiat to be 3.5 feet.[5] After the Washington study was calibrated, the 90 percent confidence interval varied from 1.8 to 7.0 feet.[6] That means that when the calibrated Hydraulic Geometry equation says the river is 3.5 feet deep, it is really less than 1.8 feet 5% of the time.[7] It is between 1.8 feet and 3.5 feet an additional 45% of the time.[8] The river was deeper 50% of the time.[9]. Navigation is generally governed by low depths.[10]

Hjalmarson indicated in the San Pedro navigability hearing that the State of Washington study is irrelevant to predevelopment times because it was performed under modern day conditions.[11] It is true that the State of Washington study was performed in post-development times. However, most all studies of Hydraulic Geometry are based on post-development flows. The original discovery of the Hydraulic Geometry method was published by Leopold and Maddock Jr. in 1953 based upon river gage data from

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[4]Thomas et. al. pg 6.
[5]Magirl and Olsen pg 3.
[6]Magirl and Olsen pg 1.
[7](100% - 90% = 10%; 10% ÷ 2 = 5% [to account for ½ being larger and ½ being smaller])
[8]((100% ÷ 2 = 50%) – 5% = 45%)
[9](100% - 45% - 5% = 50%)
[10]The Utah Special Master's Decision correctly state that sand bars generally do not matter since sand in water is so easy to move that, with a little effort, you can get over or through it.
[11]Hjalmarson August 1, 2013 pg 15-16.

numerous rivers.[12] The longest data record used was 48 years long for the Tennessee River at Knoxville.[13] That means the oldest record used dated back to about 1902-1904. During the 48 year Tennessee River study period, Wilber Dam was completed upstream in 1912 and Nolichucky Dam by 1913. Four more dams were built upstream in the 1940s.[14] The Tennessee River at Knoxville record was clearly post-development.

All of the listed information in the Leopold and Maddock Jr. report was from river gage sites. It is very rare or non-existent that the USGS established a gage before Americans were somewhere developing that water source, destroying beavers, or otherwise affecting the river system.

The data used for Leopold and Maddock Jr.'s original Hydraulic Geometry study come from the Deep South and the Midwest.[15] None of the data were located in the Southwest. 75% of the records for the other rivers were less than 20 years old.[16] That means 75% of the data was after the Great Depression started. By that time, we all agree that even the fledgling State of Arizona had dramatically affected its river flows. The Midwest and Southern parts of the United States were well ahead of Arizona in the development of rivers. Stated otherwise, all or virtually all data[17] used in creating and calibrating the Hydraulic Geometry method was from developed rivers.

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[12] Leopold and Maddock Jr. generally.
[13] Leopold and Maddock Jr. Appendix A.
[14] Tennessee Valley Authority no page number.
[15] Leopold and Maddock Jr. Appendix A.
[16] Leopold and Maddock Jr. Appendix A generally.
[17] I only say virtually all because I have not gone through detailed analyses of the development upstream of all the river gages used in the USGS analysis. My expectation is that all would be developed.

The source of the specific adaptation of the equation Hjalmarson used was written in by Osterkamp in 1980. This article by Osterkamp, which provided the specific equations referenced by Hjalmarson, does not include its data. Osterkamp did state that his study was based on work performed in Kansas in the "recent decade" and in "recent years". This work involved studying the processes of channel formation.[18] Osterkamp further indicates that his article was written to integrate the information from several documents "in various stages of preparation".[19]

In short, the error in the State of Washington study was based on a calibration of the formula using post-development data to predict post-development answers. There is no Hydraulic Geometry equation that is based on pre-development conditions.

The State of Washington was not the only study that had large errors. Other studies provide similar large errors. Figure V-1 shows the data. Some of the studies considered alpine areas. These alpine (mountain) studies had consistently smaller errors than other studies. While listed, the alpine studies are of no relevance to the mainstem Santa Cruz River past Nogales.

Examination of all the errors computed by field measurements being compared to the Hydraulic Geometry method shows very high standard errors except for those uses for alpine streams. Many times the 90% confidence interval error exceeds 100%. This is not possible. We cannot have a negative width or a negative flow. This probably means that the distributions of error did not follow a "normal distribution".

[18] Osterkamp 1980 pg 188.

[19] Osterkamp 1980 pg 188-189.

Other Studies of Hydraulic Geometry Error Rates				
State	Standard Error	95% Confidence	Comments	Source:
Montana	58	113.68	Based on Active Channel Width Not Perrenial	Omang et. al. pg 13
Montana	79	154.84	Based on Bankfull Channel Width Not Perrenial	Omang et. al. pg 13
Western	50	98.00	Intermittent	Osterkamp pg 13
Western	75	147.00	Ephemerral	Osterkamp pg 13
Colorado	19.3	37.83	Mountain Streams	Hedman et.al. pg 10
Western	28	54.88	Alpine Streams	Osterkamp pg 13
Missouri	35	68.60	High Silt Clay Bed	Osterkamp and Hedman pg.8
Missouri	56	109.76	Median Silt Clay	Osterkamp and Hedman pg. 9
Missouri	83	162.68	Low Silt Clay	Osterkamp and Hedman pg. 9
Missouri	57	111.72	Sand Bed Silt Banks	Osterkamp and Hedman pg. 9
Missouri	73	143.08	Sand Bed Sand Banks	Osterkamp and Hedman pg. 9
Missouri	54	105.84	Gravel Bed	Osterkamp and Hedman pg. 9
Missouri	24	47.04	Cobble Bed	Osterkamp and Hedman pg. 9
Nebraska	10	19.60	Sandy	Osterkamp and Hedman pg. 12
Nebraska	16	31.36	Sandy	Osterkamp and Hedman pg. 12
Montana	47	92.12	Based on Active Channel Width	Omang et. al. pg 13
Montana	73	143.08	Based on Bankfull Channel Width	Omang et. al. pg 13
Missouri	79	154.84	All Channels	Osterkamp and Hedman pg. 10
Missouri	71	139.16	Low flood to average flow ratio	Osterkamp and Hedman pg. 17
Missouri	59	115.64	High flood to average flow ration (Southwest)	Osterkamp and Hedman pg. 17

Red entries represent Hydaulic Geometry Errors that indicate the depth could be negative

Figure V-1

Unfortunately, the articles and reports do not indicate what kind of distribution occurs. I infer that the distributions were a logarithmic normal distribution but I cannot point to a source that says it. Even if it is a logarithmic normal distribution, the problems compound because statisticians do not agree on how to compute the confidence interval. Differing techniques can give significantly different answers. What the normal distribution confidence interval does tell us is that the Hydraulic Geometry method has huge errors. As Schumm indicated:

> … in a general sense channel width increased downstream as the 0.5 power of discharge, but a prediction of what the width was around the next bend could be in **gross error**, and, therefore recognizing this variability could be of considerable practical significance [emphasis added] .[20]

A more recent source stated:

> Some recent studies do not endorse Leopold and Maddock's conclusion that this [the hydraulic geometry method] is a rational or even a good way of describing cross-sectional adjustment. Some have also questioned whether [the] log-linear model of hydraulic geometry is either appropriate or meaningful.[21]

If the Hydraulic Geometry equation is used, it must not be used to predict exact widths. A substantial error must be added to the width computed to reasonably demonstrate that the river is navigable. Ignoring all the other problems discussed in this report, assuming we had good data for everything, then the proof of width and the resulting depth is only true half the time.

C. WRONG EQUATION

[20]Schumm pg 3.

[21]Garde pg 184.

Hjalmarson picks one equation to represent the entire Santa Cruz River. Due to the changing of the river, there are at least three different river types on the Santa Cruz River where different equations should have been used by Hjalmarson. These river types on the Santa Cruz are Perennial, Braided and Intermittent.

1. Perennial

Hjalmarson's source for his equations develops them for perennial rivers and provides various values based on the soil in the channel. Hjalmarson indicates that the Santa Cruz river is "coarse sand with some silt, clay and gravel."[22] I agree, for the most part. Hjalmarson then uses the formula for gravel rivers.[23]

2. Braided

Of particular importance to the question of navigability is the question of 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 Santa Cruz River. The reason why braided rivers are very shallow is explained by the Osterkamp article used by Hjalmarson:

> [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, velocities also remain nearly constant in the downstream direction.[24]

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[22] Hjalmarson 2014 pg 22. See also pg D-5.

[23] Osterkamp 1980 pg 192. Figure 1 is in metric units, but the exponent would not be affected by a change of units. The exponent of 0.55 is for ~~a~~ "Gravel-bed channels".

[24] Osterkamp 1980 pg 193.

In simpler English, as more water comes in, the river leaves the low flow channel and the river spreads and spreads. This 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 increase.

A braided channel is very wide and has an almost flat bottom with two nearly vertical banks. In that flat bottom, there will be one or more very shallow depressions that the low flows of the river occupy. When the river flow is sufficiently low, the water flows in only one of the low flow channels, and is called a compound channel. If more flow occurs, the river overflows the shallow depression and moves into a secondary low flow channel(s). This river state is called braided. With increasing flow, the river spreads out side to side. Because there are no side restrictions until the river occupies the entirety of the very wide channel, the depths increase very, very little. Then the water depth begins to increase as the rectangular channel begins to fill. This is why the Hydraulic Geometry method "will not give good results in … [b]raided channels"[25].

Portions of the Middle Santa Cruz River at Statehood were a compound channel and/or braided. The GLO surveys show the Middle Santa Cruz as being braided after the entrenchment and around the time of Statehood.[26] Braiding on the Middle Santa Cruz River is also shown on surveys in the 1870s.[27]

[25]Omang et. al. pg 12.
[26]Hjalmarson 2014 pg D-2, ,A-8
[27]Hjalmarson 2014 pg A-6

Hedman and Osterkamp state "[b]raided reaches need to be avoided" in the use of the Hydraulic Geometry method.[28] Omang found that:

> The channel-geometry method will not give good results in stream reaches having the following conditions: … Braided channels... [and] … Channels that have been widened or realigned by an extreme flood.[29]

In early hearings of ANSAC, Stantec Consulting stated:

> In general, these types of channel characteristic methodologies are not accurate when applied to most streams in Arizona because [of] the influence of floods (rather than median flow) on channel geomorphology.[30]

Hjalmarson's source document for the Hydraulic Geometry method warned that "…it is not accurate for channels of most sand-bed streams…"[31] and further that "the most significant effect on channel morphology appears to be the timing of flood events."[32] In Hjalmarson's source, the author, Osterkamp, found that there had been one study found where the Hydraulic Geometry equation had been calibrated for braided conditions. The correct equation for a braided channel is $W=3.0\ Q^{1.0}$ (in metric)[33]. The formula means that as Q (flow) increases, W (width) increases three times. I used this equation and the Hjalmarson assumptions at the bottom of page 19 of his Gila River 2002[34] report and converting the units from metric to the U. S. system. I then substituted

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[28] Hedman and Osterkamp pg 15.
[29] Omang et. al. pg 12.
[30] Stantec Consulting pg 60.
[31] Osterkamp 1980 pg 191.
[32] Osterkamp 1980 pg 191.
[33] Osterkamp 1980 pg 193. Note equation is in metric. $W = a\ Q^b$ where a = 3.0 and b = 1.0 so we get $W = 3\ Q^{1.0}$ or $W = 3\ Q$.
[34] Due to Hjalmarson failing to provide the data he used on the Santa Cruz (as a technical report should) it is impossible to replicate his work. See Chapter VI .

the Hydraulic Geometry method equation into the Manning's equation as Hjalmarson has done. The result is that the depth of the water in a braided channel[35] is always, regardless of flow (including zero flow), 0.155 feet or a little less than 2 inches. The reason for this outlandish result is that when the W=3Q equation is substituted for the W in the Manning's equation, the Q(flow) values mathematically drop out of the equation. At that point, the computation of depth becomes solely related to slope, the Manning's roughness factor (n), and channel geometry shape. Flow is no longer a variable to be considered in the Manning's equation. I do **not** present this answer as being realistic. I use it solely to demonstrate the problems that the Hydraulic Geometry method encounters when it gets used on a braided stream. An engineer is taught that when equations break down in this manner, it is Mother Nature's way of telling you, your procedure is not working.

Hjalmarson's solution to the existence of braiding is to assume braiding goes away very quickly after a major flood. As Huckleberry stated in a chapter of the Fuller Report about the Lower Gila River:

> … [D]ryland rivers do not adjust to gradual changes in flow regime as rapidly as rivers in wetter climates.[36]

On the Upper Gila, Huckleberry points out that "It took 50 years for the flood plain to return to conditions resembling those before 1905, …".[37]

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[35] Here I am using Hjalmarson's Gila River data because Hjalmarson did not provide his data for the Santa Cruz.

[36] Fuller 2003 pg VII-3.

[37] Fuller 2003 pg VII-3.

Osterkamp, along with others, point out how slow recovery is:

> Most natural alluvial stream channels do not have nearly constant discharge, but show variations of at least several orders of magnitude. A channel that is widened by the excessive shear stresses of an erosive flood, therefore, is not adjusted to the conditions of mean discharge following the flood. Generally, **the channel requires an extended period** of normal flow conditions and shear stresses before accretion and deposition of fine sediment are sufficient to affect channel narrowing and an essentially adjusted geometry. If the sediment available for fluvial transport is principally of sand sizes, the rate of narrowing may be slow owing to a lack of fine cohesive material to form a stable channel section [emphasis added].[38]

As Schumm, quoting Wohl, also points out:

> Wohl (2000b, p. 167) states...: A flood may cause dramatic changes along some reaches of a channel and have relatively little effect on other reaches. Similarly, a flood that occurs once every hundred years may create erosional and depositional forms that are completely reworked within 10 years along one channel, but that persists for decades along a neighboring channel.[39]

It takes several decades in arid regions for a river to undo the damage created by a flood, and restore it to a single channel, well-defined river. This is particularly true in the areas of Central and Southern Arizona.

> Arid and semiarid streams tend to be more susceptible to rapid changes in channel geometry (Graf, 1988) and require a greater amount of time to re-establish their original geometry following a disturbance (Wolman and Gerson, 1979).[40]

In 1996, 16 years after his 1980 article, Osterkamp reiterated:

[38]Osterkamp et. al. 1983 pg 14
[39]Schumm pg 127.
[40]Fuller 2003 pg V-8, V-9.

> In arid regions and smaller watersheds, flow variability is higher and extreme events can cause channel changes that persist for decades or centuries (Baker 1977).[41]

3. Intermittent

Hjalmarson correctly indicates that large portions of the Santa Cruz River are intermittent. While I have not checked the exact lengths depicted in Hjalmarson's Figure 6, it appears to be generally correct. As Osterkamp makes clear in his 1980 report, Osterkamp's formulae are based on perennial streams. In 1982, Osterkamp, with Hedman, went on to specifically study intermittent channels in the western United States.[42] Osterkamp and Hedman's study included data from Arizona and the Santa Cruz River. They determined that the equation for a sandy intermittent river channel was:

$$W = 101\ Q^{0.65}$$ footnote 43

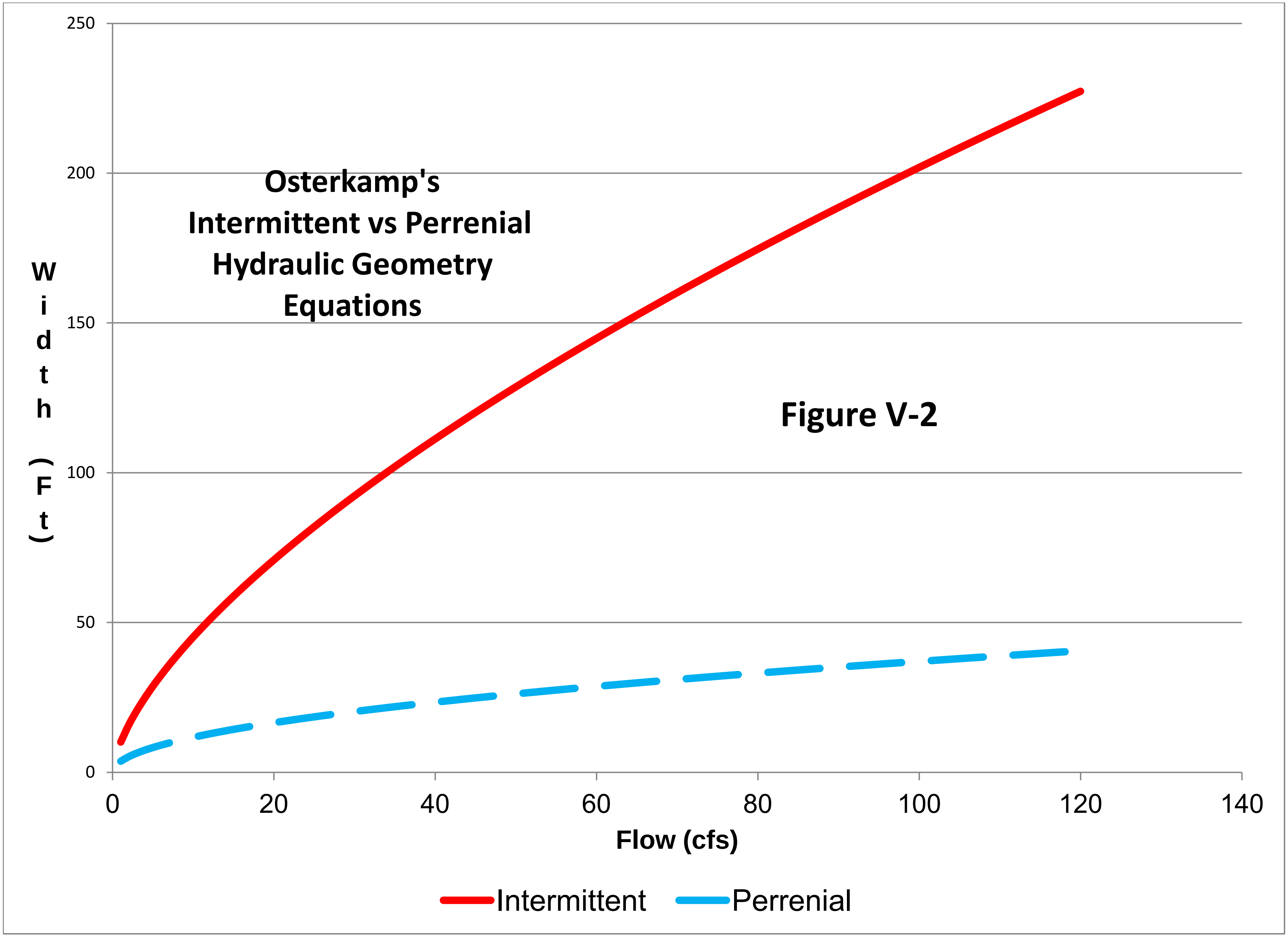
Hjalmarson's formula for an intermittent river channel was:

$$W = 3.7\ Q^{0.55}$$ footnote 44

These two equations are dramatically different as shown on Figure V-2. The two formulae predict that an intermittent channel is dramatically wider than a perennial channel for a given flow. This is consistent with physical reality. Because the width is dramatically greater, it follows that the depth of the river would be significantly less.

D. CALIBRATION

[41]Friedman et. al. pg 2168. Osterkamp was part of the et. al.
[42] Hedman and Osterkamp generally.
[43] Hedman and Osterkamp pg 13. In order to get this result it was necessary to rearrange the formula given so that Q was in cfs instead of af/year and W was the dependent variable rather than the independent variable.
[43] Hjalmarson 2014 pg 22.



Osterkamp's
Intermittent vs Perrenial
Hydraulic Geometry
Equations
Figure V-2
Width (Ft)
250
200
150
100
50
0
0
20
40
60
80
100
120
140
Flow (cfs)
Intermittent
Perrenial

For any formula, the test comes when the results are compared to measurements. We have numerous channel widths recorded in the early GLO surveys. Most of these are shown in Hjalmarson's Appendix A. A quick perusal of the GLO plats shows major problems. The results are often in hundreds of feet vs. the 10s of feet that the perennial equation predicts. Even the intermittent equation discussed in the previous section also seems smaller than some of the measured widths, but the intermittent equation is significantly closer to correct. However, as Hedman and Osterkamp claim, the standard error is 50%,[45] which means you should not expect too much accuracy out of this equation either.

[45] Hedman and Osterkamp pg 13.

VI. DEPTH

Hjalmarson's calculation of depth for the Santa Cruz River relies upon a mathematical derivation of the standard Manning's equation. Manning's equation generally considers several variables including flow (Q), channel geometry ($AxP^{2/3}$), slope (S), and channel roughness (n). Unfortunately, Hjalmarson's report does not contain the information normally contained in a technical report, which is the data used. Specifically, Hjalmarson does not provide us with the slope(s) (S) or the assumed channel roughness (n). Hjalmarson does show the slope varies considerably throughout the Santa Cruz River,[1] but does not show what values he uses for his solution. Hjalmarson states in his report that the river channel has a sandy bottom. Sandy bottoms can have dramatically different "n" values depending on the flow rates and how the sand responds to the flow. With the data for two variables missing, it is impossible to replicate Hjalmarson's work.

The specific derivation of Manning's equation used by Hjalmarson allows for a simplified solution of the equation assuming that the channel, or more accurately the canal, is one of three specific cross-section types. These types are triangular, rectangular or parabolic. Hjalmarson, by including the value of "0.67" before the variable "d" in his equation 3.5, chose a parabolic channel.

[1] Hjalmarson 2014 pg 16.

Hjalmarson assumed that there is a parabolic channel throughout the Middle Santa Cruz reach. It is a mistake to assume that any non-artificial river 102 miles long[2] can be characterized by one channel shape. Second, it is a mistake to choose a parabolic channel for the Middle Santa Cruz.

Finally, as explained in our discussion of width, it is always best to compare the results to actual measurements. We have data from Nogales and Tucson gaging stations in the early 1900's very close in time to statehood. We will examine the above topics below.

A. ONE CHANNEL SHAPE

Hjalmarson assumes one channel shape can be used to approximate a natural channel. The following discussion considers the reason that no single cross-section can be used for the Santa Cruz, which is simply that a river is variable. In Arizona, that statement becomes an even greater truism than for most areas of the United States. As Hjalmarson states in his testimony (on the San Pedro) "A one-word description of Arizona rivers is variable."[3] Hjalmarson later emphasizes "If you are going to use one word, say 'variable'".[4] Specifically, Hjalmarson also believes:

> … Q. … would you expect the flows to be extreme and variable in pre-development conditions?
>
> A. They would be – yes, that's a general characteristic of Arizona's streams.[5]

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[2] Hjalmarson 2014 pg 5

[3] Hjalmarson 2013 pg 75.

[4] Hjalmarson 2013 pg 91.

[5] Hjalmarson 2013 pg 96.

Variability occurs in the flow, and in the shapes of the channel, both of which vary over the length of the river and over time. Hjalmarson is justifiably proud of having worked with Schumm. Schumm pointed out that:

> Rivers change naturally through time as a result of climate and hydrologic change; … there can be considerable variability of channel morphology along any one river as a result of geologic and geomorphic controls.[6]

Despite his knowledge of the variability of rivers, Hjalmarson has, thus far, assumed that the San Pedro River, Lower Gila River and Santa Cruz Rivers all can be represented as a parabolic channel. However, in Hjalmarson's eagerness to rebut Burtell's declaration, he says:

> It is also important to recognize that the USGS measurements were made over a period (1975-2011) **of changing channel geometry that is typical for a sand channel** stream like the Santa Cruz River.[7] [emphasis added]

There is a technique called stream gaging wherein a stream is measured on a periodic basis. The data from these measurements are compiled into a curve that relates the measured elevation of the water surface to the stream flow. This curve is called a stage-discharge curve. Hjalmarson further states:

> **The channel** of the Santa Cruz River **is not** what is known as **a fixed channel** (Rantz, 1982, p. 376) where well-defined stage-discharge relations can usually be developed that show only minor shifting at low flow. Because of the coarse sand channel, **the stage-discharge relation is continually changing** with time because of scour and fill and also **because of changes in the configuration of**

[6]Schumm pg 4.

[7]Hjalmarson 2014 pg D-4.

> **the channel bed,** possibly associated with upper and lower regime flow, during large floods. These **changes cause the shape and position of the stage-discharge relation to vary from time to time especially from flood to flood**.[8] [emphasis added]

The version of the Manning's equation used by Hjalmarson came from a report entitled "A technique for determining depths for T-year discharges in **rigid-boundary** channels"[9] [emphasis added]. Sand channels are neither fixed nor rigid.

B. PARABOLIC CHANNEL

A parabola is a very specific curve with numerous unique characteristics. For example, if you look into a parabolic mirror and close one eye, you will always see not only the open eye, but the pupil of the open eye will appear dead center in the middle of the mirror. Also, a parabola has the mathematical advantage that the cross-sectional area is exactly equal to 2/3 of the top width times the center (maximum) depth. This 2/3 is the origin of that 2/3 value in Hjalmarson's version of the Manning's equation.

If one channel cross-section was to be used for the Santa Cruz, it should be either rectangular or irregular. The Santa Cruz went through an entrenchment process in 1890 and again in 1905 due to massive floods. When a channel entrenchment occurs, particularly one that is consistently described as being an arroyo by Hjalmarson and many others,[10] the resulting channel form is with

[8] Hjalmarson 2014 pg D-5.

[9] Burkham pg 8

[10] Parker 1996 pg 216; Freeman pg 25, Parker 1993 pg 1; Betancourt pg xi; Haynes and Huckell pg 2 (says "vertical walled channel"); Hendrickson and Minckley pg 153; Condes

vertical or very nearly vertical walls and a wide relatively flat channel bed, i.e. a rectangle. In fact, the *Oxford Dictionary* defines arroyo as '[a] steep-sided gully cut by running water in an arid or semiarid region."[11] Parabolas do not have vertical sides.

After some time, an arroyo begins to develop bottom irregularities. The USGS studied numerous cross-sections located in the Santa Cruz River Basin in 1995-1998.[12] Of the 42 cross-sections studied, only five appeared reasonably curvilinear.[13] Even with the nice curved appearance, it could be a catenary curve, a hyperbolic, a cubed parabolic, [14] a fourth power curve, etc. All of these curves have different formulas for area. Most of the cross-sections were highly erratic.

Hjalmarson further indicates his knowledge of how arroyos work in Appendix D when he presents his graphics on page D-6. Hjalmarson correctly points out that there is a small channel with a large overflow area. This description and graphic demonstrate Hjalmarson's fervent belief that whatever the Santa Cruz is, it is not a parabola.

Hjalmarson is upset about the exponent being over 3 in Burtell's stage-discharge curve for Nogales.[15] Hjalmarson cut and pasted a quotation from Rantz into his report. Hjalmarson then indicates that Rantz's equation $Q=C\ (G-e)^N$ is a parabolic

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de la Torre pg A5; Noonan pg 8; Wood, House, and Pearthree pg ii; Hjalmarson 2014 pg D-1.

[11]Oxford Dictionary

[12] Beaulieu et. al. generally

[13] Specifically pgs 59(B), 93(C), 94(E), 116(F), 150(F).

[14] A cubic parabola uses an absolute value function to flip the negative portion of the curve to be positive.

[15] Hjalmarson 2014 pg D-7.

equation. That is only true if the N in the Rantz equation equals 2. Parabolic equations are subsets of quadratic (second power) equations. Yet Hjalmarson's source goes on to say that "N will ... practically never reach a value as high as 2."[16] This means that channels are "practically never" a parabola. This makes a big difference in the answer. If the exponent is between 1.3 and 1.8 as Hjalmarson quotes or is above 3 as Burtell computes, then Hjalmarson's derivation of the Manning's formula is wrong.

The pasted Rantz quotation comes from a section in the Rantz report entitled[17] "Channel Control for Stable Channels". I think there is very little doubt, based on Hjalmarson's statements[18], that the Nogales gaging site is anything but stable. Rantz apparently wanted to make certain that nobody would think the equation Hjalmarson pasted from Rantz into his report applies to a sandy channel. Shortly before, the quotation and equation Hjalmarson pasted into his report Rantz stated that "[f]or the purpose of this manual, stable channels include all but sand channels. Sand channels are discussed in the section titled, "Sand-Channel Streams."".[19] Oddly, Hjalmarson referenced the "Sand-Channel Streams" section two pages earlier in his paragraph starting with "Note".[20]

In Rantz's section on "Sand-Channel Streams", there is a long discussion that can be paraphrased as saying that in a sand channel the stage-discharge line or

[16]Hjalmarson 2014 pg D-7.
[17] Rantz pg 328.
[18] Hjalmarson 2014 pg D-5.
[19] Rantz pg 328.
[20] Hjalmarson 2014 pg D-5.

curve can be anything it wants. It even shows of one example of an ellipse being part of a stage-discharge equation for a sandy channel. Hjalmarson's source is correct, sand channels are unique. My father, in his youth, inspected gages in streams for the USGS. He told a story, many times, that he had one gage where, because it was in sand, the water level would decrease as the flow increased. Stated otherwise, the coefficient was not between 1.3 and 1.8, it was a negative number. Sand channels are not stable. Stage-discharge curves in sand channels do not follow nice rules or uniformly form nice parabolas.

C CALIBRATION

There are two stream gages on the Santa Cruz River that have been in operation since early in the 1900s. Measurements at Nogales began in 1913 and at Tucson in 1911. A very important part of any stream gaging station is having hydrographers go out into the field and repeatedly survey the river. The measurements enable the USGS to create stage-discharge curves. Stage-discharge curves are used to enable the flow to be determined by simply measuring the elevation (based on an arbitrary datum) and using a mathematically derived curve. When the survey is made, measurements are made of the width of the water along with several measurements of the water depth and the water velocity. These records are kept by the USGS and with considerable effort are available from the USGS. The Community has managed to acquire these records which are presented in Appendix A. This is a very valuable resource. With the measurements, we do not have to argue about channel shape, Manning's "n", river slopes, widths, soils or whatever. We know, within the physical ability to measure, what the depth of the water was for various flows.

Fortunately, it does not matter whether the flow is depleted or not for this analysis. When a given flow rate occurs, we know what the depth was very near the time of Statehood. All that is left is the question of how often the flow occurs.

I plotted the measurements from the gage data from its beginning until mid December 1914. In late December 1914, there was a large flood on the Santa Cruz River. There are two reasons why I stopped before the December 1914 flood. First, we are not concerned about depths during floods. We are worried about flows that are "Ordinary and Natural". Second, a major flood often creates major changes in the channel configuration. We are interested in what the flow depths would have been in 1912, at the time of Statehood. I then plotted these points on a special type of graph paper called log-log paper. If you look at each of the axes, you will see the major divisions increase in the number of digits (i.e. 1, 10, 100, etc.). I used a statistical technique called regression analysis to fit a power curve to each of the two datasets. The power curve is a type of equation that plots a straight line on the log-log paper. This is how stage-discharge curves are normally plotted.

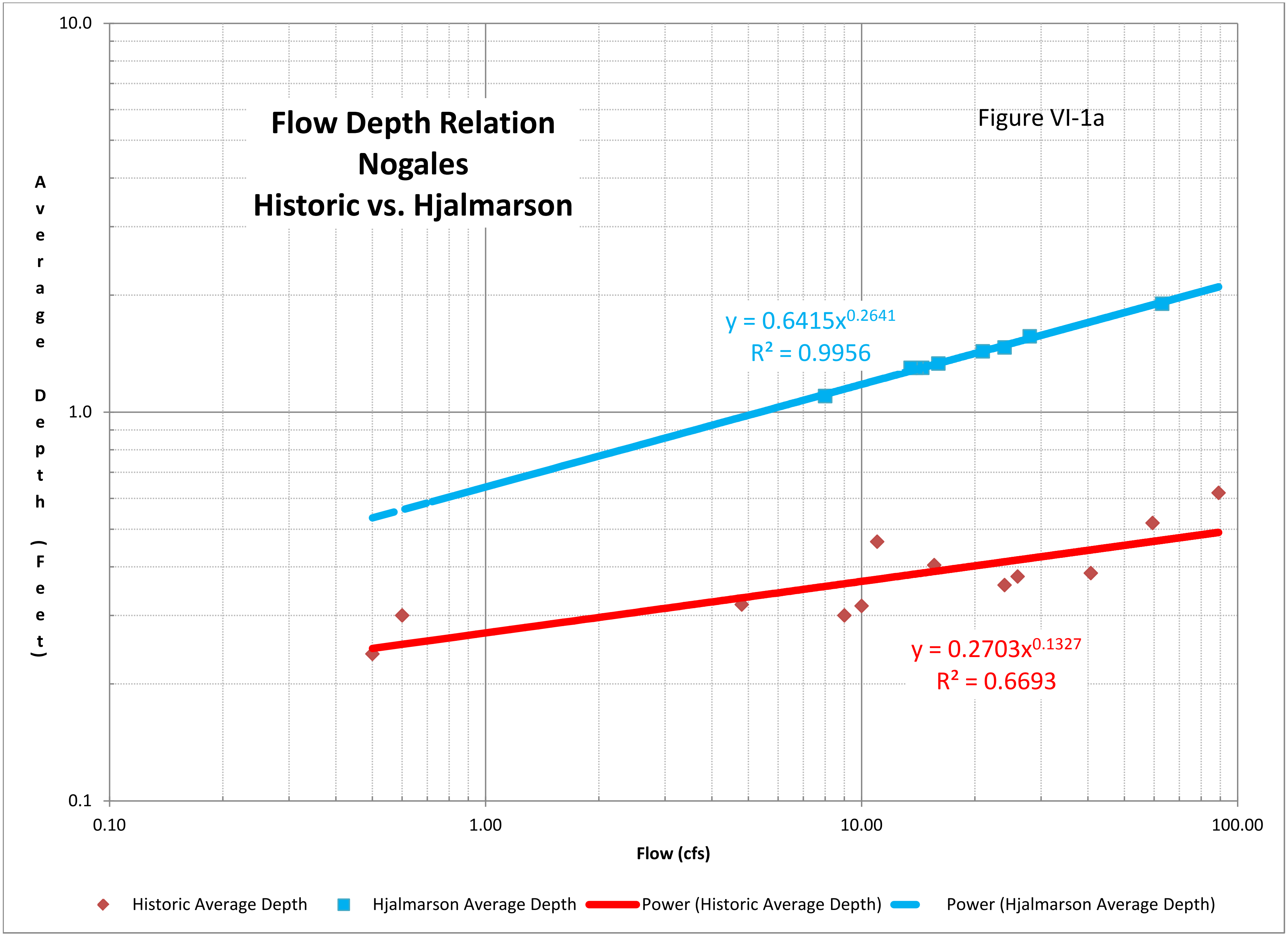
In order to compare Hjalmarson's calculated depth to actual depth, I extracted the flow-duration curve and the depth-duration curve from the .PDF copy of Hjalmarson's Santa Cruz report. I printed blow ups of the charts and measured the flow and depth at each 10% mark. As can be seen, the points very closely follow the power curve line. The minor deviations are probably scaling error on my part. The trend, however, is clear. (See Figure VI-1)

This analysis has been done for both the Nogales Gage and the Tucson Gage. As can be seen, the Hjalmarson reconstruction of the flow-depth relationships considerably overstates depths. In the following chapter, there is a considerable discussion about the depth of water required. The values that are cited are 1 foot, 2 feet, and 3 feet. Figure VI-2 contains the flow rates to depth values that are the statistical result of the data.

To reasonably guarantee the required flow depths, a safety margin should be added. I did not do so in this analysis. Also the two gage locations are in places where the Santa Cruz was perennial and the most favorable for navigation along the Santa Cruz. The dry reaches would be significantly less likely to be navigable. To eliminate argument about the probability of flow, I am using the flow and depth values from Hjalmarson's Report (his Figures 5 and 12). As indicated in Chapter IV, I believe the chart is not substantiated by his data.

If the required flow exceeded 100 cfs, I simply indicated >100 cfs, because it is very difficult to scale the left end of the chart and 100 cfs occurs less than 10% of the time according to Hjalmarson. I agree that 100 cfs or more of streamflow occurs less than 10% of the time on the Santa Cruz.

As the Figures demonstrate, if the near Statehood measurements of the river sections are used, then it is obvious the Santa Cruz was not navigable under any of the



Flow Depth Relation
Nogales
Historic vs. Hjalmarson
Figure VI-1a
y = 0.6415x^0.2641
R² = 0.9956
y = 0.2703x^0.1327
R² = 0.6693
10.0
1.0
0.1
0.10
1.00
10.00
100.00
Average Depth (Feet)
Flow (cfs)
Historic Average Depth
Hjalmarson Average Depth
Power (Historic Average Depth)
Power (Hjalmarson Average Depth)

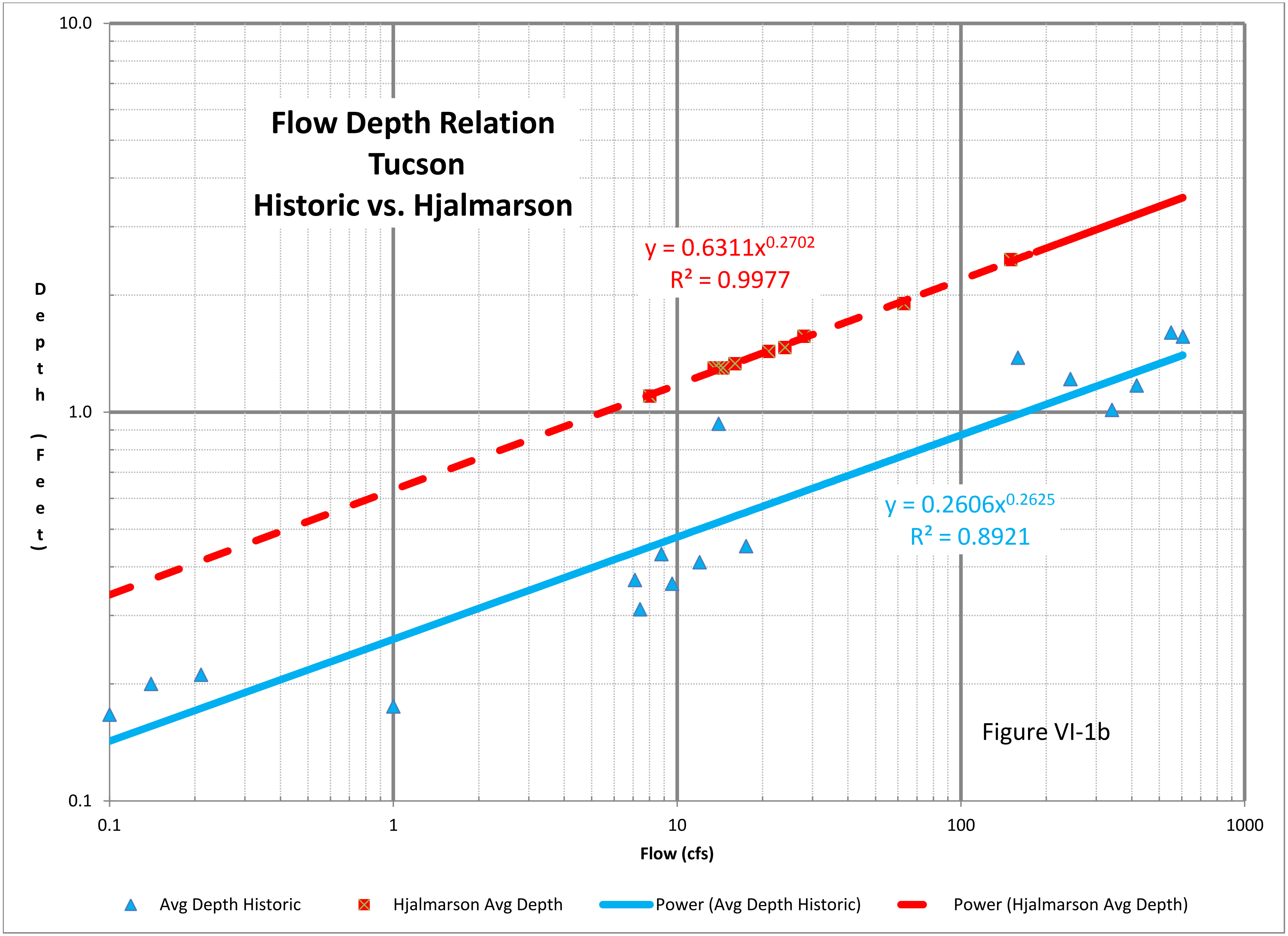

Flow Depth Relation
Tucson
Historic vs. Hjalmarson
y = 0.6311x^0.2702
R² = 0.9977
y = 0.2606x^0.2625
R² = 0.8921
Figure VI-1b
Depth (Feet)
Flow (cfs)
10.0
1.0
0.1
0.1
1
10
100
1000
Avg Depth Historic
Hjalmarson Avg Depth
Power (Avg Depth Historic)
Power (Hjalmarson Avg Depth)

Figure VI-2	Equivalent Mean	Nogales				Tucson			
		Historic		Hjalmarson		Historic		Hjalmarson	
Max Depth	Depth	Flow	Frequency	Flow	Frequency	Flow	Frequency	Flow	Frequency
1 foot	.67 feet	>100	<10%	<8	100%	35	25%	< 8	100%
1.5 feet	1 foot	>100	<10%	<8	100%	>100	<10%	< 8	100%
2 feet	1.33 feet	>100	<10%	15	83%	>100	<10%	14	100%
3 feet	2 feet	>100	<10%	75	<10%	>100	<10%	70	12%
4.5 feet	3 feet	>100	<10%	>100	<10%	>100	<10%	>100	<10%

Relation of Maximum Depth to Mean Depth is based on a Parabola criteria for navigability or flow data set forth even with the Hjalmarson reconstruction of the flow curves.

VII. CRITERIA

The question then arises as to what is required for a commercial boat to travel on the Santa Cruz River at the time of Statehood. To that end, Hjalmarson utilizes two sets of criteria, which Hjalmarson designates as the Bureau of Outdoor Recreation criteria, and the Fish and Wildlife Service criteria. In one other river, the Lower Gila River, Hjalmarson used the U.S. Geological Survey criteria. There are also other criteria Hjalmarson did not consider. The criteria are: the Utah Precedent, the Pinkerton Report, the Washington State Law, and the Army Corps of Engineers Standards. Each of these criteria are discussed below.

A. BUREAU OF OUTDOOR RECREATION CRITERIA

The Bureau of Outdoor Recreation criteria do not deal with commercial navigability. This criteria deals with modern day recreational boating that is for outdoor adventure, i.e. whitewater boating. This technique is irrelevant to the question of minimum flow necessary for commercial purposes.

Hjalmarson’s Figure 14 is a modification of a chart from the Bureau of Outdoor Recreation. Hjalmarson's modification implies that the lines can be extended into the areas of the graph not considered by the Bureau of Outdoor Recreation. According to the original chart, assuming for argument's sake that the chart is relevant, you cannot navigate any river when it is below 500 cfs. 500 cfs is literally off the Hjalmarson Flow-Duration chart (Figure 5).

The Bureau of Outdoor Recreation does provide some valuable information. Specifically, while you can float a modern day recreational canoe in one foot of water, two feet of depth is required to paddle the canoe.[1] It further indicates the minimum width required for canoeing is 25 feet.[2]

As the U.S. Supreme Court stated: "The Montana Supreme Court further erred as a matter of law in its reliance upon the evidence of present-day, primarily recreational use...".[3] In addition to the Bureau of Outdoor Recreation criteria being inapplicable as a matter of law, the Bureau of Outdoor Recreation criteria is also inapplicable to navigability as a matter of fact.

Current day small water craft are built differently from those in 1912. In 1912, small water craft were built of wood. Today small water craft are made of stronger materials such as fiberglass. Fiberglass is much stronger than wood. To determine this, I went to materials manufacturer's websites and found that fiberglass' strength is 30,000 psi.[4] The 1912 *Sears Catalog* shows canoes made out of cedar. Cedar's strength varies on how the load is applied to the grain. If the load is parallel to the grain, cedar can handle 1990 psi to 6310 psi depending on what type of cedar. If the load is perpendicular to the grain, which is the most likely scenario, cedar can handle from 240 psi to 920 psi.[5] As can be seen, fiberglass is far stronger than wood.

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[1] Cortell pg 14
[2] Cortell pg 21
[3] 132 S.Ct. 1215 pg 21.
[4] American Acrylic Corporation no page number.
[5] Green et al. pg 4-11, 4-12.

The graph presented by Hjalmarson is not really the approach that the Bureau of Outdoor Recreation recommends. The Bureau of Outdoor Recreation recommends that aerial data and field visits be performed to locate problem areas. After all, as Hjalmarson points out, "rivers are variable."Specifically, the Bureau of Outdoor Recreation states:

> Failure to locate such areas, and to take into account the limiting conditions they present, may lead to error in recommendations based on remote information alone.[6]

If the field verification varies from the prediction, among the reasons postulated by the Bureau of Outdoor Recreation is that the Hydraulic Geometry method is "not applicable to the stream".[7] The Hydraulic Geometry method is a part of the Bureau of Outdoor Recreation's derivation of their criteria.

B. FISH AND WILDLIFE SERVICE CRITERIA

The second technique used by Hjalmarson is the Fish and Wildlife Service criteria. This criteria also uses modern day recreational watercraft for its basis of navigability. As discussed above, use of recreational watercraft is inapplicable as a matter of law and fact.

The Fish and Wildlife Service approach was misapplied by Hjalmarson. As the Fish and Wildlife Service's report indicates:

> The approach is based upon the assumption that a single cross section, properly located, can define a minimum flow requirement. Such a cross

[6] Cortell (b) pg 61.

[7] Cortell (b) pg 83.

> section is located at an area displaying the **least depth** across the entire stream [emphasis added]. [8]

Hjalmarson's technique is based on maximum depth. As discussed in Chapter V, the prediction of width by the Hydraulic Geometry Method computes the narrowest width. This normally will make the depth the maximum depth. The Fish and Wildlife Service criteria is supposed to be used for the "least depth".

Hjalmarson also chose to use the less accurate of the two methods provided by the Fish and Wildlife Service. The incremental method, which Hjalmarson did not use, is the one that is supposed to be used when "The most 'exact' answer, available with today's state-of-the-art, is desired."[9] Further, the Fish and Wildlife Service suggests that we must understand the limitations prior to the next step which is "field testing".[10]

C. U.S.G.S. CRITERIA

The U.S.G.S. criteria was developed by Langbein of the United States Geological Survey and was published in 1962. This criteria was used by Hjalmarson on the Lower Gila River. Hjalmarson did not use the U.S.G.S. criteria on the San Pedro River. On the San Pedro, this was likely because the answers did not support navigation. Hjalmarson does not use the U.S.G.S. Criteria on the Santa Cruz. A plot of Hjalmarson's computed values of 2 feet for depth[11] and 0.5 to 2.0 feet for velocity[12] on Figure 13 of the USGS criteria shows the tractive force (a term used in the USGS

[8]Hyra pg 3.
[9]Hyra pg 13.
[10]Hyra pg 14.
[11]Hjalmarson 2014 pg 24.
[12] Hjalmarson 2014 pg 23.

criteria report) to be greater than .001 which the USGS says flunks the test for navigability.

D. THE UTAH DECISION

The Utah Decision is the primary decision that expanded and developed the concept of susceptibility of navigation. Reviewing how the Utah Special Master came to his conclusions as to what was navigable is very instructive. The Utah Special Master reviewed a great number of historic navigations that actually occurred on the four rivers that he considered. Based on the boats that had been used, both before and somewhat after Utah Statehood (1896), the Utah Special Master concluded it took a "mean depth" of 3 feet for commercial activity as of 1896.

For those reaches where navigation did not occur, the Utah Special Master first determined that there was a reason other than river characteristics that caused the lack of navigation; specifically there was no reason to navigate the reach. There were no population centers or mines or other activities that could have benefitted from trade. It was pretty much wilderness. The Utah Special Master then applied the three foot depth to those river reaches and said, if the three foot criteria were met, the river reach may be navigable. The Utah Special Master also went on to consider whether or not there were rapids or other obstructions[13] that created "an impediment to the practicable use of the Rivers… ".[14]

[13]Based on considerable evidence, the Utah Special Master concluded sand bars did not qualify as an obstacle.
[14]Warren pg 91-92.

The Utah Special Master used the river as it was before and somewhat after 1896 in order to determine if the river was navigable. The Utah Special Master did not use data from periods long after Utah's statehood. The period of consideration for navigation and the various boats that went over the rivers extended from the mid 1800s to the late 1920s. Hence, the Utah Special Master's conclusions of depth requirement are just as relevant to the Santa Cruz River watershed as they were to the watersheds the Utah Special Master considered. Based on the evidence presented above, I think three foot of "mean depth" is an accurate requirement.

This leaves the question of what the Utah Special Master meant by "mean depth"? Does the Utah Special Master mean the maximum depth that occurred during mean average flow or did the Utah Special Master want the depth across the channel to average three feet (what the hydrologists call the hydraulic depth)? The context makes it clear that the Utah Special Master was not talking about the depth at mean average flow. The Utah Special Master very carefully used historic data to determine at what flow rates there would be a three foot or greater "mean depth" (aka hydraulic depth) in the river. The Utah Special Master then totaled all of the flow rates that provided three feet or more of "mean depth" and decided whether it was for a sufficient period to allow commercial activity. This means the Utah Special Master used the hydraulic depth, not the maximum depth.

E. PINKERTON

In 1914, a report was prepared by Pinkerton about canoeing. In that report, Pinkerton indicates that it takes 19 inches of water for a freight canoe to float.[15] Plus, the United States Army Corp of Engineers has indicated that you cannot effectively navigate a river if you are dragging bottom and in fact, due to the hydraulics of boating, you should limit your draft to 75 percent of river depth. These two sources together suggest that for a commercial canoe, the river should have a depth of at least 25 inches.[16]

F. WASHINGTON STATE CRITERIA

The State of Washington has examined the concept of navigability and created various laws for it. Statutorily, the State of Washington has determined that if the average depth on the river is greater than 3.5 feet deep, and 45 feet wide, then the river is probably navigable. The State of Washington believes two feet is the minimum depth to have any real chance of navigation and the range 2 to 3.5 feet is a "maybe".[17]

G. ARMY CORPS OF ENGINEERS CRITERIA

Finally, the Army Corp of Engineers is the agency directed by the United States Congress to maintain navigability. As documented at Slide 104 of my testimony in the San Pedro, the following depths were legislated by Congress as depths the Army Corp of Engineers was to maintain:

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[15] Pinkerton, near the end of chapter 2.
[16] (19 inches/0.75 = 25 inches)
[17] Magirl and Olsen pg 2.

YEAR	DEPTH (FEET)	RIVER REACH
1866	4	Upper Mississippi
1878	4.5	Upper Mississippi
1896	9	Lower Mississippi
1907	6	Upper Mississippi
1907	6	Lower Missouri
1910	9	Ohio

H. OBSTACLES

The use of the Manning's Equation as described in chapter VI does not consider obstacles. Obstacles can, and often do, exist in the natural state.

> Many streams that may not be boatable due to boulders, vegetation, frequent waterfalls, or significant natural hazards may have average annual flow rates or flood peaks that, … indicate that boating could occur.[18]

Obstacles that must be considered are beaver dams, riffles, marshes and braiding.

1. Beaver Dams

Beaver dams do not appear to have been prevalent on the Santa Cruz River. From my research, it appears that there is no consensus as to why. In any case, beaver dams do not appear to have been an obstacle on the Santa Cruz.

2. Riffles

The second obstacle is riffles. A riffle is described as follows:

[18] Stantec Consulting Inc. pg 15.

> The riffle is a bed feature that may have gravel or larger rock particles. The water depth is relatively shallow, and the slope is steeper than the average slope of the channel. At low flows, water moves faster over riffles, which removes fine sediments and provides oxygen to the stream. Riffles enter and exit meanders and control the streambed elevation. Pools are located on the outside bends of meanders between riffles. The pool has a flat surface (with little or no slope) and is much deeper than the stream's average depth. At low flows, pools are depositional features and riffles are scour features.[19]

Riffles are prevalent on most streams.

> Natural channels characteristically exhibit alternating pools or deep reaches and riffles or shallow reaches, regardless of the type of pattern.[20]

Hjalmarson indicates that riffles would be minor because the Santa Cruz River meandered throughout its length in 1912. The contemporary GLO surveys presented in Hjalmarson's Appendix A show differently. Contemporary GLO surveys show that some reaches did meander, some reaches had no visible channel, some reaches were pretty straight, some reaches were marshes, and some reaches were braided on or along the Santa Cruz.

The issue of riffles affects navigability in two ways. First, sometimes riffles are minor obstacles but other times, riffles can be rapids. Second, riffles affect the depth of water.

In the Utah Decision, the Utah Special Master found that a riffle per se was not enough to stop navigation. Rapids, however, were enough to stop navigation. This distinction was primarily based on the experiences of people who had navigated the

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[19] North Carolina Stream Restoration Institute pg 10.

[20] Leopold and Wolman pg 39.

river. The distinction between riffles and rapids were based on a wave heights, head losses, and slopes.[21]

The second effect of riffles is that riffles change the slopes of a river. Rivers descend in a kind of stair-step manner. There are shallow short steep reaches followed by relatively flat deeper pools of water followed by another shallow short steep reach followed by etc. A steeper slope changes the depth.

3. Marshes

The third obstacle is marshes. Marshes are also called swamps or cienegas. We know from travelers that:

> There is also little doubt that the channel consisted of braided, weaving strands through sandy islands in the center. Several marshy areas, possibly sustaining alkali sacaton, were present, including near present-day Sacaton, at the Santa Cruz-Gila confluence and near the mouth of the Salt River.[22]

The Santa Cruz River had marshes or cienegas near Tucson and San Xavier del Bac.[23] As shown in my testimony for the San Pedro, cienegas are so overgrown with vegetation including dense thickets of grass and fallen trees, that cienegas (marshes) would provide a considerable obstacle to navigation.[24]

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[21] Warren pg 82-83.
[22] Webb et al pg 337.
[23] Freeman pg 99.
[24] Gookin 2013 Slides.

4. **Braiding**

As discussed in Chapter V, some reaches of the Santa Cruz River were braided in the early 1870s. After the major floods of 1890 and 1905, many portions of the Santa Cruz River were braided.

A braided channel is very wide. It has an almost totally flat bottom with two vertical banks. In that bottom, there will be one or more very shallow depressions that the low flows occupy. If more flow occurs, the river overflows the shallow depression and the water spreads out side to side. Because there are no side restrictions until the river occupies the entirety of the very wide channel, the depths increase very little. Then the depth begins to increase as the rectangular channel begins to fill.

On the Middle Santa Cruz River, we have two locations that have been studied in detail. One location is at Tubac and the other is at Cortaro (aka Rillito).[25] Several cross-sections were measured. An examination of the Cortaro cross-sections show the river is braided. The Cortaro cross-sections with their measured water surfaces indicate that not only were there two channels but the water surfaces in the two channels were at different elevations (see Figure VII-1). These measurements were taken on January 12, 1998. The flow that day at Cortaro was 80 cfs.[26] 80 cfs is 33% greater than the mean average of 60 cfs documented by myself, the "White Book", and Hjalmarson[27] At 80 cfs, the maximum depth was only 0.24 meters (slightly less than 9 1/2 inches).

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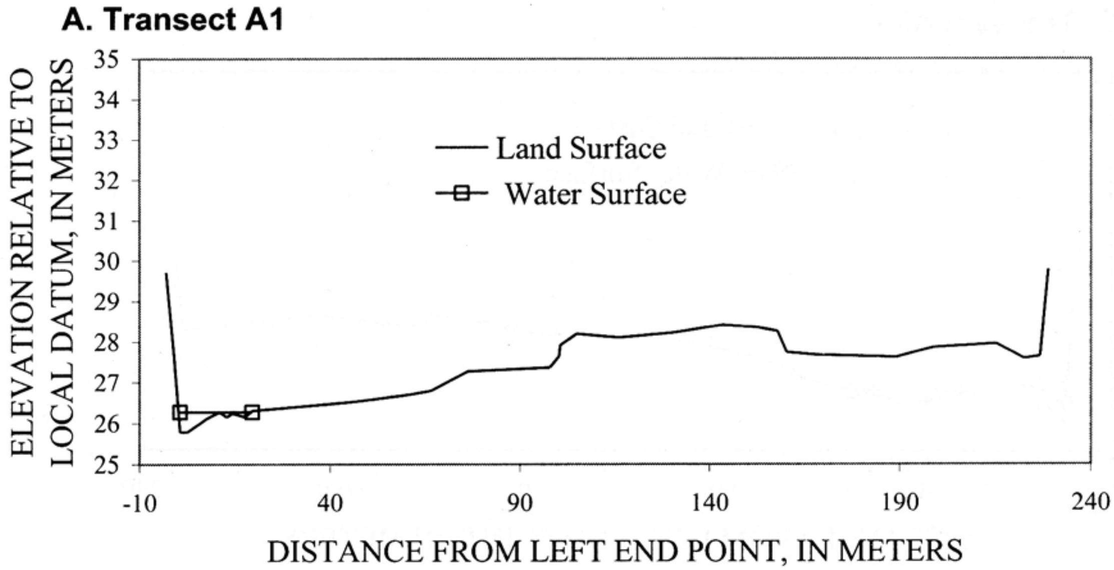
[25]Beaulieu et. al. pg 66-87.

[28]USGS Records online.

[27]Hjalmarson 2014 pg C-4.



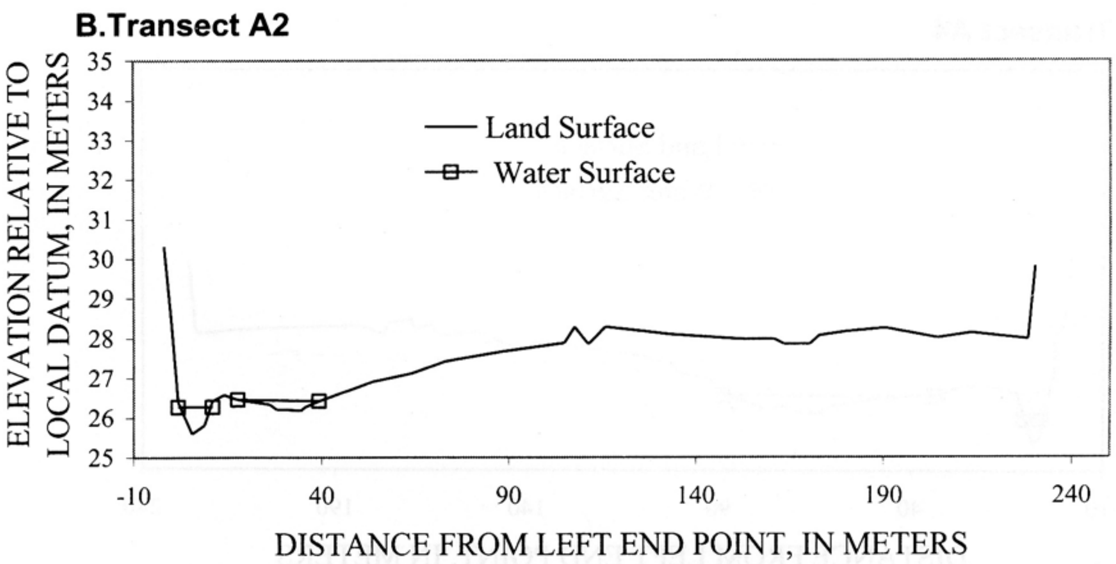
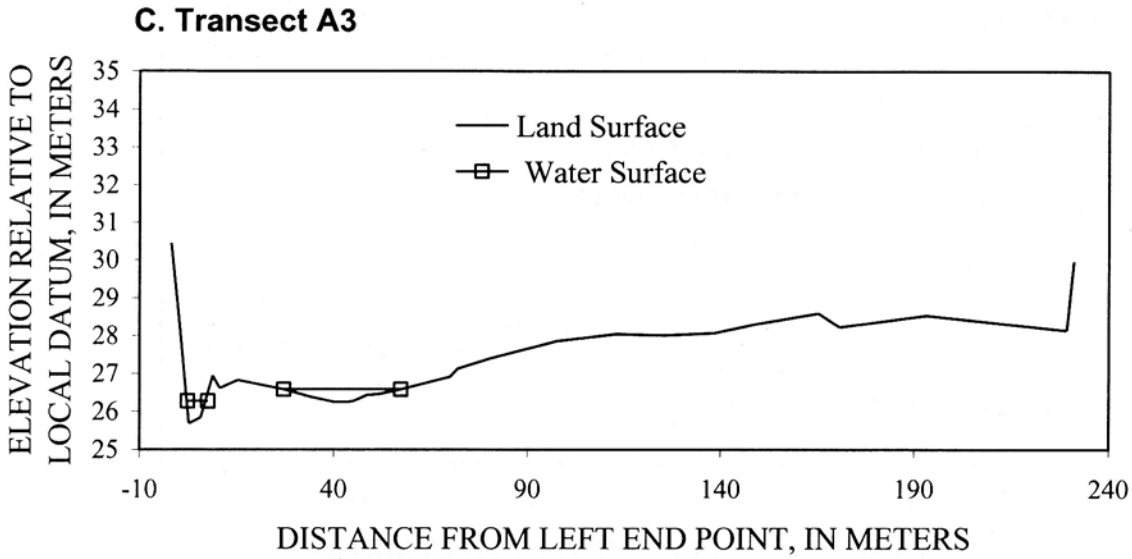


Figure 41A–F. Cross sections of channel, reach A, Santa Cruz River at Cortaro, Arizona, January 26, 1998. *A*, Transect A1. *B*, Transect A2. *C*, Transect A3. *D*, Transect A4. *E*, Transect A5. *F*, Transect A6. Local datum established as the zero point of the reference gage at streamflow-gaging station, Santa Cruz River at Cortaro, Arizona (09486500).

Figure VII-1a



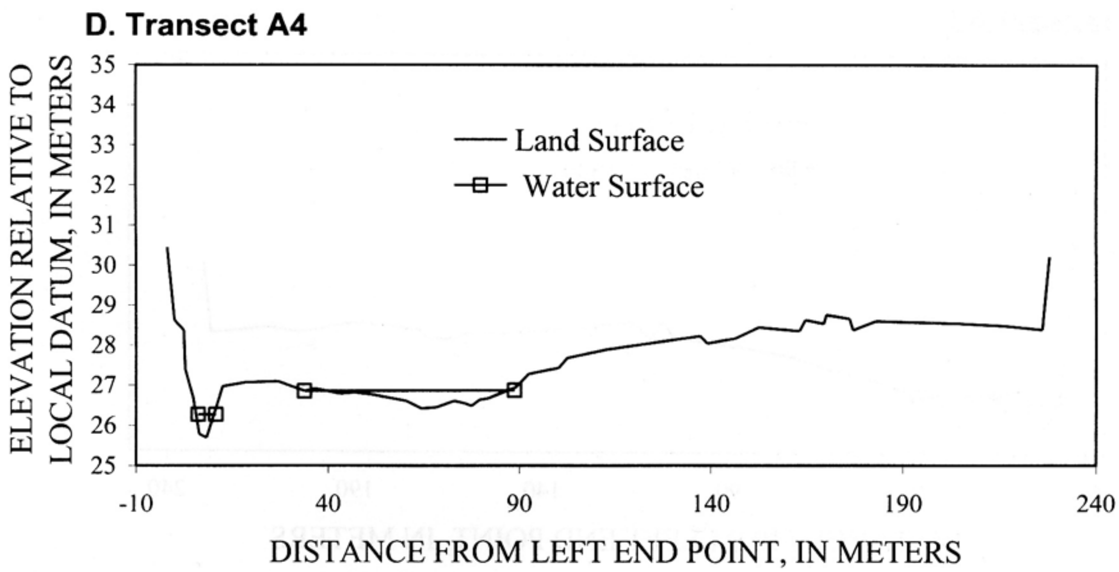
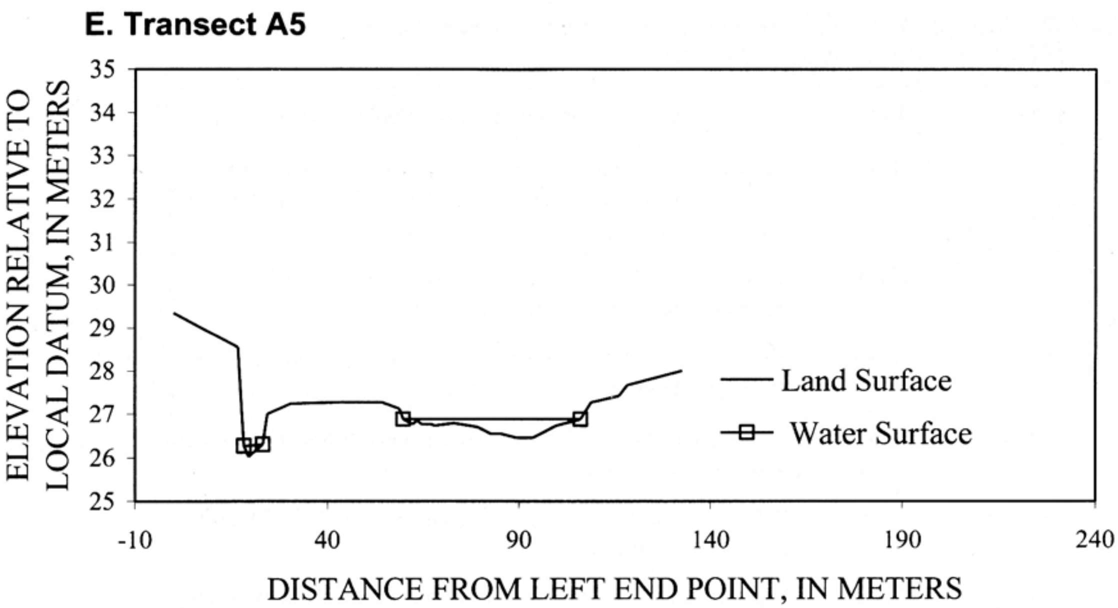


Figure 41A–F. Continued.

Figure VII-1b



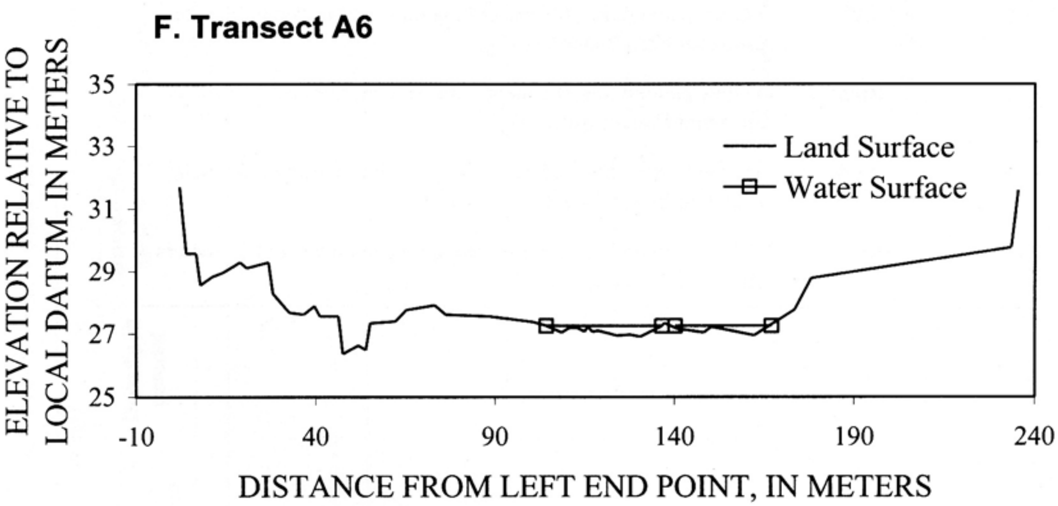


Figure 41A–F. Continued.

Figure VII-1c

At 80 cfs, Hjalmarson computes, using his parabolic cross-section, that the depth is about 3 feet. This is a dramatically different answer than 9 1/2 inches. According to the Hjalmarson flow-duration curve, 80 cfs would, in predevelopment times, be more than the natural flow 90% of the time. This actual field measurement shows that the river at Cortaro (aka Rillito) is not navigable even by the standards for modern recreational canoes. The 0.24 meter deep channel was only 4-5 feet wide. The secondary channel, which was wider, was also considerably shallower.

Due to the extensive braiding, the Middle Santa Cruz River was not navigable in its ordinary and natural condition as of Statehood.

I. SUMMARY

Three feet was what was necessary for navigation in the Southwest in 1896. Depths required for river navigation have generally increased over time. I doubt that over a period of 16 years,[28] the increase in required depth for navigation has been significant. Three feet is a valid depth to use as a standard for navigability as of Statehood. Additional obstacles such as cienegas, riffles, and braiding would have also prevented navigation on the Middle Santa Cruz.

[28] 1912-1896 = 16

Appendix A

Computation of Average Virgin Flows

Gage	Drainage Areas	Additional Drainage Area	Percent	Allocate 31 cfs Virgin Flow Gain	Add 29 cfs Virgin Flow	Hjalmarson Flows
Nogales	533	0	0%	0.0	29.0	29
Tubac	1209	676	23%	7.1	36.1	32.4
Continental	1662	1129	38%	11.8	40.8	34.5
Tucson	2222	1689	57%	17.6	46.6	37.2
Rillito	3503	2970	100%	31.0	60.0	60

Computation of Base Flow

Item	------------------Area 57------------------------				------------------Area 58-----------------------			
	Degrees	Percent	Quantity	Hjalmarson	Degrees	Percent	Quantity	Hjalmarson
Inflow	180		11,000	4,100	180		62,000	4,100
Recharge	180	100%	11,000	3,200	169	94%	58,211	3,200
Underflow	0	0%	0	0	11	6%	3,789	0
Losses	0	0%	0	900	0	0%	0	900
Outflow	180		-11,000	-4,100	180		62,000	-4,100
Evapotranspiration	0	0%	0	-4,000	14	8%	4,822	-4,000
Underflow	35	19%	-2,139	-100	18	10%	6,200	-100
Base Flow	145	81%	-8,861	???	148	82%	50,978	???

Negative represents Outflow

Tucson	Date	avg. width feet	avg. Area sq. feet	avg. Veloci ft/sec	Gage ht. feet	Q ft^3/sec	calc_AvgDepth feet	Q from A*V	notes
	8/21/1911	30	41.4	3.8	0.34	158.8	1.38	157.32	
	8/22/1911	69	107.9	5.6	1.16	605.6	1.56	604.24	
	8/22/1911	67	107.3	5.1	1.2	550.4	1.60	547.23	
	8/24/1911				0.25	12			
	9/15/1911	78	91.3	4.55	1.1	416.3	1.17	415.42	
	9/18/1911	61	61.8	5.5	1.08	340.6	1.01	339.90	
	9/18/1911	44	53.5	4.54	0.6	243.1	1.22	242.89	
1	10/13/1912	8	1.4	0.71	-0.45	1	0.18	0.99	
2	11/24/1912	18	5.6	1.32	-0.02	7.4	0.31	7.39	
3	12/12/1912	21	7.6	1.26	0.13	9.6	0.36	9.58	
4	12/27/1912	16	6.9	1.28	0.28	8.8	0.43	8.83	
5	1/24/1913	18	7.4	1.67	0.31	12	0.41	12.36	
6	2/18/1913	9	8.4	1.67	0.37	14	0.93	14.03	
7	3/4/1913	10	3.7	1.92	0.11	7.1	0.37	7.10	
8	3/20/1913	1	0.2	0.7	-0.15	0.14	0.20	0.14	
9	3/24/1913	1.2	0.2	0.5	-0.14	0.1	0.17	0.10	
10	4/22/1913	0.9	0.19	1.1	-0.09	0.21	0.21	0.21	
11	7/20/1913					0			
12	9/18/1913				-1	0			
13	11/22/1913				0.95	0			
14	1/18/1914					0			
15	2/13/1914					0			
16	2/28/1913					0			
17	3/27/1914					0			
18	8/23/1914	23	10.4	1.68	1.74	17.5	0.45	17.47	
19	10/16/1914				1	0			
20	12/20/1914	72	168	6.61	4.4	1110	2.33	1110.48	
21	12/21/1914	90	313	6.6	4.27	2060	3.48	2065.80	
22	12/21/1914	70	199	6.38	3.27	1270	2.84	1269.62	

23	12/23/1914	136	714	7.19	7.59	5120	5.25	5133.66	
24	12/23/1914				8.9	7100			
25	12/24/1914	117	867	10.06	6.45	8720	7.41	8722.02	
26	12/26/1914	125	188	5.71	3.95	1070	1.50	1073.48	
27	12/28/1914	98	48	3.27	2.69	157	0.49	156.96	
28	1/4/1915	23.5	9.1	2	2.47	17	0.39	18.20	
29	2/4/1915				4	311			
30	2/13/1915				4.39	491			
31	2/27/1915				3.12	48			
32	3/9/1915				3.08	78			
33	3/9/1915				3.08	82			
34	3/31/1915				2.82	8.8			
35	4/6/1915				2.72	1.5			
36	4/7/1915					0			
37	10/3/1915					0			
38	11/10/1915					0			
39	1/20/1916				2.3	2000			
40	1/22/1916				2.4	2110			
41	1/24/1916				1	274			
42	1/28/1916					217			
43	1/29/1916				1.08	246			
44	2/2/1916				0.58	17			
45	7/14/1916				0.75	16			
46	7/20/1916				1.1	348			
47	7/20/1916				0.87	229			
48	7/26/1916				0.97	187			
49	7/26/1916				0.45	63			
50	7/27/1916				1.47	600			
51	7/28/1916				1.37	620			
52	7/28/1916				0.82	135			
53	7/31/1916				0.9	159			
54	7/31/1916								striken

55	8/1/1916	0.7	25	
56	8/2/1916	0.5	5	
57	8/8/1916	0.6	7	
58	8/11/1916	1.08	184	
59	8/12/1916	1.29	436	
60	8/13/1916		166	
61	8/14/1916	0.87	100	
62	8/15/1916	1.45	818	
63	8/16/1916	1.32	932	
64	8/16/1916	1.22	760	
65	8/24/1916	1.1	210	
66	9/7/1916	2.6	21	new gage
67	9/8/1916	3.9	608	
68	9/8/1916	4	642	
69	9/11/1916	2.83	73	
70	7/2/1917	5.8	82	
71	7/9/1917	4.4	9.2	
72	7/10/1917	4.52	48	
73	7/16/1917	4.3	34.5	
74	7/22/1917	4.85	224	
75	7/23/1917	4.5	83	
76	7/23/1917	4.68	192	
77	7/24/1917	6.5	1920	
78	7/24/1917	5.8	1600	
79	7/24/1917	5.28	892	
80	7/25/1917	5.3	725	
81	7/28/1917	4.45	114	
82	8/3/1917	6.7	3280	
83	8/3/1917	7.05	3520	
84	8/3/1917	7.2	3010	
85	8/4/1917	6	931	
86	8/4/1917	5	751	

87	8/9/1917				4.65	103			
88	8/11/1917				5.42	1170			
89	8/11/1917				5.15	908			
90	8/14/1917				4.5	30.3			
91	8/16/1917				4.83	281			
1	3/20/1926					0.1			estimate
2	4/9/1926	27	7.23	1.7	11.43	12.3	0.27	12.29	
3	7/21/1926	78	53.4	1.52	11.68	81	0.68	81.17	
4	8/6/1926	94	69.2	3.57	12.16	247	0.74	247.04	
5	9/15/1926	94	236	6.91	14.21	1630	2.51	1630.76	
6	9/27/1926	96	249	6.46	13.94	1610	2.59	1608.54	
7	9/28/1926	184	1140	7.07	17.93	8070	6.20	8059.80	
8	9/30/1926	41	15	2.11	11.9	31.7	0.37	31.65	
9	11/1/1926	44	21.8	3.09	12.34	67.3	0.50	67.36	
10	12/8/1926	11	2.66	1.35	12.15	3.6	0.24	3.59	
11	1/5/1927	3.5	0.33	0.61	11.64	0.2	0.09	0.20	
12	8/5/1927	113	77.6	4.09	13.51	317	0.69	317.38	
13	8/16/1927	15	4.77	2.37	12.53	11.3	0.32	11.30	
14	8/22/1927	62	40.1	3.69	13.16	148	0.65	147.97	
15	8/22/1927	49	24.4	3.03	12.69	73.9	0.50	73.93	
16	9/8/1927	57			12.59	18			
17	9/12/1927	75	55.3	4.47	13.42	247	0.74	247.19	
18	9/13/1927	85	29.1	2.61	12.39	75.9	0.34	75.95	
19	2/17/1928	6	0.99	1.39	11.63	1.3	0.17	1.38	
20	7/17/1928	81	75	4.87	13.27	365	0.93	365.25	
21	7/17/1928	38	13.9	2.5	12.3	34.4	0.37	34.75	
22	7/18/1928	81	73.3	4.8	13.22	352	0.90	351.84	
23	7/31/1928	15.5	7.4	2.57	10.7	19	0.48	19.02	
24	8/1/1928	130	218	6.42	14.41	1400	1.68	1399.56	
25	8/1/1928	76	60.2	4.32	12.95	260	0.79	260.06	
26	8/26/1928	8	3.75	2.52	11.99	9.4	0.47	9.45	

27	9/2/1928	80			12.81	192			channels
28	9/2/1928				12.62	108			channels
29	9/2/1928	46	26.1	2.37	12.44	61.8	0.57	61.86	
30	9/2/1928	33	15.2	2.65	12.26	40.3	0.46	40.28	
31	9/2/1928	27	11.2	2.78	12.18	31.2	0.41	31.14	
32	7/10/1929	115	140	5.52	13.62	775	1.22	772.80	
33	7/10/1929	97	74.4	4.15	12.88	309	0.77	308.76	
34	7/10/1929	92	39	2.5	12.22	97.3	0.42	97.50	
35	7/10/1929				11.9	3			
36	7/11/1929					0			
37	7/22/1929	11	3.09	1.33	11.45	4.1	0.28	4.11	
38	7/23/1929	58	23.5	2.2	11.98	51.7	0.41	51.70	
39	7/25/1929	67	46	4	12.6	184	0.69	184.00	
40	7/25/1929	56	41.9	3.84	12.54	161	0.75	160.90	
41	7/26/1929	43	16.4	1.96	11.98	32.2	0.38	32.14	
42	7/27/1929	71	67.1	6.33	13.31	425	0.95	424.74	
43	7/27/1929	69.5	68.7	4.72	13.09	324	0.99	324.26	
44	7/28/1929	128	226	5.97	14.35	1350	1.77	1349.22	
45	7/28/1929	67	51.4	4.63	12.72	238	0.77	237.98	
46	7/29/1929				11.74	1			
47	7/29/1929	129	216	6.8	14.3	1470	1.67	1468.80	
48	7/30/1929	99	119	5.04	13.34	598	1.20	599.76	
49	7/31/1929	56	31.9	3.34	12.5	107	0.57	106.55	
50	8/2/1929	65	71.2	1.96	12.5	140	1.10	139.55	
51	8/3/1929				13.52	894			channels
52	8/3/1929	34	13.6	3.13	11.69	42.6	0.40	42.57	
53	8/10/1929				14.02	668			channels
54	8/10/1929				13.98	681			channels
55	8/11/1929	94	88.9	4.66	13.3	400	0.95	414.27	
56	8/21/1929								striken
57	9/8/1929	168	736	7.06	16.97	5200	4.38	5196.16	
58	9/25/1929	148	92	3.1	13.46	285	0.62	285.20	

	59	9/26/1929	82	22.1	1.47	12.82	32.5	0.27	32.49	
59a		9/27/1929				13.94	1610			
59b		9/28/1929				17.95	8070			
	60	3/16/1930					12			estimated
	61	3/16/1930					1			estimated
	62	3/18/1930	14	3.69	1.6		5.9	0.26	5.90	
	63	3/18/1930				6.62	643			estimated
	64	3/19/1930	96	86.4	4.48	6.46	387	0.90	387.07	
	65	3/20/1930	33	13.5	2.56	5.42	34.6	0.41	34.56	
	66	3/20/1930	23.9	8.59	1.96	5.27	16.8	0.36	16.84	
	67	3/21/1930				4.3	0.2			
	68	6/19/1930				6.19	356			channels
	69	6/19/1930	20	8.55	2.22	5.22	19	0.43	18.98	
	70	6/23/1930				5.33	154			channels
	71	7/8/1930				6.42	323			channels
	72	7/8/1930				5.73	101			channels
	73	7/9/1930				5.43	57.5			channels
	74	7/11/1930				5.47	26.8			channels
	75	7/11/1930				5.24	4.11			channels
75a		7/12/1930				4.89	0.1			
	76	7/22/1930	49	24.9	3.19	5.46	79.4	0.51	79.43	
	77	7/23/1930	23	9.6	2.36	5.17	22.7	0.42	22.66	
	78	7/24/1930	11.5	3.74	1.73	4.96	6.43	0.33	6.47	
	79	8/2/1930				6.32	300			
	80	8/2/1930	43.5	27.4	3.15	5.84	86.4	0.63	86.31	
	81	8/4/1930				6.59	38.3			channels
	82	8/7/1930	180	284	6.09	7.97	1730	1.58	1729.56	
	83	8/7/1930	178	290	5.55	7.72	1630	1.63	1609.50	
	84	8/7/1930	172	209	5.45	7.28	1140	1.22	1139.05	
	85	8/8/1930	124	124	4.61	6.49	572	1.00	571.64	
	86	8/8/1930	95	68.1	3.53	6.18	230	0.72	240.39	
	87	8/9/1930	54	18.6	2.02	5.37	37.5	0.34	37.57	

88	8/13/1930				5.28	1			
89	2/13/1931	160	140	4.17	5.89	651	0.88	583.80	
90	2/14/1931				6.15	151			channels
91	2/14/1931				6.16	149			channels
92	2/15/1931				5.74	31.7			channels
93	2/16/1931				6.9	1080			channels
94	2/17/1931	96	66.1	3.93	6.42	260	0.69	259.77	
95	2/18/1931	35	13.6	2.04	5.94	27.7	0.39	27.74	
96	6/30/1931	25	8.7	2.14		18.6	0.35	18.62	
97	7/14/1931	79.5	31.7	2.7	5.88	85.5	0.40	85.59	
98	7/23/1931				5.51	30.4			channels
99	7/29/1931	98.5	106	4.87	6.35	516	1.08	516.22	
100	7/29/1931	33	27.4	3.56		97.5	0.83	97.54	
101	7/29/1931	35	17.6	2.88		50.7	0.50	50.69	
102	7/29/1931	174	329	6.35	7.81	2090	1.89	2089.15	
103	7/30/1931	177	363	6.86	8.03	2490	2.05	2490.18	
104	7/30/1931	180	485	6.68	8.8	3240	2.69	3239.80	
105	7/31/1931	59	28.1	2.55	5.99	71.7	0.48	71.66	
106	7/31/1931	48	19.2	1.79	5.82	34.3	0.40	34.37	
107	8/1/1931				5.79	53.2			channels
108	8/1/1931				5.67	24			channels
109	8/1/1931	9	1.57	1.03	5.4	1.61	0.17	1.62	
110	8/3/1931	144	116	5.57	6.74	646	0.81	646.12	
111	8/5/1931				6.71	726			channels
112	8/6/1931	63	76.8	4.83	6.21	366	1.22	370.94	
113	8/7/1931	150	175	5.56	7.03	973	1.17	973.00	
114	8/8/1931	32	11	2.86	6.42	31.2	0.34	31.46	
115	8/9/1931	135	290	6.48	7.84	1880	2.15	1879.20	
116	8/10/1931	153	234	5.23	7.12	1210	1.53	1223.82	
117	8/10/1931	165	868	7.98	10.56	7040	5.26	6926.64	
118	8/10/1931	160	199	5.88	7.41	1170	1.24	1170.12	
119	8/11/1931				6.37	269			channels

120	8/12/1931				5.51	15.4			channels
121	8/16/1931	173	191	6.09	7.53	1160	1.10	1163.19	
122	8/18/1931				5.9	121			channels
123	8/20/1931	50	28.5	2.62	5.6	74	0.57	74.67	
124	8/21/1931	177	279	6.42	8.9	1790	1.58	1791.18	
125	8/22/1931	50	16.4	2.12		34.7	0.33	34.77	
126	8/23/1931				6.74	458			channels
127	8/31/1931				6.64	390			channels
128	9/2/1931				6.92	447			channels
129	9/29/1931	135	143	5.03	6.91	719	1.06	719.29	
130	10/1/1931				5.6	0.4			
131	11/22/1931				6.83	509			channels
132	11/23/1931				6.21	189			
133	11/24/1931	35	13	2.25	5.7	29.3	0.37	29.25	

Nogales	Date	avg. width	avg. Area	avg. Veloci	Gage ht.	Q	calc_AvgDepth	Q from A*V	notes
		feet	sq. feet	ft/sec	feet	ft^3/sec	feet		
	1/26/1913	10	3.2	1.5	1.64	4.80	0.32	4.80	
	2/16/1913	24	9.7	1.61	1.77	15.60	0.40	15.62	
	2/19/1913	14	6.5	1.69	1.77	11.00	0.46	10.99	
	3/19/1913	18			1.92	11.00			
	4/23/1913	1.8	0.43	1.2	1.77	0.50	0.24	0.52	
	7/29/1913					0.00			
	8/19/1913	1.4	0.42	1.43	1.35	0.60	0.30	0.60	
	9/17/1913				1.48	0.00			
	11/20/1913	55	21.2	1.9	1.84	40.70	0.39	40.28	
	1/9/1914	2.5			1.51	0.93			
	2/14/1914					0.00			
	3/3/1914					0.00			
	6/26/1914					0.00			
	8/22/1914	59	30.6	1.94	1.93	59.40	0.52	59.36	
	11/24/1914	44	15.8	1.51	2.25	24.00	0.36	23.86	
	12/18/1914	45	17	1.54	0.98	26.00	0.38	26.18	
	1/22/1915	50	31	2.88	0.65	89.00	0.62	89.28	
	3/13/1915				0.6	0.00			
	10/23/1915					0.00			
	12/7/1915	23	6.9	1.3	1.15	9.00	0.30	8.97	
	12/7/1915	23	7.3	1.37	1.15	10.00	0.32	10.00	
	1/3/1916	28	11.3	1.82	1.49	20.60	0.40	20.57	
	1/3/1916	28	11.6	1.72	1.49	20.60	0.41	19.95	
	2/20/1916	52	24.9	1.86	1.75	46.30	0.48	46.31	
	2/20/1916	52	25.2	1.92	1.75	48.50	0.48	48.38	
	3/23/1916	24	14.3	1.87	1.73	26.80	0.60	26.74	
	3/23/1916	24	14.6	1.85	1.73	27.00	0.61	27.01	
	4/23/1916	20	5.8	1.11	1.63	6.50	0.29	6.44	
	4/23/1916	20	5.8	1.14	1.63	6.60	0.29	6.61	
	7/26/1916	38	9.4	1.32	1.47	12.40	0.25	12.41	
	7/26/1916	39	10.7	1.32	1.47	14.10	0.27	14.12	
	8/11/1916	52	16.9	1.42	1.55	24.00	0.33	24.00	
40	10/9/1916	9.3	2.1	1.1	1.25	2.30	0.23	2.31	

41	10/20/1916	10.4	2	0.75	1.3	1.50	*0.19*	*1.50*
42	10/30/1916	13	2.4	0.91	1.3	2.20	*0.18*	*2.18*
43	11/10/1916	10.3	2	1	1.3	2.00	*0.19*	*2.00*
44	11/20/1916	13.4	2.5	0.84	1.3	2.10	*0.19*	*2.10*
45	11/29/1916	14	2.9	1.07	1.3	3.10	*0.21*	*3.10*
46	12/10/1916	16	6.1	1.47	1.35	9.00	*0.38*	*8.97*
47	12/22/1916	19	5.1	3.96	1.3	20.20	*0.27*	*20.20*
48	12/29/1916	20.3	7.5	1.27	1.4	9.60	*0.37*	*9.53*
49	1/9/1917	26	8.8	1.32	1.35	11.60	*0.34*	*11.62*
50	1/22/1917	62	24.1	1.16	1.45	27.20	*0.39*	*27.96*
51	1/30/1917	24	10.4	1.4	1.35	14.60	*0.43*	*14.56*
52	2/9/1917	25	7.1	1.35	1.35	9.60	*0.28*	*9.59*
53	2/20/1917	27	11.2	1.47	1.4	16.50	*0.41*	*16.46*
54	2/28/1917	25	8.9	1.4	1.4	12.40	*0.36*	*12.46*
55	3/9/1917	25	4.9	0.98	1.3	4.80	*0.20*	*4.80*
56	3/20/1917	22	3.5	0.92	1.25	3.20	*0.16*	*3.22*
57	3/30/1917	16.3	3.4	1.12	1.25	3.80	*0.21*	*3.81*
58	4/10/1917	20	3.6	0.97	1.2	3.50	*0.18*	*3.49*
59	4/20/1917	16.3	3.3	0.94	1.1	3.10	*0.20*	*3.10*
60	4/30/1917	19	2.9	0.72	1.1	2.10	*0.15*	*2.09*
61	7/21/1917	43	17.5	1.43	1.45	25.00	*0.41*	*25.03*
62	7/27/1917	91	75	2.93	2.35	220.00	*0.82*	*219.75*
63	8/5/1917	80	63	1.84	1.9	122.00	*0.79*	*115.92*
64	8/17/1917	40	21.9	1.76	1.5	38.60	*0.55*	*38.54*
65	8/25/1917	40	14.2	1.41	1.35	20.10	*0.36*	*20.02*
67	8/30/1917	35	12.2	1.48	1.39	18.00	*0.35*	*18.06*
66	8/30/1917	35	12.6	1.47	1.39	18.60	*0.36*	*18.52*
68	9/7/1917	40	24.2	1.99	1.55	48.20	*0.61*	*48.16*
69	9/14/1917	40	23.2	2.15	1.6	50.00	*0.58*	*49.88*
70	9/21/1917	46.2	25.8	2.29	1.7	59.00	*0.56*	*59.08*
71	9/28/1917	40.2	15.7	1.35	1.4	21.10	*0.39*	*21.20*
72	10/12/1917	20	5	1.16	1.31	5.80	*0.25*	*5.80*
73	10/22/1917	20.2	4.7	1.36	1.35	6.40	*0.23*	*6.39*
74	10/31/1917	20	5.6	1.48	1.36	8.30	*0.28*	*8.29*
75	11/9/1917	19.3	7	1.49	1.38	10.40	*0.36*	*10.43*

76	11/19/1917	19	7.8	1.64	1.4	12.80	*0.41*	*12.79*
77	11/30/1917	20	7.2	1.65	1.38	11.90	*0.36*	*11.88*
78	12/7/1917	21.3	7.6	1.53	1.35	11.60	*0.36*	*11.63*
79	12/21/1917	21.3	5.4	1.22	1.35	6.60	*0.25*	*6.59*
80	1/4/1918	20.4	4.3	1.16	1.35	5.00	*0.21*	*4.99*
81	1/18/1918	20.4	6.4	1.41	1.37	9.00	*0.31*	*9.02*
82	1/31/1918	42.4	18.6	1.56	1.48	29.00	*0.44*	*29.02*
83	2/15/1918	20.3	7.7	1.38	1.45	10.60	*0.38*	*10.63*
84	2/23/1918	20.3	7.4	1.47	1.45	10.90	*0.36*	*10.88*
85	2/28/1918	40.3	19.2	1.63	1.5	31.40	*0.48*	*31.30*
86	3/8/1918	20.2	6.1	1.31	1.45	8.00	*0.30*	*7.99*
87	3/22/1918	19	2.9	0.86	1.43	2.50	*0.15*	*2.49*
88	3/29/1918	15	1.6	0.75	1.4	1.20	*0.11*	*1.20*
89	4/5/1918	18.3	2.9	0.83	1.4	2.40	*0.16*	*2.41*
90	4/19/1918	15.4	1.7	0.82	1.4	1.40	*0.11*	*1.39*
91	4/25/1918	3.2	0.5	1	1.29	0.50	*0.16*	*0.50*
92	1/8/1919				1.1	0.00		
93	3/11/1919	16	2.9	1	1.32	2.90	*0.18*	*2.90*
94	5/24/1919				1.1	0.00		
95	7/2/1919	60	27.6	1.78	1.8	49.00	*0.46*	*49.13*
96	7/18/1919	48.5	27.9	2.04	2	57.00	*0.58*	*56.92*
97	7/19/1919	75	30.3	1.54	1.93	47.00	*0.40*	*46.66*
98	7/20/1919	74	23.7	1.4	1.87	33.00	*0.32*	*33.18*
99	7/25/1919	21.5	6.3	1.27	1.7	8.00	*0.29*	*8.00*
100	8/10/1919	81	35.4	1.84	2.08	65.00	*0.44*	*65.14*
101	8/15/1919	45	16.4	1.51	1.92	25.00	*0.36*	*24.76*
102	8/22/1919	11	2.5	1.12	1.74	2.80	*0.23*	*2.80*
103	8/29/1919	48	19.5	2.12	1.98	41.00	*0.41*	*41.34*
104	9/5/1919	24	9.8	1.76	1.85	17.00	*0.41*	*17.25*
105	10/3/1919	19	5.4	1.44	1.9	7.80	*0.28*	*7.78*
106	10/10/1919	22	5.4	1.19	1.93	6.40	*0.25*	*6.43*
107	10/17/1919	15	5.8	1.6	2	9.30	*0.39*	*9.28*
108	10/24/1919	19	6.7	1.64	1.98	11.00	*0.35*	*10.99*
109	10/31/1919	16	6.1	1.87	2	11.40	*0.38*	*11.41*
110	11/7/1919	16	5.5	1.67	1.99	9.20	*0.34*	*9.19*

111	11/14/1919	16	6.8	1.54	2	10.50	*0.43*	*10.47*
112	11/21/1919	15	7	1.79	1.99	12.50	*0.47*	*12.53*
113	12/5/1919	54	28.4	2.57	2.3	73.00	*0.53*	*72.99*
114	12/12/1919	48	19.1	2.12	2.2	40.40	*0.40*	*40.49*
115	12/20/1919	46	16.3	1.61	2.18	26.20	*0.35*	*26.24*
116	12/27/1919	20	6.5	2.34	2.12	15.20	*0.33*	*15.21*
117	1/2/1920	18	6.7	1.73	2.13	11.60	*0.37*	*11.59*
118	1/8/1920	82	43.7	2.77	2.44	121.00	*0.53*	*121.05*
119	1/16/1920	72	53	2.87	2.54	152.00	*0.74*	*152.11*
120	1/23/1920	42	18.3	2.09	2.41	38.20	*0.44*	*38.25*
121	1/29/1920	32	12.9	2.14	2.34	27.60	*0.40*	*27.61*
122	2/6/1920	22	10.2	2.22	2.33	22.60	*0.46*	*22.64*
123	2/13/1920	51	16.4	1.8	2.32	29.50	*0.32*	*29.52*
124	2/20/1920	44	11.8	1.67	2.31	19.70	*0.27*	*19.71*
125	2/28/1920	30	9.8	1.56	2.26	15.30	*0.33*	*15.29*
126	3/5/1920	36	11.5	1.45	2.22	16.70	*0.32*	*16.68*
127	3/12/1920	23	6.2	1.4	2.21	8.70	*0.27*	*8.68*
128	3/19/1920	21	4.8	0.96	2.18	4.60	*0.23*	*4.61*
129	3/26/1920	19	9.4	1.26	2.25	11.80	*0.49*	*11.84*
130	4/2/1920	16	4.6	1.48	2.2	6.80	*0.29*	*6.81*
131	4/9/1920	16	2.1	1.05	2.1	2.20	*0.13*	*2.21*
132	4/16/1920	14	2.7	1.37	2.12	3.70	*0.19*	*3.70*
133	4/23/1920	16	4.2	1.26	2.18	5.30	*0.26*	*5.29*
134	4/30/1920	11	1.8	1	2.1	1.80	*0.16*	*1.80*
135	5/7/1920	13	1.8	0.94	2.05	1.70	*0.14*	*1.69*
136	5/14/1920	6	1	1.2	2.05	1.20	*0.17*	*1.20*
137	5/21/1920	6	1	1.1	2.02	1.10	*0.17*	*1.10*
138	7/23/1920	18			2.3	7.40		
139	7/27/1920				2.64	10.00		
140	7/30/1920				2	3.30		
141	8/1/1920				2.45	12.00		
142	8/6/1920				1.95	11.00		
143	8/11/1920				2.4	89.00		
144	8/13/1920				2.25	35.00		
145	8/18/1920				2.66	125.00		

146	8/24/1920				2.56	15.00			
147	8/27/1920				1.93	9.20			
148	8/31/1920				1.82	2.20			
149	9/16/1920	17.6	4.6	1.04	1.85	4.80	*0.26*	*4.78*	
150	2/8/1921	4.5	2.6	0.93	1.62	2.40	*0.58*	*2.42*	
151	2/28/1921	6	2.1	1.16	1.62	2.50	*0.35*	*2.44*	
152	3/8/1921	4.5	1.6	0.69	1.58	1.90	*0.36*	*1.10*	
153	3/12/1921	4	1.6	0.74	1.58	1.70	*0.40*	*1.18*	
1	7/20/1921				5.25	44.00			Two channels
4	7/20/1921				5.36	78.00			Two channels
3	7/20/1921				5.4	98.00			Two channels
2	7/20/1921				5.5	154.00			Two channels
5	7/21/1921				5.3	28.00			Two channels
6	12/1/1921	44			5.1	10.00			Channels
7	12/2/1921				5.13	11.00			Channels
8	1/2/1922	40	9	1.24	5.14	11.00	*0.23*	*11.16*	
9	2/22/1922	22	5.7	1.31	5.12	7.50	*0.26*	*7.47*	
10	3/14/1922	42	11	0.91	5.15	10.00	*0.26*	*10.01*	
1	5/10/1930	14	2.7	1.15	2.96	3.12	*0.19*	*3.11*	
2	5/24/1930				2.85	0.75			
3	5/30/1930				2.8	0.20			
4	6/4/1930	4.5	0.94	0.62	2.97	0.58	*0.21*	*0.58*	
5	6/17/1930	11	5	1.83	2.89	9.16	*0.45*	*9.15*	
6	6/21/1930	10.2	2.57	1.02	2.86	2.61	*0.25*	*2.62*	
8	6/22/1930	38	19.2	2.19	3.33	42.20	*0.51*	*42.05*	
7	6/22/1930	60.5	35.9	2.69	3.34	96.70	*0.59*	*96.57*	
9	7/1/1930	6.5	0.7	0.5	2.67	0.35	*0.11*	*0.35*	
10	7/10/1930	5.5	0.77	0.78	2.68	0.60	*0.14*	*0.60*	
11	7/23/1930	35	22.2	2.42	3.22	53.60	*0.63*	*53.72*	
12	7/31/1930		14.8	1.69	3.11	25.00		*25.01*	Channels
13	8/7/1930	55	130	4.62	4.21	601.00	*2.36*	*600.60*	
14	8/10/1930	36	23.6	2.44	3.35	57.60	*0.66*	*57.58*	
15	8/10/1930	57	41.8	3.04	3.63	127.00	*0.73*	*127.07*	

16	8/15/1930	21	9.7	1.94	3.17	18.80	*0.46*	*18.82*
17	9/2/1930	13.3	3.83	1.54	3.01	5.89	*0.29*	*5.90*
18	9/29/1930	5.5	0.9	0.84	2.89	0.76	*0.16*	*0.76*
19	10/13/1930	6	1.17	1.1	2.89	1.29	*0.20*	*1.29*
20	11/3/1930	7	1.41	1.16	2.96	1.64	*0.20*	*1.64*
21	11/24/1930	13.5	3.68	1.16	3.07	4.27	*0.27*	*4.27*
22	12/15/1930	26	5.68	1.11	3.2	6.32	*0.22*	*6.30*
23	1/7/1931	16	4.56	1.24	3.16	5.67	*0.29*	*5.65*
24	1/26/1931	16.5	4.71	1.15	3.14	5.41	*0.29*	*5.42*
25	2/15/1931	62	125	6.03	4.74	754.00	*2.02*	*753.75*
26	2/16/1931	60	98.8	5.3	4.32	524.00	*1.65*	*523.64*
27	2/17/1931	92.5	70.1	3.15	3.87	221.00	*0.76*	*220.82*
28	2/19/1931	92	44.5	2.22	3.49	99.00	*0.48*	*98.79*
29	3/2/1931	90	28.4	1.47	3.43	41.70	*0.32*	*41.75*
30	3/23/1931	41.5	11	1.25	3.23	13.90	*0.27*	*13.75*
31	4/13/1931	27	6.5	1.2	3.13	7.82	*0.24*	*7.80*
33	5/1/1931	6.6	1.82	1.67	3.12	3.04	*0.28*	*3.04*
32	5/1/1931	7.2	2.29	1.37	3.11	3.14	*0.32*	*3.14*
34	5/25/1931				3.02	0.40		
35	7/9/1931	6.5	1.02	0.86	2.46	0.88	*0.16*	*0.88*
36	7/31/1931	62	43.1	2.22	3.42	95.50	*0.70*	*95.68*
37	8/4/1931	60	90.2	3.54	4.16	319.00	*1.50*	*319.31*
41	8/5/1931	59	105	4.41	4.21	463.00	*1.78*	*463.05*
39	8/5/1931	57	115	4.89	4.33	562.00	*2.02*	*562.35*
40	8/5/1931	58	116	4.88	4.23	566.00	*2.00*	*566.08*
38	8/5/1931	56	146	4.68	4.54	683.00	*2.61*	*683.28*
43	8/6/1931	67	105	4.37	4.27	459.00	*1.57*	*458.85*
42	8/6/1931	67	111	5.15	4.37	572.00	*1.66*	*571.65*
44	8/11/1931	59	102	4	3.99	408.00	*1.73*	*408.00*
45	8/15/1931	82	36.1	1.89	3.38	68.40	*0.44*	*68.23*
46	8/18/1931	75	32.9	1.98	3.38	65.00	*0.44*	*65.14*
48	9/2/1931	96	112	3.79	4.25	425.00	*1.17*	*424.48*
47	9/2/1931	92	123	4.89	4.43	607.00	*1.34*	*601.47*
49	9/17/1931	66	40.2	2.56	3.41	103.00	*0.61*	*102.91*
50	9/29/1931	67	74	3.43	3.8	254.00	*1.10*	*253.82*

51	10/5/1931	58	24.2	1.71	3.23	41.40	*0.42*	*41.38*	
52	10/19/1931				3.21	25.20			Channels
53	11/19/1931				3.15	19.10			Channels
54	11/23/1931	84	46.2	2.51	3.56	116.00	*0.55*	*115.96*	
55	12/10/1931	74	27.1	1.68	3.32	45.40	*0.37*	*45.53*	
56	12/31/1931				3.17	23.90			Channels
57	1/14/1932	74	204	6.67	4.98	1360.00	*2.76*	*1360.68*	
59	1/15/1932	89	98.8	3.87	3.69	382.00	*1.11*	*382.36*	
58	1/15/1932	89	110	4.11	3.83	452.00	*1.24*	*452.10*	
60	1/26/1932	58	25.2	1.92	3.04	48.30	*0.43*	*48.38*	
61	2/10/1932	59	30.2	1.73	3.03	52.20	*0.51*	*52.25*	
62	2/21/1932	59	30.9	2	3.07	61.70	*0.52*	*61.80*	
63	3/2/1932	52.5	22.6	1.91	2.97	43.20	*0.43*	*43.17*	
64	3/24/1932	44.5	12.3	1.28	2.72	15.70	*0.28*	*15.74*	
65	4/7/1932	14	6.06	1.56	2.64	9.50	*0.43*	*9.45*	
66	4/20/1932	13	4.4	1.34	2.57	5.91	*0.34*	*5.90*	
67	5/3/1932	13.5	3.5	1.01	2.55	3.52	*0.26*	*3.54*	
68	5/17/1932	11	1.31	0.76	2.55	1.00	*0.12*	*1.00*	
69	6/1/1932	6	0.76	0.74	2.44	0.56	*0.13*	*0.56*	
70	6/15/1932	2	0.24	0.67	2.41	0.16	*0.12*	*0.16*	
71	7/8/1932		743	7.16	9.6	5300.00		*5319.88*	
72	7/9/1932	53	33.1	2.4	2.16	79.50	*0.62*	*79.44*	
73	7/10/1932	36.5	14.6	1.86	1.67	27.10	*0.40*	*27.16*	
74	7/13/1932	18	8.98	1.34	1.47	11.90	*0.50*	*12.03*	
75	7/15/1932	32.5	6.94	1.08	1.38	7.51	*0.21*	*7.50*	
76	7/29/1932	47	63.6	3.02	3.16	192.00	*1.35*	*192.07*	
77	7/30/1932	65	75.8	3.15	3.11	239.00	*1.17*	*238.77*	
78	8/8/1932	45	35.2	2.56	2.89	90.10	*0.78*	*90.11*	
79	8/12/1932	61	28.2	2.28	2.73	64.40	*0.46*	*64.30*	
80	8/24/1932				2.81	86.80			Channels
82	8/27/1932	83	62.8	2.75	3.22	173.00	*0.76*	*172.70*	
81	8/27/1932	117	83.8	3.09	3.45	259.00	*0.72*	*258.94*	
83	9/10/1932	8.1	4.5	1.52	2.36	6.83	*0.56*	*6.84*	
84	9/23/1932	10	3.21	1.32	2.17	4.23	*0.32*	*4.24*	
85	10/1/1932	16	4.67	1.33	2.25	6.22	*0.29*	*6.21*	

86	10/4/1932	9.5	3.77	1.36	2.2	5.12	*0.40*	*5.13*	
87	10/12/1932	11	3.9	1.38	2.21	5.38	*0.35*	*5.38*	
88	10/15/1932	10.5	3.45	1.28	2.16	4.40	*0.33*	*4.42*	
89	11/1/1932	13	4.12	1.47	2.14	6.14	*0.32*	*6.06*	
90	11/19/1932	18	6.9	1.61	2.25	11.10	*0.38*	*11.11*	
91	12/11/1932	19	6.31	1.54	2.21	9.71	*0.33*	*9.72*	
92	12/28/1932	18.5	9.86	1.61	2.3	15.90	*0.53*	*15.87*	
93	1/13/1933	18	6.69	1.48	2.23	9.88	*0.37*	*9.90*	
94	2/2/1933	39	15.4	1.45	3.52	22.30	*0.39*	*22.33*	
95	2/16/1933	38	12.4	1.54	2.47	19.10	*0.33*	*19.10*	
96	3/1/1933				2.38	18.80			Channels
97	3/14/1933	14	6.3	1.79	2.29	11.30	*0.45*	*11.28*	
98	3/23/1933	21.5	5.72	1.24	2.22	7.09	*0.27*	*7.09*	
99	4/10/1933	15	4.74	1.22	2.17	5.76	*0.32*	*5.78*	
100	4/24/1933	15	2.75	0.9	1.98	2.48	*0.18*	*2.48*	
101	5/8/1933	5	1.45	1.34	2.05	1.94	*0.29*	*1.94*	
102	5/21/1933	5	1.25	1.06	3.06	1.34	*0.25*	*1.33*	
103	6/4/1933	4	1.06	0.74	3.03	0.78	*0.27*	*0.78*	
104	6/20/1933	4	0.85	1.11	3.06	0.94	*0.21*	*0.94*	
105	7/5/1933	3	0.6	0.62	2.02	0.37	*0.20*	*0.37*	
106	7/17/1933	19.5	6.1	1.09	2.15	6.65	*0.31*	*6.65*	
107	7/30/1933	3	0.36	0.78	1.98	0.66	*0.12*	*0.28*	
108	8/9/1933	5	1.2	1.13	1.31	1.36	*0.24*	*1.36*	
109	8/21/1933	4.5	0.75	0.87	1.78	0.65	*0.17*	*0.65*	
110	9/5/1933	4	0.7	1	1.86	0.70	*0.18*	*0.70*	
111	9/15/1933	5	0.9	0.74	1.84	0.67	*0.18*	*0.67*	
112	9/27/1933	8	2.14	0.63	1.85	1.34	*0.27*	*1.35*	
113	10/8/1933	22	6.9	1.35	2.28	9.29	*0.31*	*9.32*	
114	5/27/1935	5	0.8	0.78	2.3	0.62	*0.16*	*0.62*	
115	7/14/1935				2.21	0.50			
116	7/21/1935	2.5	0.38	0.74	2.03	0.28	*0.15*	*0.28*	
117	7/29/1935				2	0.20			
118	8/5/1935	45	27	2.5	2.9	67.50	*0.60*	*67.50*	

119	8/12/1935	22	6.35	1.4	2.44	8.90	*0.29*	*8.89*
120	8/16/1935	40.5	24.5	1.96	2.72	48.10	*0.60*	*48.02*
121	8/26/1935	52	30.6	2.64	2.8	80.90	*0.59*	*80.78*
122	8/31/1935	69	536	4.18	5.59	2240.00	*7.77*	*2240.48*
123	9/1/1935	66	129	3.86	3.75	498.00	*1.95*	*497.94*
124	9/2/1935	68	79.4	3.07	3.47	244.00	*1.17*	*243.76*
125	9/3/1935	37	17.6	2.21	2.83	38.70	*0.48*	*38.90*
127	9/21/1935	23	9.39	1.53	2.6	14.40	*0.41*	*14.37*
128	10/6/1935	14	6.74	1.59	2.65	10.70	*0.48*	*10.72*
129	10/20/1935	13.5	5.88	1.77	2.59	10.40	*0.44*	*10.41*
130	11/3/1935	13.5	6.58	1.7	2.57	11.20	*0.49*	*11.19*
131	11/17/1935	10	6.5	1.77	2.61	11.50	*0.65*	*11.51*
132	12/1/1935	12	8.1	2.37	2.77	19.20	*0.68*	*19.20*
133	12/15/1935	13	5.9	2.25	2.73	13.30	*0.45*	*13.28*
134	12/28/1935	21	10.4	1.91	2.82	19.90	*0.50*	*19.86*
135	1/14/1936	20	7.1	1.89	2.72	13.40	*0.36*	*13.42*
136	1/25/1936	8	4	1.92	2.65	7.66	*0.50*	*7.68*
137	2/5/1936	21	7.25	1.77	2.57	12.80	*0.35*	*12.83*
138	2/24/1936	17	7.58	1.64	2.68	12.40	*0.45*	*12.43*
139	3/15/1936	10	3.3	1.59	2.52	5.26	*0.33*	*5.25*
140	3/30/1936	11	3.6	1.7	2.53	6.12	*0.33*	*6.12*
141	4/10/1936	10	3.45	1.47	2.62	5.07	*0.35*	*5.07*
142	4/30/1936	6.5	1.39	1.02	2.45	1.42	*0.21*	*1.42*
143	5/21/1936	3.5	0.5	0.74	2.41	0.37	*0.14*	*0.37*
144	6/11/1936	1	0.1	0.5	2.36	0.05	*0.10*	*0.05*
145	7/6/1936	2	0.2	0.6	1.77	0.12	*0.10*	*0.12*
146	7/21/1936	21	10.4	2.73	2.4	28.40	*0.50*	*28.39*
147	7/27/1936	36	13.7	2.09	2.85	28.70	*0.38*	*28.63*
148	8/7/1936	23	9.7	1.77	2.8	17.20	*0.42*	*17.17*
149	8/8/1936	34	20.2	2.16	3.09	43.60	*0.59*	*43.63*
150	8/14/1936	32	10.3	1.48	2.9	15.20	*0.32*	*15.24*
151	8/21/1936	38	13	1.46	3.04	19.00	*0.34*	*18.98*
152	8/31/1936	9	1.7	1.05	2.77	1.79	*0.19*	*1.79*
153	9/12/1936	40	17	2.19	3.15	37.30	*0.43*	*37.23*
154	9/28/1936	5	0.7	1.01	2.67	0.71	*0.14*	*0.71*

155	10/16/1936	6	0.9	0.86	2.64	0.77	*0.15*	*0.77*	
156	10/29/1936	4.5	1.02	1.24	2.67	1.27	*0.23*	*1.26*	
157	11/17/1936	9.5	2.64	1.22	2.72	3.23	*0.28*	*3.22*	
158	12/1/1936	15	5.34	1.42	2.78	7.56	*0.36*	*7.58*	
159	12/9/1936	15	4.55	1.4	2.73	6.36	*0.30*	*6.37*	
160	12/31/1936	15	5.59	1.73	2.8	9.69	*0.37*	*9.67*	
161	1/18/1937	37	16	1.66	3.17	26.50	*0.43*	*26.56*	
162	2/8/1937				3.11	12.20			Channels
163	2/17/1937	34.5	8.53	1.06	3.08	9.04	*0.25*	*9.04*	
164	2/27/1937	16.5	6.31	1.18	3.06	7.45	*0.38*	*7.45*	
165	3/16/1937				3.06	7.51			Channels
166	3/30/1937	19	5.12	1.15	3.03	5.91	*0.27*	*5.89*	
167	4/19/1937	11	2.33	1	2.96	2.32	*0.21*	*2.33*	
168	5/10/1937	2.8	0.53	0.89	2.86	0.47	*0.19*	*0.47*	
169	6/1/1937	3.5	0.84	0.29	2.8	0.24	*0.24*	*0.24*	
170	7/9/1937	12	2.58	0.88	2.84	2.27	*0.22*	*2.27*	
171	7/29/1937	7	1.99	0.86	2.39	1.72	*0.28*	*1.71*	
172	8/11/1937	23.5	5.78	1.3	2.96	7.53	*0.25*	*7.51*	
173	8/17/1937	46.5	23.2	2.58	2.83	59.90	*0.50*	*59.86*	
175	8/21/1937	93	75	3.34	3.93	250.00	*0.81*	*250.50*	
174	8/21/1937	94	84.8	3.49	4.67	296.00	*0.90*	*295.95*	
176	8/22/1937	42	23.8	2.35	3.36	56.00	*0.57*	*55.93*	
177	8/22/1937	72	179	8.32	6.4	1490.00	*2.49*	*1489.28*	
178	8/23/1937	49	35.6	2.85	3.25	101.00	*0.73*	*101.46*	
181	8/23/1937	74	111	5.39	4.34	598.00	*1.50*	*598.29*	
180	8/23/1937	72	158	5.16	5.44	815.00	*2.19*	*815.28*	
182	8/23/1937	75	172	5.02	5.05	864.00	*2.29*	*863.44*	
179	8/23/1937	77	198	5.86	8.05	1160.00	*2.57*	*1160.28*	
183	8/24/1937	66	50.4	3.41	3.55	172.00	*0.76*	*171.86*	
184	8/27/1937	37	17.8	2.11	3.22	37.60	*0.48*	*37.56*	
185	9/3/1937	60	43.9	2.73	3.72	120.00	*0.73*	*119.85*	
186	9/16/1937	36	15.5	1.66	3.38	25.80	*0.43*	*25.73*	
187	10/4/1937	9	5.25	1.67	3.19	8.77	*0.58*	*8.77*	
188	10/19/1937	8	6.4	2.44	3.24	15.60	*0.80*	*15.62*	
189	11/8/1937	18.5	5.29	1.31	3.13	6.95	*0.29*	*6.93*	

190	11/29/1937	6.5	3.92	1.85	3.1	7.26	*0.60*	*7.25*	
191	12/20/1937	11	4.4	1.53	3.06	6.72	*0.40*	*6.73*	
192	1/7/1938	8	2.8	1.56	3	4.37	*0.35*	*4.37*	
193	1/28/1938	10	3.8	1.69	3.02	6.41	*0.38*	*6.42*	
194	2/18/1938	6.5	3.51	1.92	3.01	6.74	*0.54*	*6.74*	
195	3/7/1938	26	7.4	1.3	3.1	9.60	*0.28*	*9.62*	
196	4/7/1938	2.5	0.64	0.91	2.8	0.58	*0.26*	*0.58*	
197	4/27/1938	2.5	0.25	0.91	2.68	0.23	*0.10*	*0.23*	
198	5/25/1938	3	0.9	0.75	2.67	0.68	*0.30*	*0.68*	
199	8/1/1938	11.5	2.95	1.22	2.57	3.59	*0.26*	*3.60*	
200	8/2/1938	42	24.4	2.25	3.16	55.00	*0.58*	*54.90*	
201	8/5/1938	27.5	9.93	1.67	2.93	16.60	*0.36*	*16.58*	
202	8/7/1938	26	7.71	1.53	2.74	11.80	*0.30*	*11.80*	
203	8/22/1938	3.5	4.75	0.77	2.76	0.37	*1.36*	*3.66*	
204	9/8/1938	24	12.7	1.68	2.96	21.30	*0.53*	*21.34*	
205	9/14/1938	26	12.4	1.8	3.01	22.30	*0.48*	*22.32*	
206	9/30/1938				2.62	1.00			Estimated
207	10/19/1938	5.00	1.09	0.92	2.62	1.00	*0.22*	*1.00*	
208	11/8/1938	4.00	0.70	0.71	2.63	0.50	*0.18*	*0.50*	
209	11/29/1938	5.00	1.13	0.79	2.61	0.89	*0.23*	*0.89*	
210	12/8/1938	4.00	0.89	0.63	2.76	0.56	*0.22*	*0.56*	
211	12/27/1938	11.00	4.80	1.59	2.70	7.63	*0.44*	*7.63*	
212	1/24/1939	11.00	4.25	1.17	2.73	4.98	*0.39*	*4.97*	
213	2/13/1939	11.00	5.30	1.57	2.71	8.33	*0.48*	*8.32*	
214	3/7/1939	10.00	3.06	1.28	2.59	3.91	*0.31*	*3.92*	
215	3/30/1939	10.00	3.09	1.29	2.60	3.99	*0.31*	*3.99*	
216	4/27/1939	3.00	0.76	0.39	2.51	0.30	*0.25*	*0.30*	
217	7/6/1939	2.50	0.25	0.32	2.69	0.08	*0.10*	*0.08*	
218	7/18/1939	72.00	96.00	3.95	4.39	379.00	*1.33*	*379.20*	
219	7/19/1939	31.00	12.40	1.83	2.93	22.70	*0.40*	*22.69*	
220	7/21/1939	52.00	27.40	2.50	3.34	68.50	*0.53*	*68.50*	
221	7/22/1939	64.00	52.80	2.52	3.40	133.00	*0.83*	*133.06*	
222	7/23/1939	40.00	18.00	1.77	2.91	31.80	*0.45*	*31.86*	
223	8/1/1939	16.00	4.70	1.39	2.80	6.51	*0.29*	*6.53*	
224	8/4/1939	41.00	27.50	2.23	3.04	61.40	*0.67*	*61.33*	

226	8/5/1939	70.00	81.10	3.67	3.89	298.00	*1.16*	*297.64*	
225	8/5/1939	70.00	88.60	3.40	3.97	301.00	*1.27*	*301.24*	
227	8/9/1939	75.00	53.80	3.18	3.37	171.00	*0.72*	*171.08*	
229	8/9/1939	70.00	77.50	3.90	3.86	302.00	*1.11*	*302.25*	
228	8/9/1939	70.00	101.00	4.54	4.35	459.00	*1.44*	*458.54*	
230	8/14/1939	65.00	67.60	2.47	2.87	167.00	*1.04*	*166.97*	
231	8/15/1939	72.00	52.60	2.32	3.02	122.00	*0.73*	*122.03*	
232	8/29/1939	66.00	57.70	2.22	3.21	128.00	*0.87*	*128.09*	
233	9/7/1939	34.00	20.00	2.01	2.90	40.20	*0.59*	*40.20*	
234	9/9/1939	40.00	18.50	1.84	2.96	34.10	*0.46*	*34.04*	
235	9/25/1939	20.00	5.48	1.43	2.87	7.84	*0.27*	*7.84*	
236	10/9/1939	52.00	24.60	2.15	3.06	53.00	*0.47*	*52.89*	
237	10/31/1939	29.00	6.72	1.10	2.85	7.40	*0.23*	*7.39*	
238	11/21/1939	29.00	7.36	1.10	2.88	8.12	*0.25*	*8.10*	
240	12/12/1939				2.98	8.48			Channels
239	12/12/1939	25.00	7.57	1.26	2.95	9.55	*0.30*	*9.54*	
241	12/29/1939	29.50	6.09	1.06	2.92	6.48	*0.21*	*6.46*	
242	1/19/1940				2.94	9.23			Channels
243	2/6/1940				3.06	19.50			Channels
244	2/26/1940	41.5	17.1	1.73	3.16	29.60	*0.41*	*29.58*	
245	3/13/1940	28	5.97	1.15	3.01	6.85	*0.21*	*6.87*	
246	4/3/1940	13	3.54	1.27	3.00	4.50	*0.27*	*4.50*	
247	4/23/1940	9.5	1.5	0.87	2.95	1.30	*0.16*	*1.31*	
248	5/13/1940	2.5	0.32	0.72	2.86	0.23	*0.13*	*0.23*	
249	7/25/1940				3.08	20.00			Channels
250	8/1/1940	4.5	1.29	0.67	2.71	0.87	*0.29*	*0.86*	
251	8/8/1940				2.61	2.76			Channels
252	8/14/1940	48	47.4	3.59	3.55	170.00	*0.99*	*170.17*	
253	8/14/1940	74	79.2	3.79	4.05	300.00	*1.07*	*300.17*	
254	8/19/1940	61	29	2.14	3.25	62.10	*0.48*	*62.06*	
255	8/20/1940	35	10.4	1.51	3.16	15.70	*0.30*	*15.70*	
256	8/27/1940				3.01	3.83			Channels
257	9/5/1940	6	0.86	0.49	2.81	0.42	*0.14*	*0.42*	
258	9/18/1940	6	0.95	0.81	2.84	0.77	*0.16*	*0.77*	
259	10/2/1940	5.5	0.83	0.73	2.79	0.61	*0.15*	*0.61*	

260	10/17/1940	6	0.95	0.83	2.84	0.79	*0.16*	*0.79*	
261	11/8/1940	9	2.15	0.84	2.88	1.80	*0.24*	*1.81*	
262	12/5/1940	10	2.36	1.1	2.93	2.59	*0.24*	*2.60*	
263	12/17/1940	11.5	4.52	1.7	3.00	7.69	*0.39*	*7.68*	
264	1/3/1941	28	8.6	1.33	3.02	11.40	*0.31*	*11.44*	
265	1/23/1941	23.5	5.09	1.05	2.98	5.36	*0.22*	*5.34*	
266	2/24/1941	59	29	2.06	3.54	59.80	*0.49*	*59.74*	
267	3/17/1941	34	8.54	1.28	3.20	11.00	*0.25*	*10.93*	
268	4/17/1941	6.5	1.98	1.33	3.04	2.63	*0.30*	*2.63*	
269	5/19/1941				3.00	1.50			
270	8/10/1941	13.5	4.8	1.42	2.87	6.83	*0.36*	*6.82*	
271	8/14/1941	54.5	15.2	1.47	3.11	22.40	*0.28*	*22.34*	
272	10/29/1941	3	0.59	1.08	2.83	0.64	*0.20*	*0.64*	
273	11/25/1941	3.5	0.76	1.01	2.85	0.77	*0.22*	*0.77*	
274	12/14/1941	23	6.1	1.28	3.06	7.81	*0.27*	*7.81*	
275	1/14/1942	14	4.75	1.31	3.06	6.23	*0.34*	*6.22*	
276	2/14/1942	11.5	3.56	1.23	3.06	4.38	*0.31*	*4.38*	
277	3/17/1942	21	3.95	1.08	2.97	4.25	*0.19*	*4.27*	
278	4/22/1942	9.5	1.48	0.72	2.76	1.06	*0.16*	*1.07*	
279	5/21/1942				2.81	0.30			
280	7/8/1942				10.90	8200.00			
281	7/9/1942	17	6.58	1.79	3.00	11.80	*0.39*	*11.78*	
282	7/13/1942				2.61	0.80			
283	7/25/1942	13	4.4	1.36	1.50	6.00	*0.34*	*5.98*	
284	7/31/1942				1.48	1.70			Channels
285	8/10/1942	43.5	26.8	1.85	2.50	49.70	*0.62*	*49.58*	
286	8/28/1942	23	10	1.32	2.27	13.20	*0.43*	*13.20*	
287	9/11/1942	21.5	6.75	1.48	2.30	9.97	*0.31*	*9.99*	
288	10/1/1942	6	0.64	0.59	2.09	0.38	*0.11*	*0.38*	
289	11/30/1942	8.2	2.18	1	2.08	2.17	*0.27*	*2.18*	
290	12/19/1942	6.5	1.34	0.93	2.10	1.24	*0.21*	*1.25*	
291	1/14/1943	7	2.21	1.4	2.16	3.10	*0.32*	*3.09*	
292	2/16/1943	7.5	2.21	1.25	2.15	2.77	*0.29*	*2.76*	
293	3/20/1943	5.1	1.15	1.14	2.20	1.31	*0.23*	*1.31*	
294	4/9/1943				2.17	1.60			

295	5/14/1943	3	0.46	0.3	2.22	0.14	*0.15*	*0.14*
296	7/2/1943	34	7.8	1.1	2.42	8.60	*0.23*	*8.58*
297	7/19/1943	21	8.71	1.81	2.74	15.80	*0.41*	*15.77*
298	7/20/1943	43	26.5	2.18	2.90	57.70	*0.62*	*57.77*
299	7/22/1943	6	2	1.02	2.37	2.03	*0.33*	*2.04*
300	8/2/1943	33	26.4	2.5	2.76	66.10	*0.80*	*66.00*
301	8/6/1943	49	17.6	1.92	2.65	33.80	*0.36*	*33.79*
302	8/7/1943	18	8.2	1.59	2.50	13.00	*0.46*	*13.04*
303	8/10/1943	49	31.5	2.11	3.17	66.40	*0.64*	*66.47*
304	8/16/1943	36.5	42.3	4.9	3.61	207.00	*1.16*	*207.27*
305	8/25/1943	40	13.9	1.9	3.07	26.40	*0.35*	*26.41*
306	8/29/1943	70	42.7	3.05	3.63	130.00	*0.61*	*130.24*
307	9/28/1943	11	1.7	0.75	2.76	1.27	*0.15*	*1.28*
308	10/6/1943	4	1.01	0.92	2.77	0.93	*0.25*	*0.93*
309	11/9/1943	3.5	0.875	1.28	2.83	1.12	*0.25*	*1.12*
310	12/9/1943	10	3.45	1.46	2.93	5.04	*0.35*	*5.04*
311	12/23/1943	8	2.57	1.4	2.82	3.59	*0.32*	*3.60*
312	1/10/1944	4.5	1.38	1.01	2.80	1.40	*0.31*	*1.39*
313	2/7/1944	20	4.35	1.8	2.96	7.81	*0.22*	*7.83*
314	3/10/1944		3.22	1.24	3.04	4.00		*3.99*
315	4/12/1944	10	3.12	1.59	2.98	4.96	*0.31*	*4.96*
316	5/18/1944	3	0.3	0.8	0.87	0.24	*0.10*	*0.24*
317	8/11/1944	4.5	4.15	0.58	2.58	0.24	*0.92*	*2.41*
318	8/15/1944	85	61	3.52	3.95	215.00	*0.72*	*214.72*
321	8/15/1944	94	101	2.76	4.07	279.00	*1.07*	*278.76*
320	8/15/1944	47	175	2.23	4.53	390.00	*3.72*	*390.25*
319	8/15/1944	79	268	4.4	6.42	1180.00	*3.39*	*1179.20*
323	8/16/1944	34	16.4	1.46	2.37	24.00	*0.48*	*23.94*
322	8/16/1944	49	30.1	2.09	2.75	63.00	*0.61*	*62.91*
324	8/20/1944	64	15.8	2.17	2.86	34.30	*0.25*	*34.29*
325	8/31/1944	2	0.21	0.64	2.23	0.13	*0.11*	*0.13*
326	9/12/1944	3.75	0.32	0.6	2.48	0.19	*0.09*	*0.19*
327	9/19/1944	3	0.49	0.75	2.59	0.37	*0.16*	*0.37*
328	10/6/1944	3	0.34	0.891	2.49	0.30	*0.11*	*0.30*
329	10/29/1944	5	1.04	0.84	2.46	0.87	*0.21*	*0.87*

Appendix B

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.
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- **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.
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- **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.