HYDRAULIC GEOMETRY OF THE PEDERNALES RIVER

THESIS

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CHAPTER 1

Introduction

As population in Texas increases, so does the demand for water and the need to protect water for future generations. By studying resources such as the Pedernales River, we can gain knowledge to help protect and understand how humans can live with our natural environment and not destroy the existing natural systems. Dams, bridges, and other anthropogenic features disrupt the natural flow of a river which can lead to changes in habitat for species and undesired sediment deposition and erosion downstream. With a better understanding of river dynamics, an increased population can have a minimal impact on the environment. The purpose of this study is to develop a regime model specific to the Pedernales River. A set of hydrologic geometry equations fit to the Pedernales River will be used to describe how the channels' width, depth, and velocity vary with discharge. Through this model, both development and management plans can be planned to minimize the effect on the natural flow of the river.

Purpose

Hydraulic geometry models explore variations in channel geometric and hydraulic characteristics and their relationships to changes in discharge. Hydraulic geometry is a tool which can be used to describe and predict how a channel's width, depth, and velocity will change with channel flow rate, or discharge. Hydraulic geometry assumes that the discharge in a channel is the dominant independent variable and that dependent variables are related to it in the form of simple power functions (Leopold and Maddock, 1953):

$$w=aQ^b$$

$$h=cQ^f$$

$$v=kQ^m$$

where w is channel width (m or ft), h is channel depth (m or ft), v is channel velocity (m/s or ft/sec), Q is channel discharge (m^3/s, cms or ft^3/s, cfs), and a, c, k, b, f, and m are coefficients and exponents fit to watershed or physiographic region. Even though these are simple empirical formulas, they are useful when applied to a specific river channel to explain the general changes in the river w, h, and v at different discharges and how the w, h, and v change with distance from the headwaters. These equations are most commonly applied to predict downstream river geometric adjustment. Results from using hydraulic geometry equations illustrate how the morphology of the river may change as river flows increase or decrease in the future.

This study will determine hydraulic geometry relationships for the Pedernales River, Texas. The work required for this project includes extensive field measurements of channel cross-sections over a range of flows in addition to data analysis. The research identifies two characteristic ten mile reaches where bank-full cross-section measurements were taken each mile. With a database of channel flows and cross-section data in reaches that span the length of the river, hydraulic geometry equations are developed specific to the Pedernales River.

This research answers three questions:

1. What are the specific coefficients of hydraulic geometry for the Pedernales River?
2. How do these coefficients compare to regional and other bedrock and alluvial river systems?
3. How does stream power influence the hydraulic geometry of the river system?

The significance of this project is both local and regional. On the local level, in depth knowledge of hydraulic and geomorphic processes in the Pedernales River will provide local managers and government agencies with specific tools and information that can be used to inform policy decisions regarding future water needs, flood protection and environmental protection for aquatic habitat. On a regional scale this information will add to the preexisting information for the hydraulic geometry of mixed alluvial-bedrock rivers. This study is designed to be built upon for future research in the Pedernales River basin. Research results and data collected can be used to develop more complex models for other river systems that have the same geomorphic qualities.

CHAPTER 2

Literature Review

There are two distinct ways to analyze the hydraulic geometry of a river: at-a-station and downstream. At-a-station geometry looks at short-term changes within a specific channel cross section with variations in discharge, while downstream geometry predicts longitudinal adjustments in channel size and shape at a specific discharge. Both at-a-station and downstream hydraulic geometries assume that rivers are adjusting toward or in a state of dynamic equilibrium (Ferguson, 1986; Leopold and Maddock, 1953). The mix of bedrock and alluvial sections of the Pedernales add to the complexity of the river system. Hydraulic geometry research has focused on alluvial channels which adjust geometric form more quickly to different discharges than bedrock channels. Therefore this research investigates the use of stream power in the place of discharge as a variable to describe down-stream changes in river geometry.

Hydraulic Geometry

Leopold and Maddock (1953) were the first to use the term "Hydraulic Geometry" to quantitatively describe how a river changes its width, depth, velocity and other properties in relation to discharge. They used hydraulic geometry to predict how a river will change its width, depth and velocity with a change in discharge either at-a-point or over a specified river reach. Leopold and Maddock used simple power equations to show that width (w ft.), depth (d ft.), and velocity (v fts^{-1}.) change with discharge (Q cfs.) in the downstream direction as:

$$w = aQ^b$$

$$d = cQ^f$$

$$v = kQ^m$$

In these equations a, c, and k are the coefficients for width, depth and velocity, and b, f, and m are the exponents that incorporate location specific information such as riparian area and climate. When applying these equations $b + f + m = 1$ and $a*c*k = 1$. Using these equations Leopold and Maddock plotted numerous width, depth, and velocity values against discharges from a broad range of rivers in the United States in order to identify standard values for the exponents b, f, and m (Figure 1). The studied rivers are in the eastern, north central, central, and the north western areas of the U.S. These broad regional areas cover all different river types, although neglecting semi-arid and arid climates. The average exponent values found for the downstream hydraulic geometry data were $b = 0.5$, $f = 0.4$ and $m = 0.1$. For the at-a-station data the average exponents were $b = 0.26$, $f = 0.40$, and $m = 0.34$. Leopold and Maddock realized that although there were assumptions in their method for extracting values, hydraulic geometry was a big step forward in describing river morphodynamics. By understanding these relationships, channel shape and sediment load values could now be predicted within watersheds and these values used to explain how rivers adjust their geometries due to varying flow rates (Leopold and Maddock, 1953).

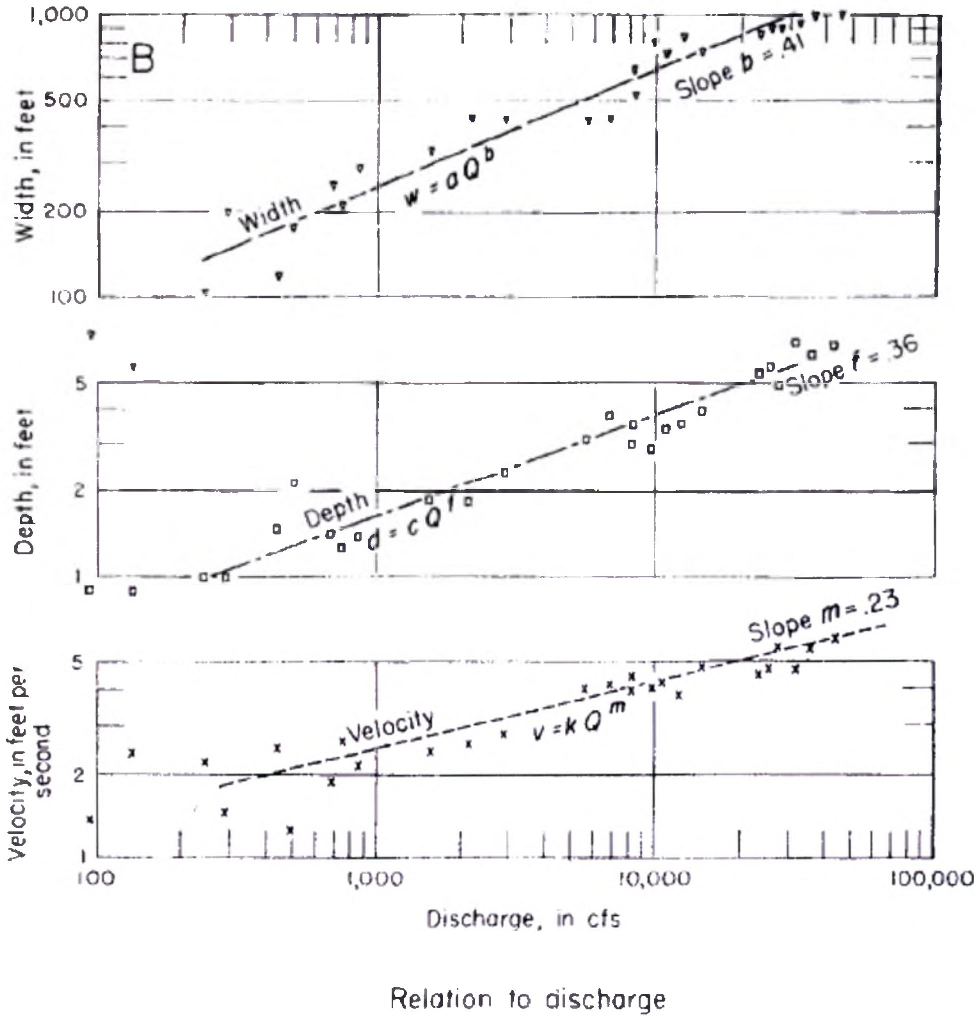


Figure 1: Example of width, depth and velocity values plotted verses discharge (Leopold and Maddock, 1953).

The regime discharge model has been used and improved upon since first proposed in 1954. Leopold and Maddock derived exponent values from a hand drawn line fit to their data. Carlston (1969) used a least squares solution for the same river basins, but plotted by a computer to minimize the error in the exponents. They found exponents that differed from Leopold and Maddock, but the differences were not significant. In further research, Carlston analyzed flow velocity variations in the downstream direction for rivers, including mountain streams and large rivers. He looked at 10 river systems each with 4 - 46 streams, most of which are in the eastern Rocky Mountain front or east of the continental divide. He derived regime equations with exponents that were significantly different than the findings by Leopold and Maddock. Carlston reviews Mackin (1963) and Brush's (1961) findings of constant average velocity in approximately half of the studied rivers. His results suggest that there might be different dominant factors that effect regime models for different types of rivers. He states that in large rivers such as the Mississippi, an increase in discharge is accompanied by a change in depth while in smaller order streams a change in width is more common as discharge increases (Carlston, 1969).

Park (1976) compared at-a-station and downstream variations for different climatic regions in order to determine if simple power functions provide the best regime models within a distinct climate region. He found that there is variability between at-a-station and downstream hydraulic geometry relationships and also variability between rivers in different climatic regions. He uses tri-axial graphs to show how the derived exponents (b, f, m) result in a large amount of scatter in all of the climatic regions and offers the suggestion that local factors are of greater influence than climatic regions.

Park proposes five reasons for the scatter seen in hydraulic geometry exponents. First, there can be variations in both the discharge at the time a cross-section was measured and the determination of bank-full level. Second, data collected from both gauging stations and from a specific field site are often combined in the analysis. Field site locations may not be accessible due to high discharges. In this case a cross-section will be taken from a bridge, or gauging station data may be used to substitute field measurements. Third, different methods are used to fit power equations to the data from which exponents are derived. Fourth, linear regression may not be the best way of describing relationships of hydraulic geometry because of instability in a channel reach (Park 1976). Fifth, variations result from the lack of process understanding behind hydraulic geometry. Park concludes that there needs to be more research focused on the "variations in hydraulic geometry relationships along streams, between streams in homogeneous areas, and between areas" (Park, 1976).

Stream Power

Stream power is an alternative tool for describing fluvial processes. Stream power is the rate at which a river which a river can do work (Goudie, 2004). Within the flow, gravitational forces create potential energy in the flow, allowing the river to erode its banks, degrade its bed and transport sediment. This energy changes the shape and sinuosity of the channel as it flows downstream. Total potential energy in the channel adjusts directly with the flow rate and is expressed per unit channel length (W m^{-1}) as:

$$\Omega = \gamma Q S$$

where γ is the specific weight of water (= 9810 N m $^{-3}$), Q is water discharge (m^3 s^{-1}) and S is the energy slope (m m^{-1}, S is approximated by bed slope). Stream power can also be expressed per unit width as unit stream power:

$$\omega = \Omega / w$$

where w is width (m) (Knighton, 1999).

Lecce (1997) investigated nonlinear downstream changes in stream power in Wisconsin's Blue River. He found the nonlinear trends in stream power resulted mainly from changes in bed slope forced by geomorphic and lithologic controls. It is highest in the mid basin reaches and reduced in the lower reaches. Lecce's (1997) study found stream power provides a better description of downstream channel geometry than hydraulic geometry. He concludes that stream power provides an alternative means for describing channel processes where hydraulic geometry and channel network laws are not sufficient. He states "the results of this study suggest that considering the mechanisms influencing spatial variations of stream power may be useful in advancing our knowledge of these watershed scale processes. Such studies will require additional field data that describe stream power variations in a variety of different geomorphic settings" (Lecce, 1997).

Fonstad (2003) researched the geographical variation of stream power in mountain streams in New Mexico. He also looked for variables other than the traditional hydraulic geometry to describe geomorphic variability in these steams. He found that stream power varied nonlinearly in the downstream direction due to differences in bed and bank substrate. Fonstad (2003) used a structural equation model to strengthen hydraulic geometry relationships. His model takes into consideration slope, bank stability, grain size, and shear stress. Fonstad (2003) mentions two limitations to using statistically analyzed process-response models. These limitations include: "absence of known fluvial thresholds", and "the absence of direct temporal knowledge within the model". These limitations are of consequence for extended prediction capabilities, when a time frame beyond that of the management cycle is of interest.

Study Area

A study by Blum and Valastro (1989) of the geologic history of the Pedernales River describes changes in the river due to the late Holocene climate change. The author used sediment deposits to show how the river has changed in its bed-load properties and shape due to an overall reduction in river flow over the last ten thousand years (Blum and Valastro, 1989). Other work done in Central Texas includes a large scale study of hydraulic roughness on the Edwards plateau in central Texas. The work indicated that there may be problems with using generalized equations to express river channel characteristics in Central Texas due to the complexity of the river systems in the Edwards plateau region (Conyers and Fonstad, 2005).

Numerous studies of both at-a-point and downstream hydraulic geometry have been conducted to try to improve understanding of how rivers. With increasing availability of computers and software packages with robust computing power, equations that predict flows can be are used to model and predict river flow (for example, HEC models). Dividing the river into smaller reach sections with more data per reach will allow for more detailed modeling and will increase accuracy for predicting downstream and at-a-point hydraulic geometries (Stewardson, 2005). New technologies such as remote sensing have been applied to hydraulic systems to estimate depth and discharge for entire river basins (Bjerklie *et al.*, 2005, Fonstad and Marcus, 2005). This technology does not require actual field measurements but uses high resolution images to quantify measurements (Bjerklie *et al.*, 2005, Fonstad and Marcus, 2005). Other technological improvements such as the use of an Acoustic Doppler Profiler to take cross sectional measurements are gaining in popularity because a researcher can gather flow measurements at high flows in a non-intrusive manner from the water surface (Ellis and Church, 2005). All of these methods focus improvements on data collection and not data analysis.

Studies of Bedrock River Systems

Most bedrock rivers that have been studied are in mountainous regions with high relief. As populations living adjacent to bedrock rivers increases, more interest is placed on how these streams and rivers will react to changes in flow (Richardson and Carling, 2006; Tinkler and Wohl, 1998, 2, 297). Studies have been conducted throughout the world on bedrock rivers but the body of knowledge concerning bedrock channel processes remains limited when compared to gravel and alluvial rivers (Carling, 2006).

For the hydraulic geometry of bedrock river systems, incision into bedrock regulates bed scour, and thus changes to channel width and velocity. The study of bed incision and flow velocity in bedrock rivers becomes increasingly important when developing regime models. Tinkler and Wohl (1998, 207) compare terraces and the terraces' longitudinal profiles to the modern day river longitudinal profile in order to develop a conceptual model of how a river incises in to bedrock. Using computer models, they predict longitudinal profiles under varying boundary conditions and sediment supply rates in order to find the rate of incision into bedrock. Sklar and Dietrich (2004) model the effect of sediment supply on bed incision rates by focusing on the effects of saltation. Incision from saltation occurs when the sediment that is supplied to a river is picked up in suspension and then falls on the bed with enough force to erode the bedrock. Their model predicts erosion rates in a basin given a discharge and sediment supply. Both of these studies focus on landscape evolution over a geologic time scale. When looking at such large time scales of river formation, finding an erosion constant that can be used to estimate the rate of river incision is very important to understanding how the basin has formed and to predict how it will change in the future.

Other studies have tried to distinguish the dominant control over bedrock erosion (Hartshorn, et al., 2002, Tinkler and Wohl, 1998, 153). Tinkler and Wohl (1998, 153) use examples from Australia, and India to show how bedrock channels vary in size and shape. With these different sizes and shapes Tinkler and Wohl (1998, 153) argue that extreme floods shape the channels instead of moderate flows because of a lack of smaller sediment and an accumulation of larger boulders. In order to mobilize the large boulders high flows are needed, which supports their case that extreme floods do most of the work in these bedrock areas. Hartshorn et al. (2002) study erosion at both moderate and extreme flows. They conclude that most bedrock channel incision results from moderate flows and coarse sediment abrasion but that extreme flows do more to erode the banks and widen the channel. In both studies extreme flows have shown to erode the channel and its banks.

Although hydraulic geometries have not been defined for central Texas Rivers, there have been hydraulic geometry studies completed on bedrock channels which will prove to be useful for the present study. In the last decade bedrock rivers have started gaining the interest of researchers (Carling, 2006). Montgomery and Gran (2001) reviewed studies for bedrock river channels in mountainous regions and compared measured flow values to the hydraulic geometry equations. They found the hydraulic geometry relationships for alluvial rivers also describe bedrock hydraulic geometries. There is more variation in the equations for bedrock rivers but it is not substantially different from that in alluvial rivers (Montgomery and Gran, 2001). Because hydraulic geometry is important for predicting how a river will adjust to different discharges both at-a-point and downstream, accuracy of the equations and significance of the coefficient and exponent fit are very important. Wohl (2004) tested the limits of downstream hydraulic geometry by using data from 10 mountain rivers from around the world. Wohl compared rivers with a well-developed downstream hydraulic geometry to those that have a poorly developed downstream hydraulic geometry. Her definition of a well-developed downstream hydraulic geometry is "when the coefficient of determination (R^2) between discharge and at least two of the three response variables (w, d, v) is 0.5 or greater." Consequently, rivers that have response variables less than 0.5 were considered to have poorly developed downstream hydraulic geometry. The study found that even with a high threshold value there is a significant similarity in hydraulic geometry relationships between bedrock rivers and alluvial rivers (Wohl, 2004). Both of these studies show a correlation between bedrock and alluvial rivers. This relationship should prove useful in the study of the Pedernales River, which includes long reaches of bedrock channel with intermittent alluvial reaches.

CHAPTER 3

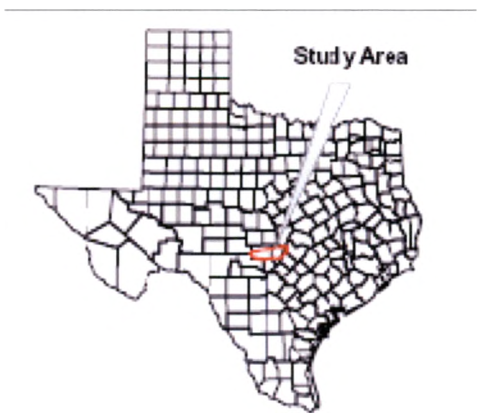
Study Area

The Pedernales River in central Texas flows east along Edwards Plateau until its confluence with the Colorado River at Lake Travis North West of Austin near the Balcones Escarpment, and then flows to the Gulf of Mexico. The river is bordered by the Llano River to the North and the Blanco and Guadalupe Rivers to the south. The Edwards Plateau is composed primarily of limestone bedrock. Due to faulting on the Balcones escarpment bedrock dominates the stream bed although there are intermittent alluvial reaches. The Pedernales River channel is primarily alluvial in its upper reaches until it transitions into a bedrock dominated reach near Hye (west of Johnson City). The river remains primarily bedrock until it reaches a down dip near Pedernales Falls State Park where it transforms into a mixed bedrock and alluvium channel (Fisher, 1986).

The climate in the area is sub-humid to semiarid. The Balcones escarpment causes warm saturated air to rise and gives way to thunders storms that can produce large quantities of rain. Hurricanes in the Gulf of Mexico also bring driving rain to the Edwards Plateau. This abundance of rain in short time spans accompanied with bedrock channels and valleys produce rapid flooding in the area (Earl and Dixon, 2005). As the population increases along the Pedernales River so does impervious cover. With added runoff to the river, flood rates and flow variability will only increase, and the study of

Central Texas Rivers becomes more important to landowners and residents within this area.

Other than the study by Blum and Valastro (1989) Pedernales River has not been studied significantly over the years. There are two USGS gauging stations for the Pedernales River, one in Fredericksburg and one in Johnson City. The Fredericksburg station is the upper most gauging station, has a drainage area of 955.7 km^2 (369 mi^2), and has been in operation since 1979. The Johnson City gauge has a period of record dating to 1939, and is the easternmost station with a drainage area of 2333.6 km^2 (901 mi^2) (USGS). The research encompass two reaches is the Pedernales River basin from above Fredericksburg down to Johnson City (Figure 2).



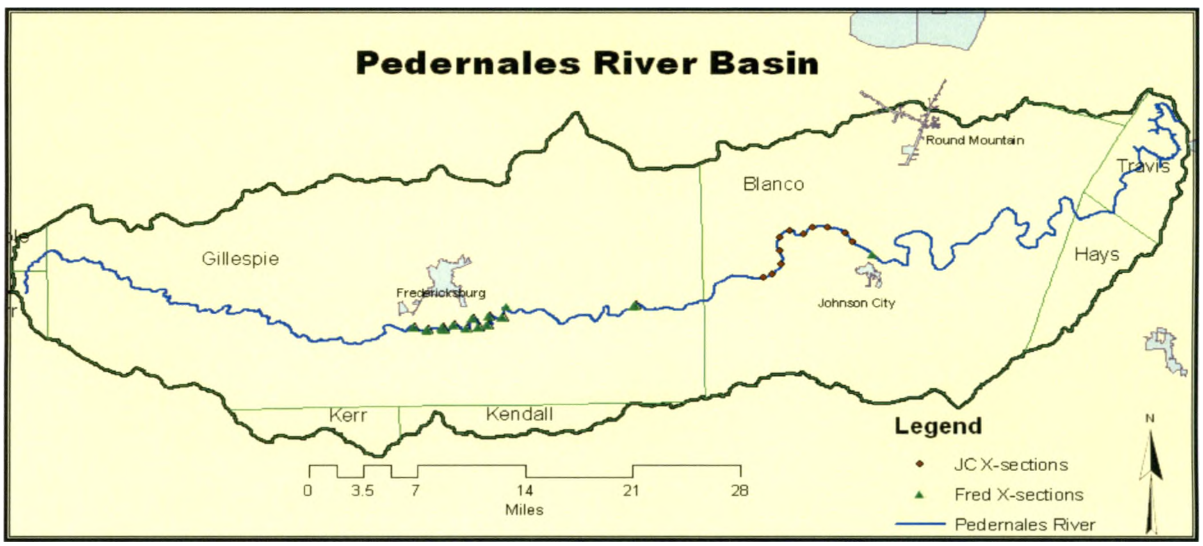


Figure 2: This map illustrates the Pedernales River basin. The green triangles and red dots represent Cross-sections taken in the field.

Two ten mile reaches of the river were analyzed in order to derive the average exponents for the hydraulic geometry equations. The upper most section analyzed was Barons Creek, and the lower section centers on North Grape Creek. The named feature being observed at in the middle of the ten mile section. By extending each reach around a feature, the influence of that feature on the flow will be illustrated.

The Fredericksburg waste water treatment plant discharges into Barons Creek, which flows into the Pedernales River just south of Fredericksburg between US Highway 87 and US Highway 290 (Figure 2). This reach is the uppermost section and coincides with where discharge from the Fredericksburg wastewater treatment plant makes the Pedernales River below Barons Creek perennial, while the upstream reach is seasonal. This ten mile section flows over the Cretaceous Hensell Sand (145 – 65 Ma) which is a sand, silt, clay, conglomerate which is easily eroded and transported at bank-full flows.

The lower section is located west of Johnson City centered on North Grape Creek (Figure 2). This section flows over the Cambrian Wilberns and Riley Formations (543 - 490 Ma), which are bedrock dominated layers. The Wilberns formation is the dominant formation in this section and composed of Morgan Creek Limestone and wedge Sandstone Member undivided. This section also includes a series of three low head dams in the upper stretches of the reach (Fisher, 1986).

These two sections of the Pedernales River include many types of anthropogenic changes and natural flow variations that are used to create an average hydraulic geometry for the river. In order to create an average hydraulic geometry for the river as a whole, each section was analyzed individually and regime equations developed for the individual reaches. Once each section was analyzed the exponents were averaged in order to develop an overall hydraulic geometry.

CHAPTER 4

Methods

The first step of this project was an analysis of the topographic and geologic maps of the Pedernales River basin. USGS topographic maps allow for an identification of elevation changes and structural features that control river flow through the basin. Underlying geologic characteristics contribute to the uniqueness of the basin. Soil depth and exposed bedrock control how precipitation will runoff, and how the river will transmit water downstream. Bankfull discharges were determined using a combination of field methods and flood frequency analyses.

Downstream Data Collection

GIS was used to create a map of the river basin and to locate cross-section locations. This work was completed by utilizing the 2004 Digital Ortho Quarter Quads (DOQQ's, or aerial photographs) from the Texas Natural Resource Information System (TNRIS). Using the DOQQ's of the river basin, a centerline was digitized and then the line was broken into the two ten mile observation reaches. One mile increments were marked in each of these sections and these lines represent the actual cross-section locations. The rationale for breaking the river into equally spaced, one mile sections is that these sections will isolate most of the channel variations, including bedrock and alluvial reaches, pool and riffle sections, and altered flow sections near bridges, stabilized banks and low water dams. The coordinates of each mile reach were taken from the GIS map and entered into a GPS unit. The GPS unit was then used on the river so the position of each cross-section could be located.

A bank-full discharge was determined by flood frequency analysis of the one and a half to two and a half year recurrence flow interval (Dunne and Leopold, 1978). The two year flood event is equivalent to the bankfull discharge in most areas. The recurrence intervals are calculated by ranking the peak discharge data from largest to smallest flows for the length of the gauge. The number discharge values for the years the gauge has been in operation, plus one, is then divided by the rank number for that discharge. The resulting value is the recurrence interval in years.

Once on the river and in the correct location, the bank-full level was determined by looking for the first terrace and from knowledge of the approximate height of the bank-full level as predicted from the stage-discharge curve (Frye, 1969). Each cross-section requires measurements of river width, depth and velocity and has two separate parts. First, a bank-full cross-section was surveyed to define the width and depth of the total bank-full cross-sectional area. Bankfull level measurements allow for the comparison between cross-sections from different river locations and at different discharges. The second cross-section measures the velocity of the wetted channel. A Marsh-McBirney flow mate 2000 was used to measure velocity at 20 and 80 percent of the flow depth every tenth of the width perpendicular to the river flow (Goudie, 1990). Each cross-section was taken using the same flow meter (Marsh-McBirney Flowmate 2000) that has a error rate of approximately 2% (Kondolf and Piegay, 2003). The same field methods were followed at all cross-sections to ensure reliable and reproducible field work. The velocity measurements were multiplied by the wetted channel area to obtain a discharge value for each cross-section that was compared to the USGS and LCRA gauging stations and to determine the Manning's n value for each cross-section.

At each cross-section, ten GPS points, pictures, azimuth, time and a short site description were recorded. This information can be used to reproduce the field work completed during this study.

Analysis of Data

The data were collected and entered into excel for analysis (Table 1). Discharge was computed using three different methods. First, average depth was multiplied by the bankfull width to calculate the cross-sectional area. Second, the cross-sectional area was determined using a computer program called AreaComp. This program uses the bankfull cross-section as well but it integrates the depth and width measurements and produces a more accurate cross-sectional area. Manning's n values were determined through two different methods as well. First, using the USGS visual guide, and then by back calculating using the velocity cross-sections, a known discharge, and the Manning's equation. Using the bankfull discharge the bankfull velocity was determined along with the stream power. Once all the variables were calculated, the hydraulic geometry graphs could be completed. In order to extrapolate the exponents for the downstream hydraulic geometry, width, depth and velocity were plotted against discharge, stream power, basin area, distance downstream and slope (Figures 4-18). After the graphs were constructed linear regression was performed in order to extrapolate the necessary coefficients from the resulting trend line. The coefficient of determination (R^2) shows to what degree the data fits the trend line. The R^2 value provides a means for determining the statistical strength of the relationship between the variables being analyzed. The exponents determined to create the best fit for hydraulic geometry of the Pedernales are then compared to other river systems found in the literature.

CHAPTER 5

Results

Bankfull level on the Pedernales River was determined using three methods stated in Chapter 4. Assuming the bankfull discharge corresponds to the 1.5 to 2 year recurrence interval (Dune and Leopold, 1978) at the Fredericksburg gauge discharge was between 75.04 – 212.09 cms (2650 – 7490 cfs) and at the Johnson City gauge was 385.11 – 696.59 cms (13600 – 24600 cfs) (over estimated due to large floods). Using the stage discharge curve the bankfull discharge was 14.16 cms (500cfs) (this value is underestimated). Due to the fact that the Johnson City gauge is behind a low-head dam the stage discharge curve for this gage did not result in usable values for bankfull discharge. The bankfull depths measured as part of the cross-sections in the field were determined by locating the outer bank elevation that would prevent the channel from spilling over into the lower flood plain (Figure 3).

Figure 3: Determination of bankfull in the field (Cross-section 9).

Bankfull discharge was then calculated using the Manning's equation:

$$Q = \frac{Area}{n}(depth)^{2/3}(slope)^{1/2}$$

with the bankfull dimensions measured from the field. Discharge in the Fredericksburg reach ranged from 81.44 – 224.98 cms (2876 – 7945cfs) with one outlier of 657.89 cms (23,233cfs) at the Barrons Creek confluence. The values for the Johnson City reach ranged from 39.45 – 221.30 cms (1393 – 7815cfs; Table: 1). The wide range in values will be discussed in Chapter 6.

Manning's roughness coefficient values were back calculated by using the measured velocity cross-sections (wetted perimeter) which were taken in the same location as the bankfull cross-sections (Table 1). The Manning's values ranged from 0.023 – 0.247. Bankfull velocity values for each cross-section were calculated by dividing the bankfull discharge by the bankfull area. The velocity values ranged from 0.34 – 4.46 m/s (1.13 – 14.63 ft/s). Once all the necessary parameters were calculated the hydraulic geometry relationships were plotted and regression equations developed.

Table 1: Cross-section values (Johnson City reach is 1-10, and Fredericksburg reach is 12-22).

Cross-section	Distance (km)	Watershed Area (km^2)	Bed Slope	Manning's n	Bankfull Q (cms)	Bank Full Stream Power	Average Width (m)	Average Depth (m)	Velocity (m/s)
1	1 6	0 1	0 0020	0 044	124	85983	26208	7988 1	2434 8
2	3 2	0 3	0 0019	0 023	225	148080	45135	13757 1	4193 2
3	4 8	0 4	0 0019	0 041	133	87710	26734	8148 5	2483 7
4	6 4	0 6	0 0015	0 063	81	42322	12900	3931 8	1198 4
5	8 0	0 7	0 0015	0 062	114	59289	18071	5508 2	1678 9
6	9 7	0 9	0 0100	0 060	658	2279180	694694	211742 7	64539 2
7	11 3	1 0	0 0100	0 247	158	549205	167398	51022 8	15551.8
8	12 9	1 2	0 0021	0 109	149	108262	32998	10057 9	3065 6
9	14 5	1 3	0 0038	0 023	131	172558	52596	16031 1	4886 3
10	16 1	1 5	0 0027	0 061	103	96013	29265	8919 9	2718 8
12	19 3	1 8	0 0017	0 045	191	112389	34256	10441 3	3182 5
13	20 9	1 9	0 0016	0 051	164	91018	27742	8455 8	2577 3
14	22 5	2 1	0 0024	0 045	104	86515	26370	8037 5	2449 8
15	24 1	2 2	0 0024	0 032	96	79574	24254	7392 7	2253 3
16	25 7	2 4	0 0025	0 063	71	61774	18829	5739 0	1749 2
17	27 4	2 5	0 0025	0 045	221	191664	58419	17806 2	5427 3
18	29 0	2 7	0 0036	0 045	175	218077	66470	20260 0	6175 3
19	30 6	2 8	0 0028	0 045	112	108278	33003	10059 4	3066 1
20	32 2	3 0	0 0043	0 045	127	189387	57725	17594 6	5362 8
21	33 8	3 1	0 0043	0 045	173	258428	78769	24008 7	7317 9
22	35 4	3 3	0 0024	0 045	39	32798	9997	3047 0	928 7

Table 2: a,c, k and b, f, m exponents for discharge (Q), stream power (SP), area, distance downstream (Dist.), and slope from the Pedernales River. Johnson City (JC) and Fredericksburg (Fred).

	Width	Depth	Velocity		Width	Depth	Velocity	
	a	**c**	**k**	ack = 1	**b**	**f**	**m**	b+f+m = 1
Q Fred	39 050	1 106	0 059	2 548	0 128	0 244	0 540	0 912
Q JC	159 600	0 024	0 099	0 379	0 058	0 610	0 449	1 117
Q Fred, JC	335 000	0 050	0 046	0 771	-0 070	0 563	0 554	1 047
SP Fred	25 540	4 511	1 306	150 465	0 148	0 067	0 151	0 366
SP JC	250 000	0 147	0 077	2 830	0 003	0 329	0 399	0 731
SP Fred, JC	125 500	0 745	0 443	41 419	0 034	0 203	0 240	0 477
Area Fred	0 000	217 100	10828 000	0 012	3 976	-0 530	-1 240	2 206
Area JC	22 030	6 00E+07	102 200	1 35E+11	0 371	-2 490	-0 470	-2 589
Area Fred, JC	0 079	15937 000	210 000	264394 830	1 219	-1 240	-0 580	-0 601
Dist. Fred	6 00E+16	0 003	0.000	1 80E+08	-7 620	1 742	3 525	-2 353
Dist JC	25 970	0 000	1 402	0 000	0 576	3 479	0 278	4 333
Dist Fred, JC	2 06E+04	0 003	0 155	9 569	-1 670	1 793	0 830	0 953
Slope Fred	754 500	10 340	8 686	6 78E+04	0 316	0 022	0 056	0 394
Slope JC	122 000	0 707	34 190	2 95E+03	-0 120	-0 290	0 351	-0 059
Slope Fred, JC	511 400	6 664	11 460	3 91E+04	0 178	0 020	0 137	0 335

Width, depth, and velocity were plotted versus discharge for the Fredericksburg reach, Johnson City Reach and then both were plotted together. The Fredericksburg reach shows velocity as the most dominating variable with an R^2 of 0.319 and an exponent of 0.540 (Figure 5). The Johnson City reach shows that depth has the strongest correlation to discharge with an R^2 of 0.796, and velocity also shows a strong correlation with an R^2 of 0.528 (Figure 6). When both reaches were analyzed together, depth and velocity remained the dominating factors over channel geometry adjustment to bankfull discharge and width did not significantly correlate to discharge (Figure 4). By using the same method, stream power was regressed against bankfull width, depth and velocity. The power law exponents in both the Johnson City reach and the accumulated reaches show the same relationships as in the discharge relationships. The R^2 values were lower but the depth and velocity relationships still dominated compared to the width (Figure 7, 9). The Fredericksburg reach exhibits a strong relationship between width and velocity as stream power increases, although the correlation values are weak (Figure 8).

Area, distance and slope plotted verses width, depth and velocity produced minimal usable results. Area and distance had the highest correlation with width and depth with R^2 values ranging from 0.431 – 0.722. When analyzing area the depth exponent f, is between 2.49 - 0.53, and for distance the f values are between 3.479 – 1.742 (Figure 10 - 15). The only significant exponent value from the power equations derived using slope was in Fredericksburg where width increases with b=0.316 and an R^2 of 0.381 (Figure 17). This is the highest R^2 value found for the slope regressions.

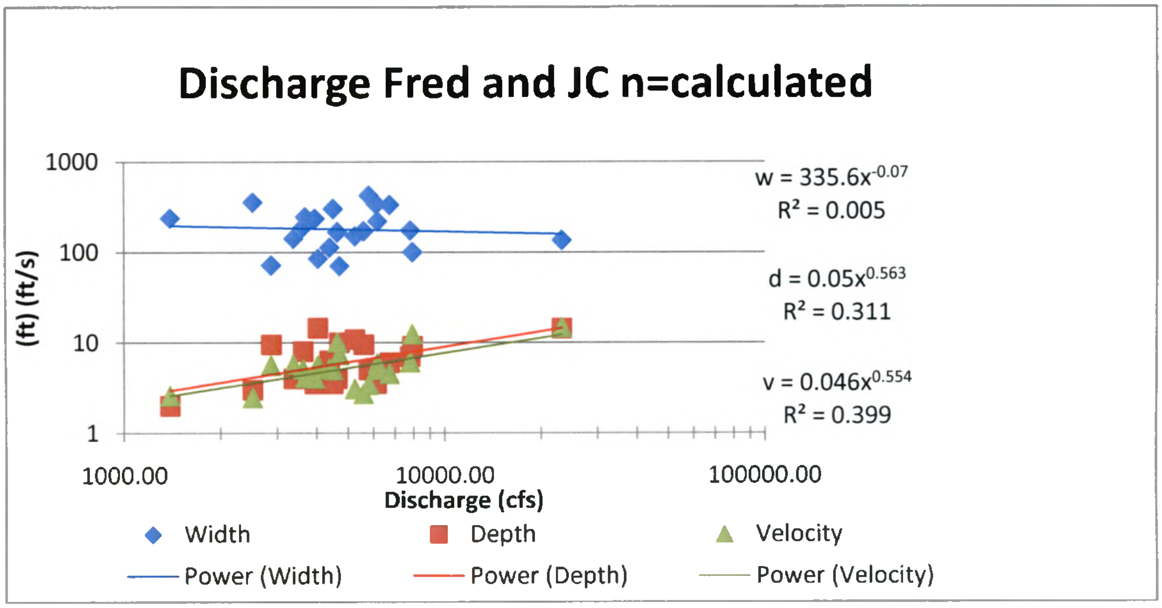


Figure 4: Discharge versus width, depth and velocity for the Fredericksburg and Johnson City reaches combined.

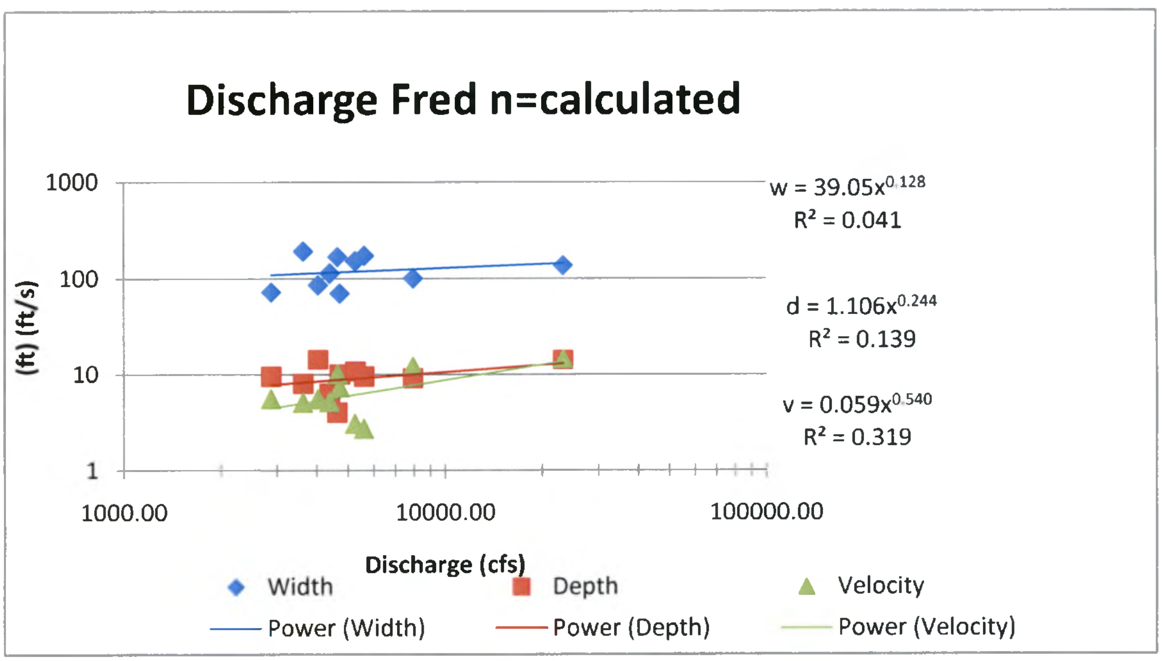


Figure 5: Discharge versus width, depth and velocity for the Fredericksburg reach.

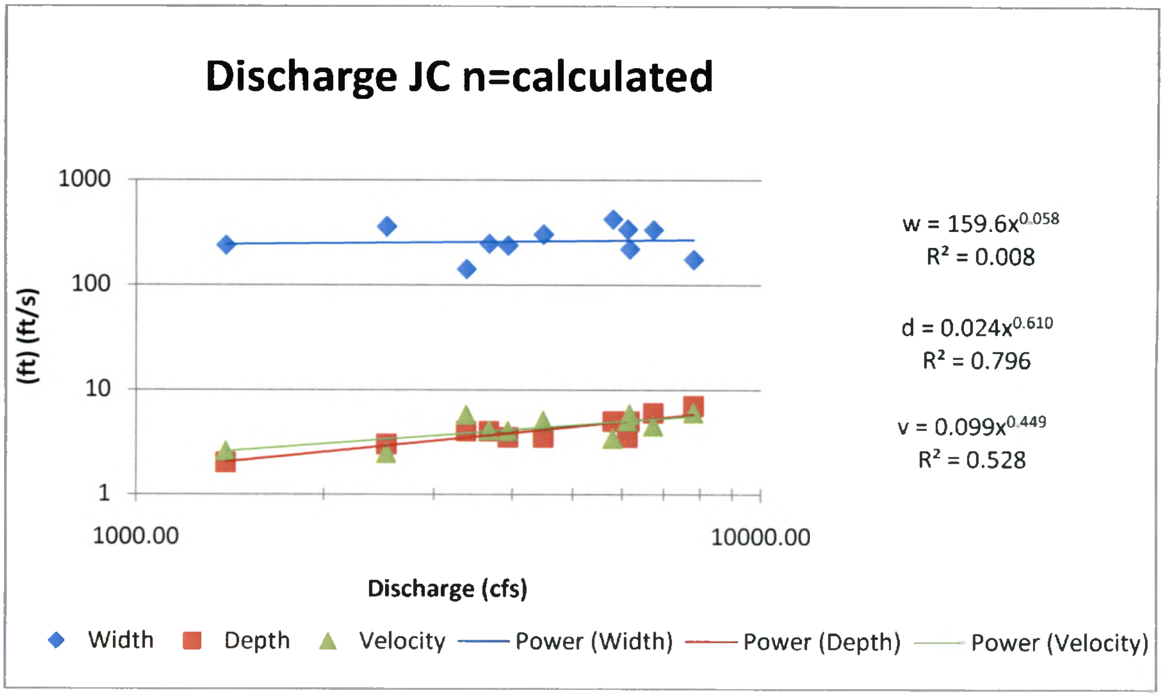


Figure 6: Discharge versus width, depth and velocity for the Johnson City reach.

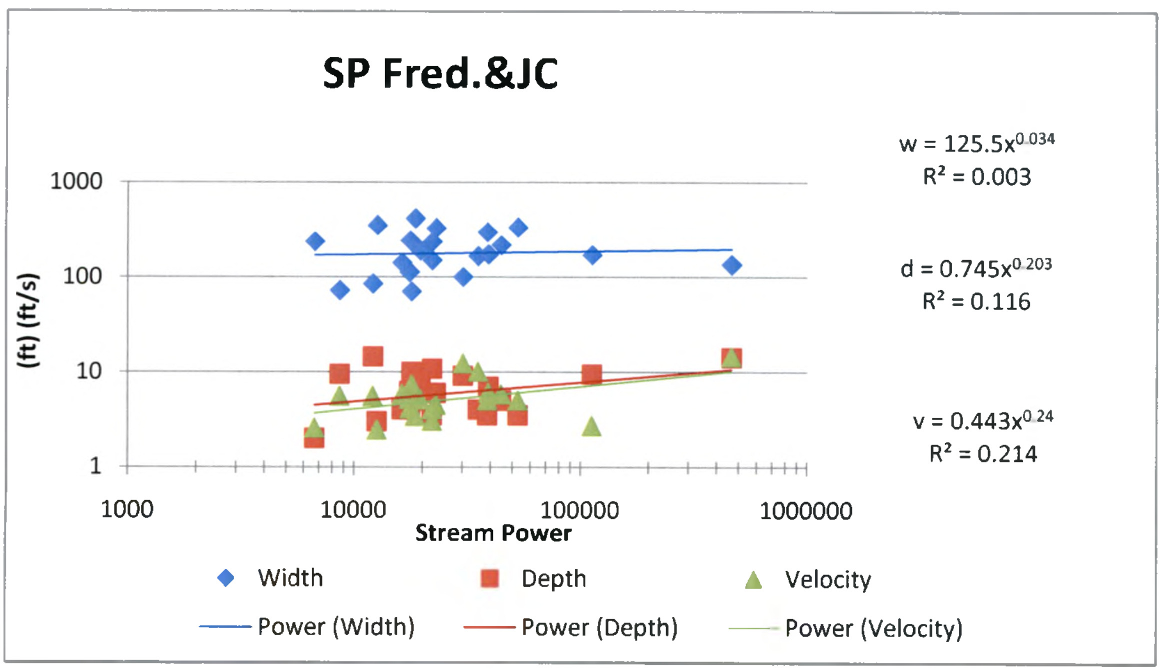


Figure 7: Stream power versus width, depth and velocity for the Fredericksburg and Johnson City reaches combined.

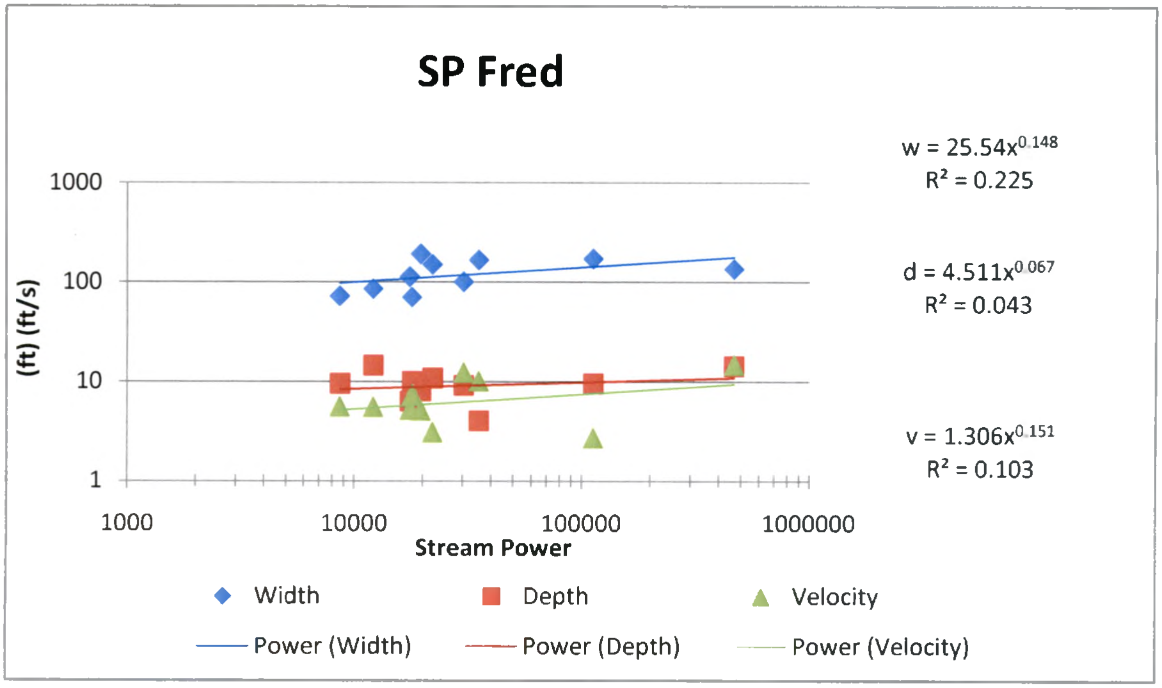


Figure 8: Stream power versus width, depth and velocity for the Fredericksburg reach.

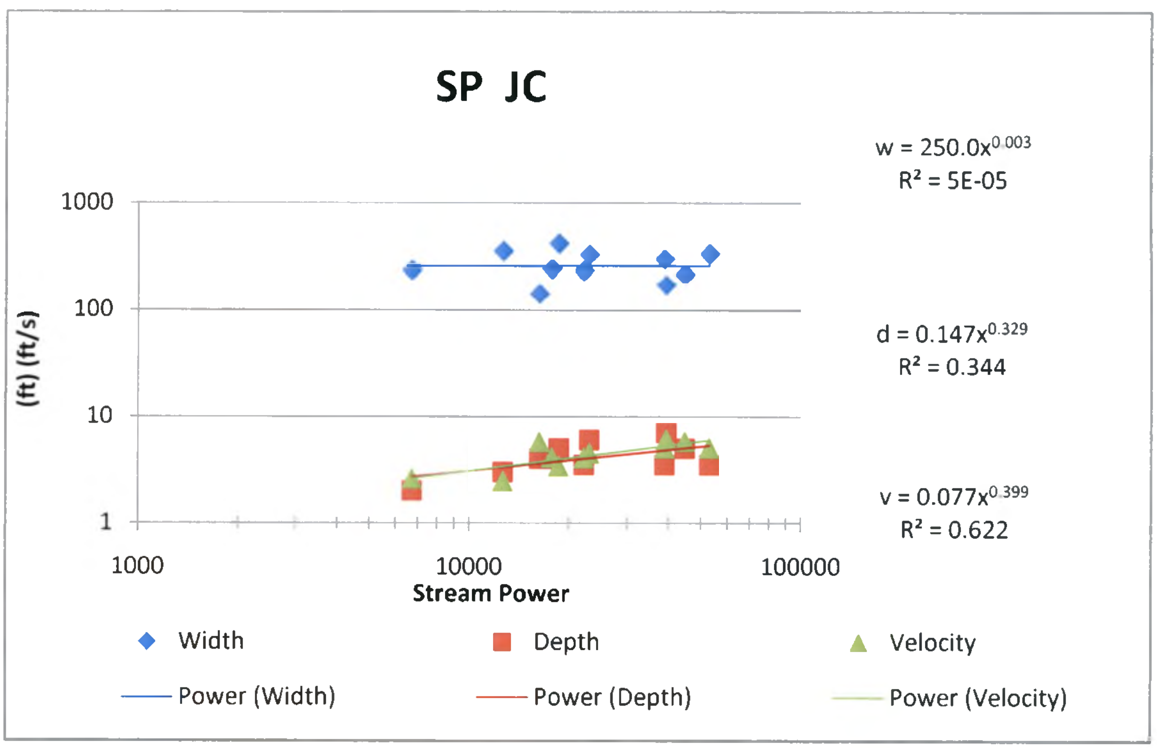


Figure 9: Stream power versus width, depth and velocity for the Johnson City reach.

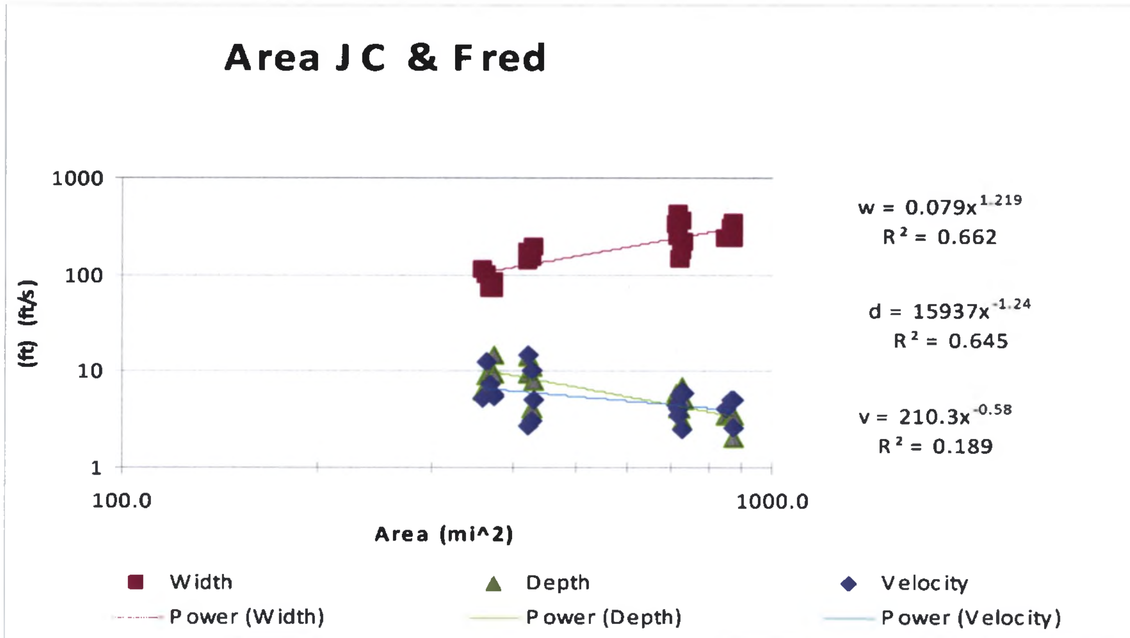


Figure 10: Area versus width, depth and velocity for the Fredericksburg and Johnson City reaches combined.

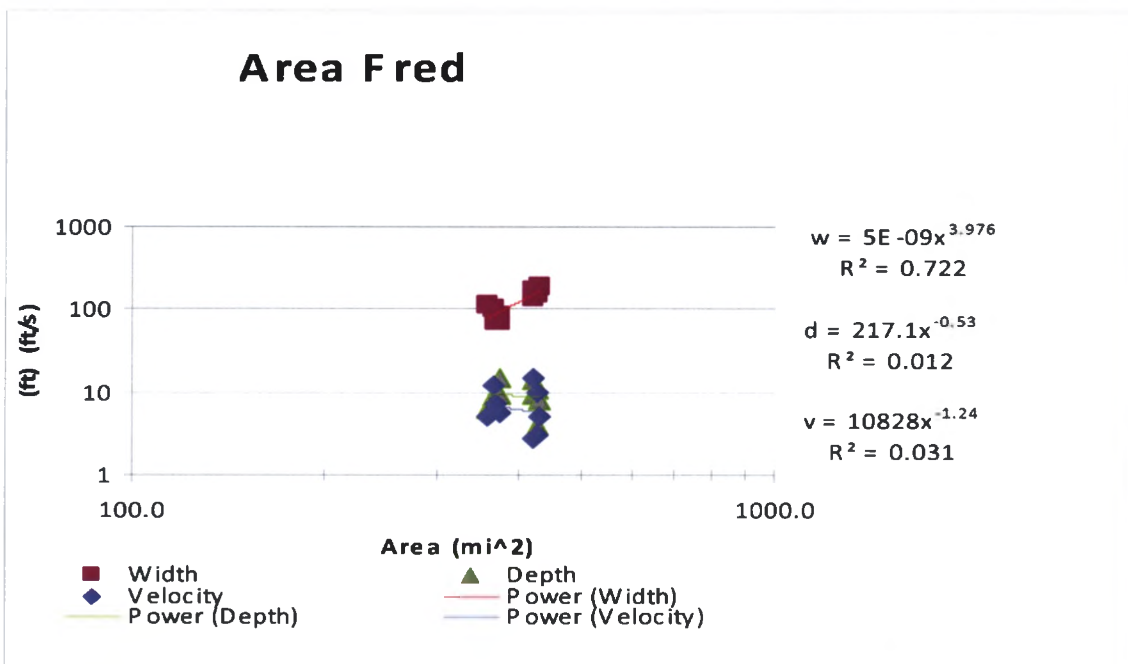


Figure 11: Area versus width, depth and velocity for the Fredericksburg reach.

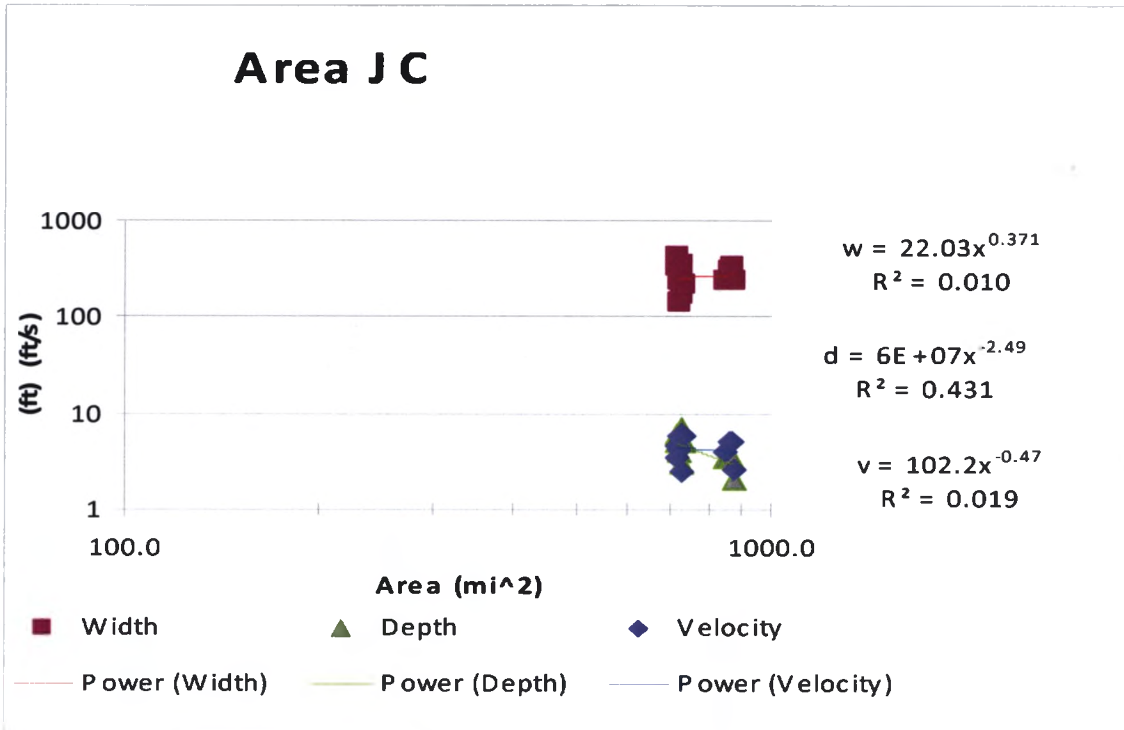


Figure 12: Area versus width, depth and velocity for the Johnson City reach.

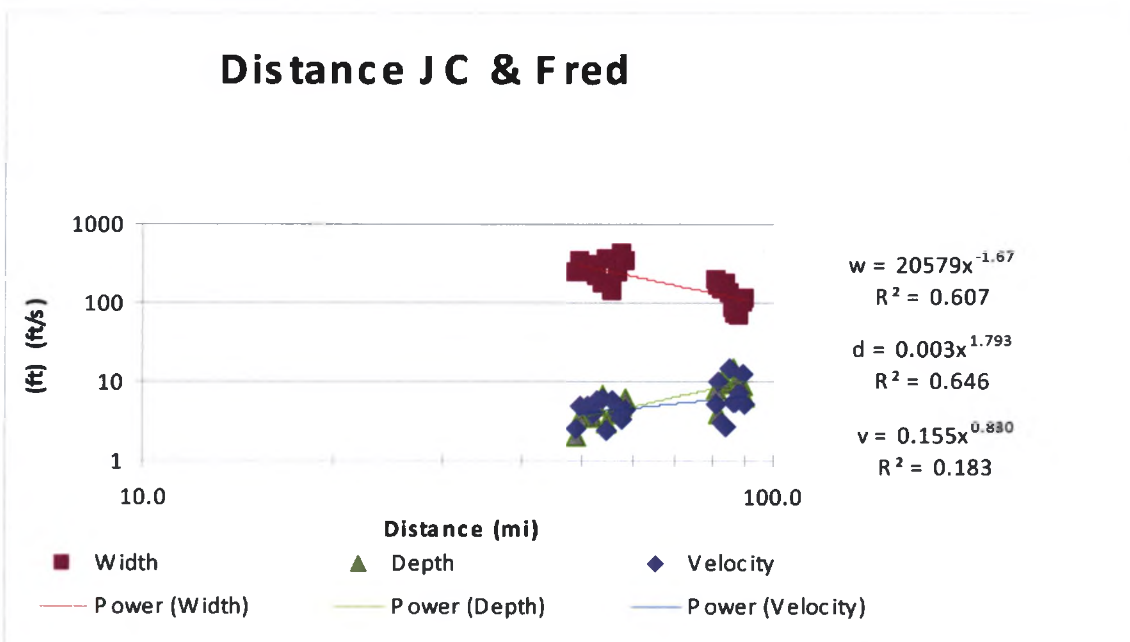


Figure 13: Distance downstream versus width, depth and velocity for the Fredericksburg and Johnson City reaches combined.

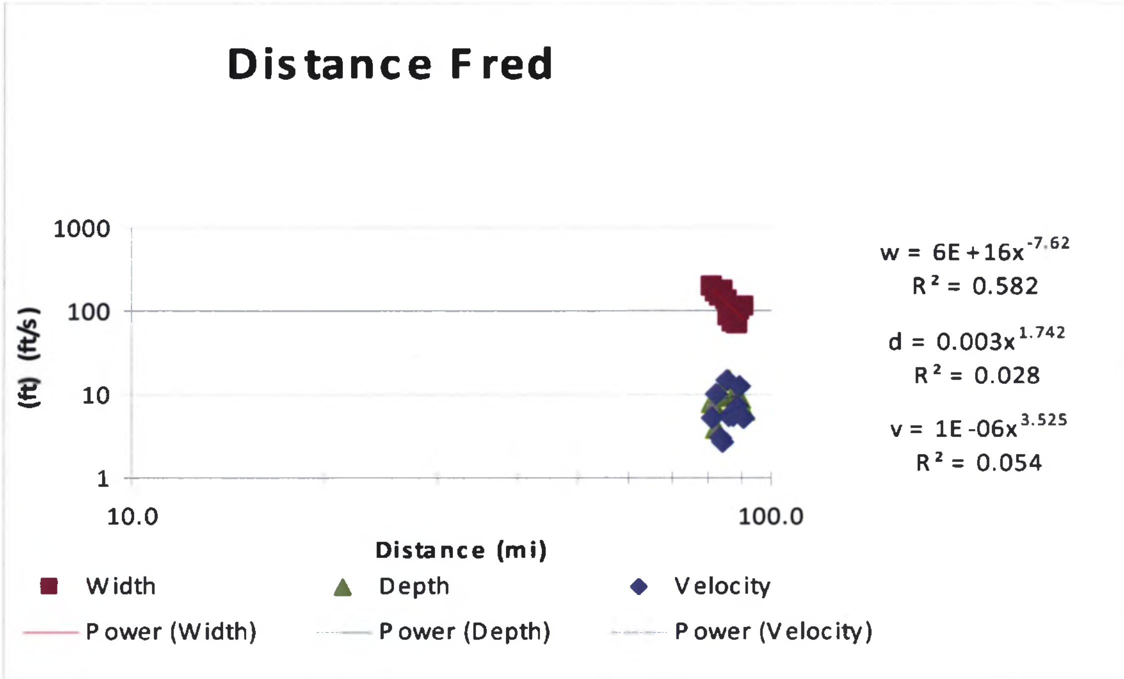


Figure 14: Distance downstream versus width, depth and velocity for the Fredericksburg reach.

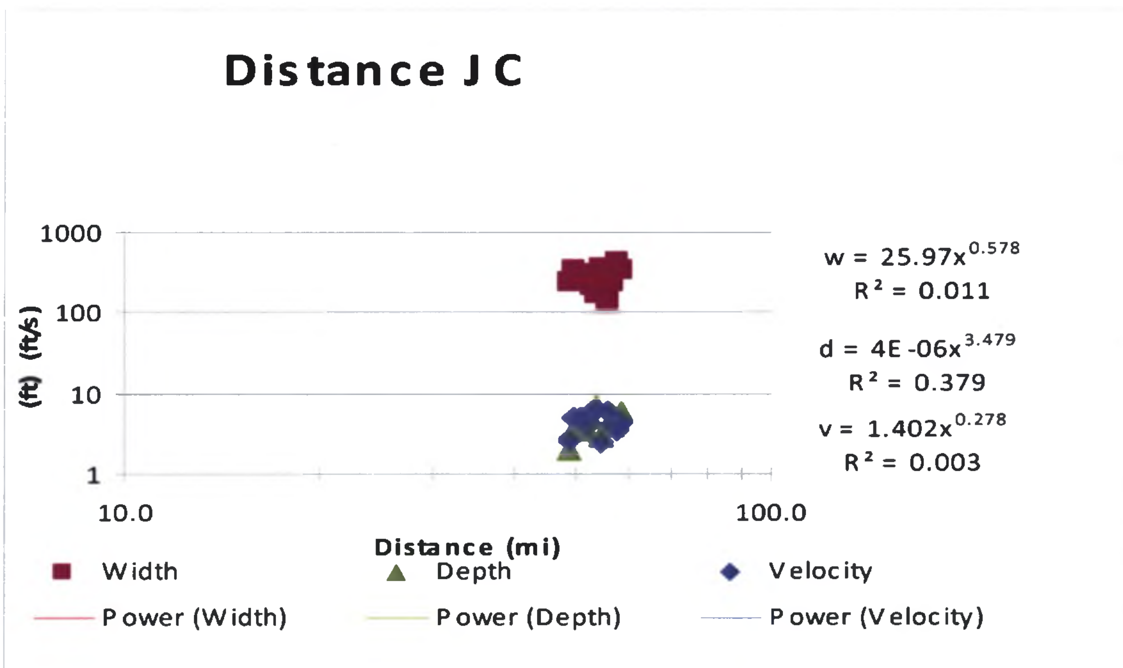


Figure 15: Distance downstream versus width, depth and velocity for the Johnson City reach.

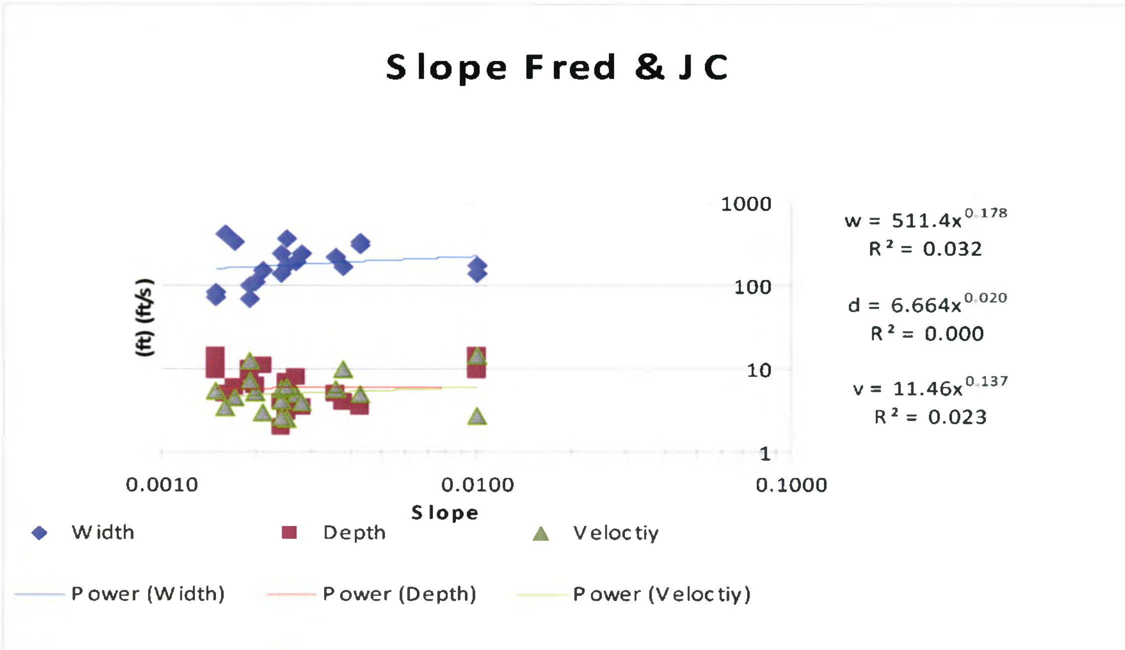


Figure 16: Slope versus width, depth and velocity for the Fredericksburg and Johnson City reaches combined.

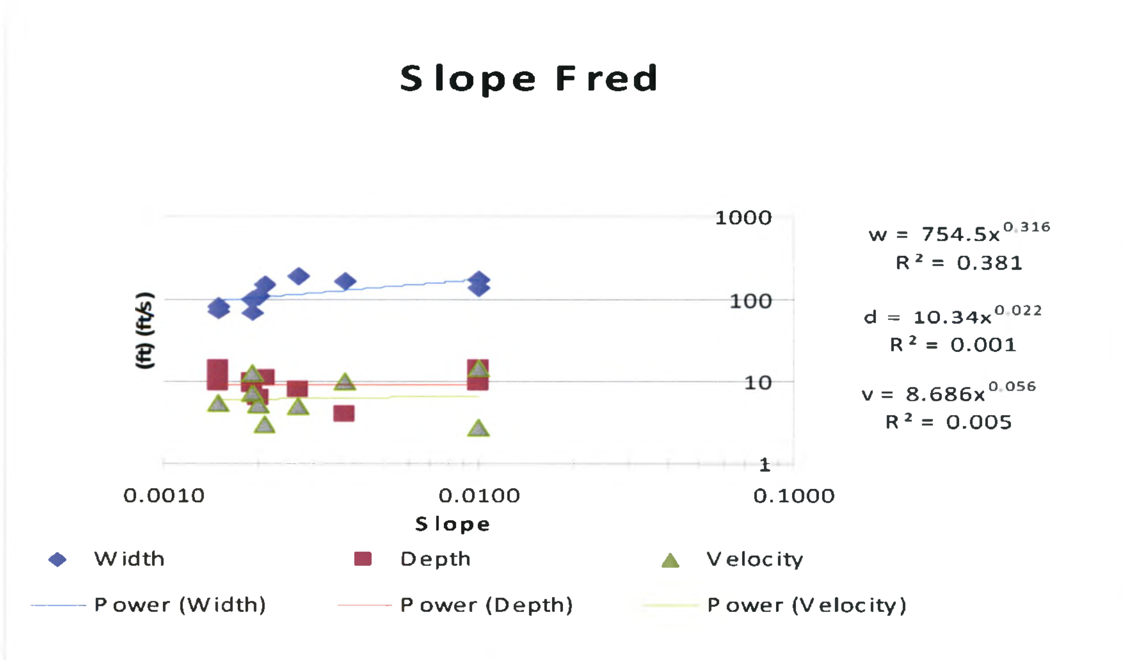


Figure 17: Slope versus width, depth and velocity for the Fredericksburg reach.

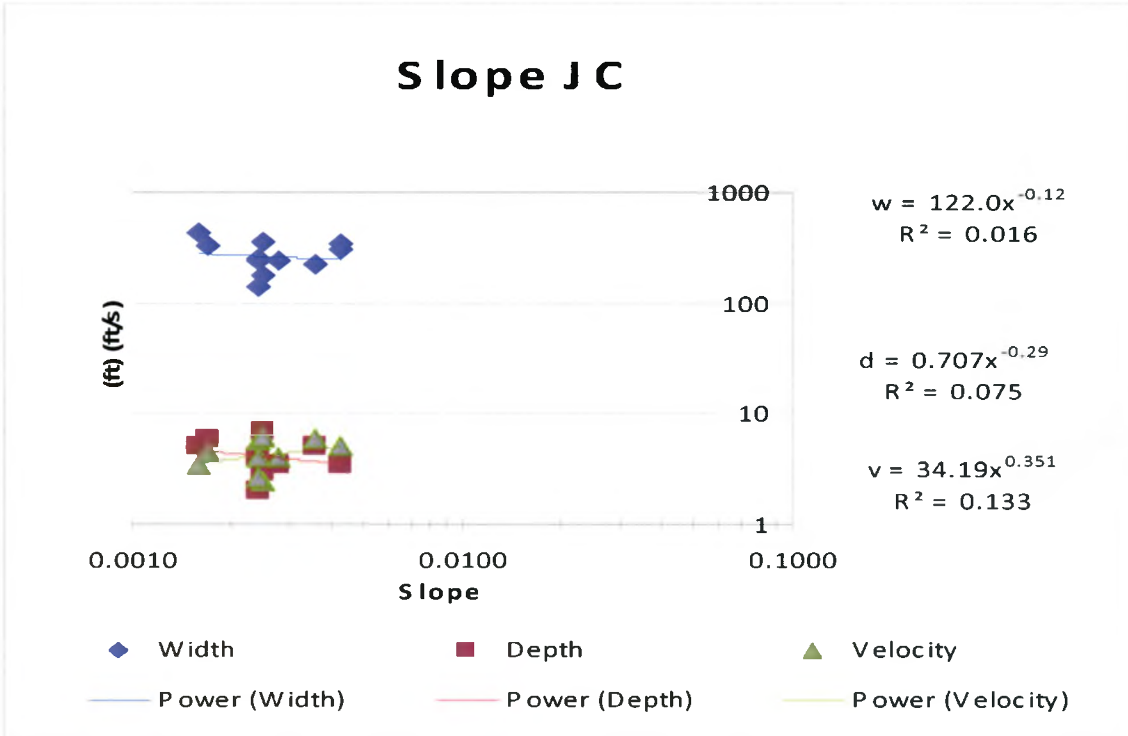


Figure 18: Slope versus width, depth and velocity for Johnson City reach.

CHAPTER 6

Discussion

Bankfull

Determination of bankfull flow is a critical step when trying to compare cross-sections for downstream hydraulic geometry. The three methods used produced scattered results. This scatter is due to the complexity of the Pedernales River system, as the river flows through two completely different bed substrates. This prompted adoption of a reach analysis approach whereby the river was split into two reaches with each reach fully in one or the other lithologies. The different channel compositions give rise to multiple bankfull cross-section geometries and bankfull discharge measurements. A stage-discharge cure was created using USGS daily data from the Fredericksburg gauging station. As stated in Chapter 5 this method produced a bankfull stage of 2.1-2.4 m (7-8 ft) and a discharge of approximately 14.16 cms (500cfs). These values contradict both the 1.5 -2 year reoccurrence interval discharge and the bankfull discharge calculated from the Manning's equation by an order of magnitude. The discrepancies are likely the result of the flow regime in the area, which is characterized by infrequent high volume flows during the rainy months and extended periods of low flows during the summer months. Because of the disagreement between the stage discharge bankfull calculation and the bankfull determined by the other two methods, values from the stage discharge method were not used in any of the calculations. Results using the recurrence interval method for bankfull estimation agreed with the Manning's indicating that the bankfull estimation in the field was conducted at the proper level. The approximate bankfull discharge for the Fredericksburg reach ranges from 84.95 – 212.38 cms (3000 – 7500 cfs) with a 1.5 -2 year reoccurrence interval. Overestimates at the Johnson City gauge result from the gage location behind a low-head dam of approximately 2.7 m (9 ft) in height. Therefore values from this gage were not used in any analysis. In the field if there was a question determining bankfull level, the cross-section was measured from the highest terrace.

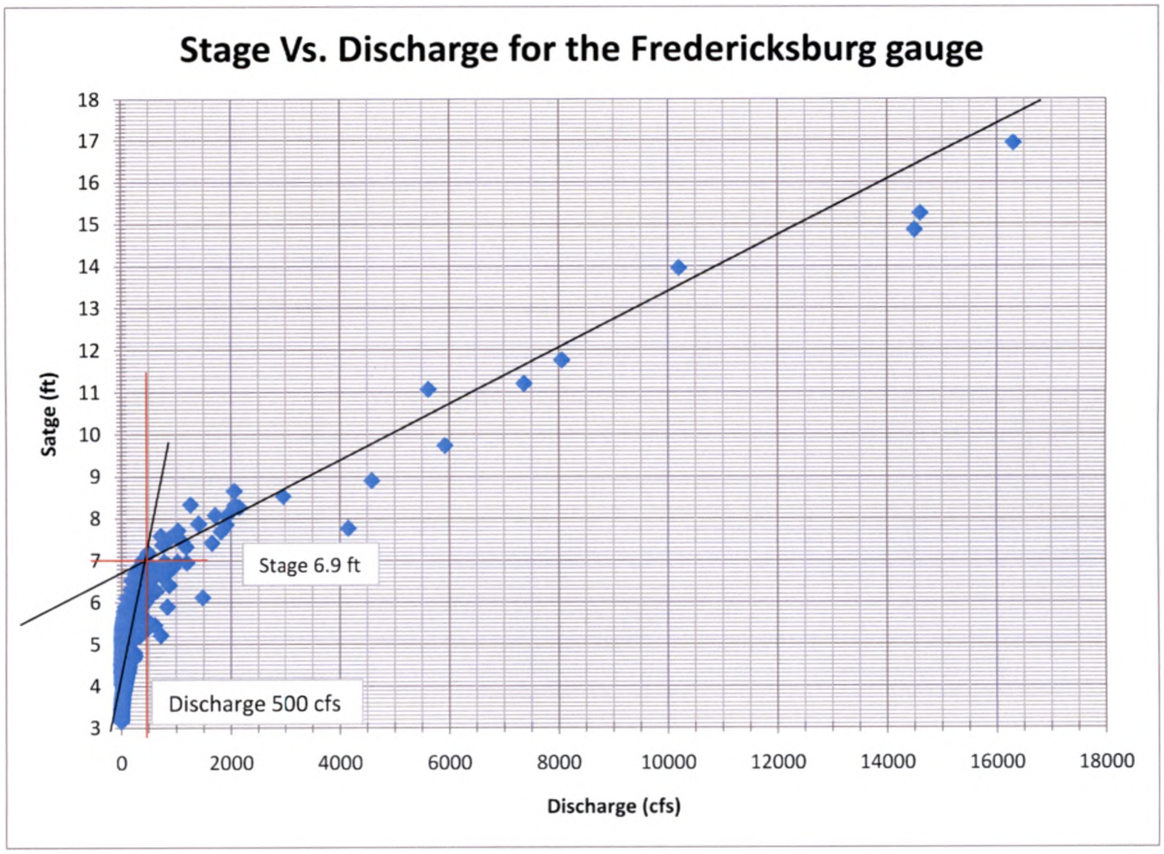


Figure 19: Stage-discharge curve for bankfull stage and discharge.

Table 3: Reoccurrence Interval table for Fredericksburg and Johnson City.

Fredericksburg (1980-2007)				Johnson City (1941-2007, RI 13.80-3.14, 1.03-1.28 not shown)			
Date	Q (cms)	Rank	RI (years)	Date	Q (cms)	Rank	RI (years)
1979	1812	1	27.00	9/11/1952	12489	1	69.00
8/17/2007	1657	2	13.50	10/4/1959	4021	2	34.50
7/5/2002	1577	3	9.00	8/3/1978	3597	3	23.00
12/20/1991	1413	4	6.75	4/24/1957	3540	4	17.25
10/19/1985	1303	5	5.40	10/13/1981	915	23	3.00
4/6/2004	937	6	4.50	12/19/1952	912	23.5	2.94
5/3/1990	527	7	3.86	9/22/1965	912	23.5	2.94
6/4/1981	379	8	3.38	11/17/2004	852	25	2.76
12/31/1984	362	9	3.00	5/13/1994	841	26	2.65
10/13/1981	354	10	2.70	3/16/1998	835	27	2.56
7/17/1987	259	11	2.45	5/23/1970	818	28	2.46
11/3/2000	251	12	2.25	1/20/1968	790	29	2.38
7/11/1988	212	13	2.08	10/18/1942	765	30	2.30
3/18/1999	180	14	1.93	8/22/1942	753	31	2.23
10/8/2002	171	15	1.80	4/6/2004	733	32	2.16
6/14/1989	116	16	1.69	9/29/1945	722	33	2.09
5/15/1980	102	17	1.59	5/3/1990	697	34	2.03
11/17/2004	75	18	1.50	5/17/1989	671	35	1.97
6/25/1983	70	19	1.42	7/15/1973	606	36	1.92
5/30/1995	65	20	1.35	4/27/1941	598	37	1.86
5/13/1994	62	21	1.29	9/13/1993	538	38	1.82
5/6/2006	61	22	1.23	10/18/1998	535	39	1.77
9/15/1991	18	23	1.17	5/26/1976	476	40	1.73
11/19/1992	11	24	1.13	9/5/2001	464	41	1.68
5/2/2000	10	25	1.08	10/29/1960	442	42	1.64
1/9/1984	4	26	1.04	12/16/1984	413	43	1.60
				5/21/1988	405	44	1.57
				9/24/1955	385	45	1.53
				6/24/1969	360	46	1.50
				6/12/1951	334	47	1.47
				2/21/2003	331	48	1.44
				3/19/1964	300	49	1.41
				12/11/1946	289	50	1.38
				5/25/1946	274	51	1.35
				5/5/2006	258	52	1.33
				8/13/1971	257	53	1.30

Bed Roughness

The value of the roughness coefficient for the Manning's equation was calculated using the velocity cross-sections taken during field work. By using measured values of mean flow velocity, hydraulic radius, and channel slope, the value of Manning's n is found using equation 2.

$$n = \frac{R^{2/3} S^{1/2}}{U}$$

This method provides more accurate roughness coefficient values than the USGS Verified Roughness Characteristics of Natural Channels Guide. The influence of the roughness factor on flow is greater at the low flows when compared to the higher bankfull discharges that minimize the effect of the roughness on the flow profile. Therefore, some of the calculated roughness values appear overestimated due to the low-flow conditions at the time of the field work.

Bankfull Discharge

The hydraulic geometry equations derived from linear analysis of discharge against each of width, depth and velocity include values for the exponents of b, f, and m. These values are specific to the Pedernales River and different from most of the values provided in the literature. Although the Pedernales values differ, they resemble values determined for ephemeral streams in Scott (1966), Dune and Leopold (1978) from Wyoming, and values from Brazil in Thornes (1970) (Table 3). In all of these cases the width exponent (b) is very low and almost insignificant. In this study, the width exponents for Fredericksburg and Johnson City are low positive values, illustrating that for an increase in discharge there is a minimal increase in width. The Fredericksburg reach has the larger of the two exponents with b= 0.128, so the width has a tendency to fluctuate more than in the bedrock reach of Johnson City where b= 0.058. This difference might not appear significant but it highlights how bedrock makes the Johnson City reach behave in a similar manner to a confined channel with stabilized bed and banks. Channel width may not be as sensitive to changes in discharge in the Johnson City reach as it is in the Fredericksburg reach. However, in both cases the R^2 values are very low (0.008 and 0.041 respectively) and the relationship to discharge is not statistically significant. Channel widths in the Johnson City reach are generally larger than in the Fredericksburg reach due to the dominance of resistant bedrock substrate in the Johnson City reach. This has led to increased erosion of the banks in the Johnson City reach because bed degradation is not an option. When both reaches are analyzed together they show a negative exponent of b=-0.07 with an R^2 of 0.005. This is not a statistically significant R^2 which shows that if the river is considered as a whole, very little change is expected in the average width of the river with an increase or decrease of discharge.

The depth and velocity exponents for the alluvial Fredericksburg reach are f=0.244 and m=0.540 and they both have low R^2 values. In contrast, in the bedrock Johnson City reach the depth and velocity hydraulic geometry exponents are f=0.610 and m=0.449 and both have high correlation values with R^2 values of 0.796 and 0.528, respectively. Both depth and velocity have a strong connection to discharge in the bedrock reach with the velocity more sensitive to changing discharges than the bankfull depth. There are a number of possible reasons for the low correlation coefficients for the Fredericksburg reach. The field data was collected in the Fredericksburg reach during 2007, which was a year with sustained high flows which might have altered the flow patterns from a more normal flow year. It is likely that the sustained increased flows induced adjustments in the channel morphology and forced the channel into a state of disequilibrium. The Fredericksburg reach has alluvial substrate and may have been actively eroding or aggrading during the course of this study. Due to the resistant bed and banks of the Johnson City reach the flood events of 2007 would not have significantly affected the channel morphology and flow hydraulics that already dominated reach behavior.

Table 4: List of b, f, and m values from the literature.

Source	b	f	m	b+f+m=1	Location (number of cross-sections)
Leopold and Maddock (1953)	0.50	0.40	0.10	1.00	
Wolman (1955)	0.34	0.45	0.32	1.11	
Wolman (1955)	0.38	0.42	0.32	1.12	
Wolman (1955)	0.45	0.43	0.17	1.05	
Wolman (1955)	0.42	0.45	0.05	0.92	
Wolman (1955)	0.57	0.40	0.03	1.00	
Wolman (1955)	0.58	0.40	0.02	1.00	
Leopold and Miller (1956)	0.29	0.15	0.58	1.02	Sedalia Gully near Sedalia, Colorado
Leopold and Miller (1956)	0.31	0.20	0.49	1.00	Sowbelly Creek near Hat Creek, Nebraska
Miller (1958)	0.38	0.25	0.39	1.02	high mountain streams
Brush (1961)	0.55	0.36	0.09	1.00	Appalachian streams
Simons and Albertson (1963)	0.51	0.36	0.13	1.00	
Ackers (1964)	0.42	0.43	0.15	1.00	
Ackers (1964)	0.43	0.43	0.14	1.00	
Ackers (1964)	0.53	0.35	0.12	1.00	
Scott (1966)	0.69	0.12	0.19	1.00	Perennial rivers
Scott (1966)	0.03	0.48	0.45	0.96	ephemeral streams
Carlston (1969)	0.46	0.38	0.16	1.00	10 river basins
Carlston (1969)	0.50	0.32	0.18	1.00	Yellow River
Thornes (1970)	0.40	0.34	0.25	0.99	Suia-Missu and Araguaia basins, Mato Gross, Brazil
Thornes (1970)	0.47	0.41	0.04	0.92	Suia-Missu and Araguaia basins, Mato Gross, Brazil
Thornes (1970)	0.11	0.32	0.59	1.02	Suia-Missu and Araguaia basins, Mato Gross, Brazil
Thornes (1970)	0.19	0.32	0.56	1.07	Suia-Missu and Araguaia basins, Mato Gross, Brazil
Thornes (1970)	0.51	0.50	0.01	1.02	Suia-Missu and Araguaia basins, Mato Gross,

Table 4: Continued.

Thornes (1970)	0.14	0.36	0.54	1.04	smaller streams
Ponton (1972)	0.60	0.40	-0.01	0.99	Green River
Ponton (1972)	0.80	0.44	-0.23	1.01	Birkenhead River
Bray (1973, 1982)	0.53	0.33	0.14	1.00	
Richards (1973)	0.44	0.31	0.25	1.00	
Richards (1973)	0.18	0.30	0.52	1.00	
Knighton (1974)	0.61	0.31	0.08	1.00	
Smith (1974)	0.60	0.30	0.10	1.00	
Smith (1974)	0.54	0.23	0.23	1.00	
Smith (1974)	0.46	0.16	0.38	1.00	
Dune and Leopold (1978)	0.16	0.39	0.44	0.99	Upper Green River Wyoming
Dune and Leopold (1978)	0.22	0.34	0.43	0.99	Upper Green River Wyoming
Dune and Leopold (1978)	0.22	0.29	0.42	0.93	Upper Green River Wyoming
Dune and Leopold (1978)	0.18	0.44	0.38	1.00	Upper Green River Wyoming
Dune and Leopold (1978)	0.08	0.42	0.50	1.00	Upper Green River Wyoming
Dune and Leopold (1978)	0.16	0.45	0.34	0.95	Upper Green River Wyoming
Dune and Leopold (1978)	0.14	0.29	0.55	0.98	Upper Green River Wyoming
Dune and Leopold (1978)	0.09	0.39	0.49	0.97	Upper Green River Wyoming
Dune and Leopold (1978)	0.19	0.45	0.33	0.97	Upper Green River Wyoming
Dune and Leopold (1978)	0.25	0.34	0.37	0.96	Upper Green River Wyoming
Dune and Leopold (1978)	0.05	0.34	0.59	0.98	Upper Green River Wyoming
Dune and Leopold (1978)	0.16	0.38	0.44	0.98	Upper Green River Wyoming
Parker (1979)	0.50	0.42	0.09	1.00	
Lane and Foster (1980)	0.46	0.46	0.08	1.00	
Griffiths (1981)	0.48	0.43	0.11	1.02	
Andrews (1984)	0.478 or 0.482	0.377 or 0.370	0.145 or 0.144		
Wasserman (1990)	0.25	0.46	0.32	1.03	Arkansas, Colorado (95)
Rhoads (1991)	0.46	0.46	-		Missouri River basin
Rhoads (1991)	0.49	0.30	-		James River basin
Rhoads (1991)	0.51	0.37	-		Smokey Hill River
Allen et al. (1994)	0.56	0.34	0.10	1.00	

Table 4: Continued.

Julien and Wargadalam (1995)	0.44	0.33	0.22	0.99	
Madesen (1995)	0.14	0.23	0.27	0.64	Columbia, Montana (89)
Cenderelli (1998)	0.27	0.47	0.26	1.00	Dudh Kosi, Nepal (18)
Zelt (2002)	0.39	0.51	0.05	0.95	Shoshone, Wyoming (20)
Tabata and Kickin (2003)	0.64	0.19	0.17	1.00	
Wohl and Wilcox (2004)	0.48	0.40	0.14	1.02	Grey, New Zeland (13)
Wohl and Wilcox (2004)	0.49	0.32	0.18	0.99	Waimakariri, New Zealand (20)
Wohl et al. (2004)	0.21	0.37	0.09	0.67	South Platte, Colorado (24)
Wohl (2004)	0.43	0.36	0.24	1.03	Chagres, Panama (40)
Wohl (2004), this study	0.59	0.39	0.16	1.14	Agua Fria, Arizona (15)
Wohl (2004), this study	0.34	0.33	0.22	0.89	Chena, Alaska (14)
Ellis (2005)	0.60	0.25	0.16	1.00	
Jong-Seok and Pierre (2006)	0.43	0.34	0.20	0.96	
This Study (Fred)	0.13	0.24	0.54	0.91	Pedernales River, Texas (10)
This Study (JC)	0.06	0.61	0.45	1.12	Pedernales River, Texas (11)
This Study (Fred, JC)	-0.07	0.56	0.55	1.05	Pedernales River, Texas (21)

<u>Stream Power</u>

The relationships between stream power and bankfull width, depth, and velocity superficially resembled the relationships between bankfull discharge and bankfull width, depth and velocity. Linear regression and power equations were derived in the same manner as for the discharge based hydraulic geometry equations. The exponent values were different between the discharge and stream power hydraulic geometry equations, but they follow the same pattern. Bankfull width was the least correlated to stream power with the lowest R^2. The depth and velocity relationships with stream power have exponents with similarly low R^2 values. The Johnson City reach shows the highest correlation between stream power and velocity, having an R^2 of 0.622 and the strongest exponent of 0.399. Stream power is based on discharge and slope, so as the stream power increases in the bedrock section the velocity increases at a greater rate than in the alluvial reach. In the Fredericksburg reach, all the R^2 values were lower with stream power in comparison to the results using discharge. As stream power increases, the width and velocity increase by approximately the same rate of 0.15, and width has an R^2 of 0.225 which is the highest of the reach. This trend is not apparent when analyzing hydraulic geometry relationships with discharge. This result indicates that in the alluvial reach stream power has more control over adjustments in streams width than in the bedrock reach. When using stream power instead of discharge in hydraulic geometry, the exponents b, f, and m do not add up to 1. Power equations do not appear to improve the hydraulic geometry relationships and are not recommended in place of discharge (Table 2).

Area, Distance downstream and Slope

The relationships between bankfull discharge and both bankfull area and distance downstream agree with the trends already discussed. In the Fredericksburg reach both area and distance downstream correlate strongly with bankfull discharge as illustrated by R^2 values of 0.722 and 0.58 and the width exponent increasing between b=3.98 and b=– 7.62. The channel adjusts to changes in discharge by widening into the erodible alluvium. In the Johnson City reach the strongest correlation is between bankfull area and depth. The depth is decreasing downstream at a rate of f=-2.49 – f=-3.48 with R^2 values of 0.38 – 0.43, showing that as the width is increasing the depth is decreasing. When analyzing changes in bankfull area and distance downstream concurrently, the results show that width increases with distance downstream while both depth and velocity decrease. The decrease in velocity could be a result of the increase in width, differences in bed type causing changes in the bed roughness and the change in channel shape.

When bankfull width, depth and velocity are regressed against channel slope, both reaches have positive trends but minimal R^2 values. The strongest R^2 of 0.38 is for width in the Fredericksburg reach which has an exponent of b=0.316. It is clear that as channel slope increases this reach is actively adjusting its shape. In the Fredericksburg reach, the bankfull velocity increases with channel slope with a power exponent of v= 0.351 and an R^2 of 0.133. Bankfull width and depth both decrease as slope increases.

Separate analysis and comparison of the two reaches in this study shows how bed substrate can influence hydraulic geometry. The upper alluvial reach illustrates an actively adjusting bed geometry where the width and depth are trying to reach a steady state condition for the bankfull discharge. The bedrock Johnson City reach shows strong correlations with its width and depth that indicate this reach is close to a steady state condition. This reach has stable banks and a bedrock channel bed that resists degradation. This also limits the ability of midrange floods from shaping the channel. Channel geometry in this reach is adjusting much slower than that of the alluvial reach and appears to reach a state of dynamic equilibrium within the historic time frame. In the event of a high magnitude flood this reach would likely experience bank destabilization which would produce widening but there would be minimal bed degradation. With this situation the correlation between width and depth would decrease until the channel re-establishes a stable geometry.

CHAPTER 7

Conclusion

Population in Central Texas is increasing and will continue to increase with or without regard to the impact on the natural environment. Landuse changes affect all aspects of the riparian system and countless other variables in the same respect. This study presents a snap shot of how the Pedernales River conveys water with the current population and anthropogenic features in place. This study forms baseline information for rivers that flow through mixed lithologies, and is a step forward in determining the regional hydraulic geometry for Central Texas.

Results from this project indicate that bankfull velocities are most sensitive to changes in bankfull discharge in the upper reach of the Pedernales while bankfull depth is most sensitive in the downstream reach. When analyzed together, depth and velocity are almost equal in their response to discharge, as is expected given the individual reach results. This difference in channel response to discharge is a consequence of the bed substrates. In the upper reach the channel has an alluvial bed that changes to bedrock downstream. In neither case is channel width greatly affected by bankfull discharge rates. The lack of sensitivity shown by the width exponent differs from the original work of Leopold and Maddock (1953) but does agree with results for rivers in areas where alluvium is either shallow or nonexistent (i.e. Scott, 1966; Thorne, 1970). The hydraulic geometry of the Pedernales River shows similarities to small and ephemeral streams from locations in the United States and Brazil.

There are inherent difficulties in field measurements of bankfull channel geometry. The bankfull depth was determined using the best available methods, but some scatter in the data remains that can be attributed to vagaries in these measurements. In an attempt to provide an improved bankfull geometry relationship, stream power was tested as a replacement variable for bankfull discharge. Stream power results show the relationships of width, depth and velocity have the same trends with increases in stream power as those observed for increases in bankfull discharge. However, there was no statistical significance for any of the stream power trends.

The hydraulic geometry of the Pedernales River did not show strong relationships that can be directly used as a regime model due to low R^2 values and scatter in the data. However, the trends of the relationships show how the river reacts to different discharges which can describe the general morphology of the Pedernales River. There are many possible reasons why there are not stronger relationships in the data. The Johnson City reach is sediment deficient and the channel is confined laterally. The local geology limits the river's ability to reach the quasi equilibrium state that is required for hydraulic geometry modeling. Watershed development and urbanization could also play a role in limiting the system's ability to establish equilibrium (Dunne and Leopold, 1978).

The importance of research in this area is more evident every year. As development increases in more rural areas the study of fluvial systems through time and space are need in order to show the effect of population on the environment. This research can provide insight for instream flow studies in Central Texas and provide useful information for evaluating and predicting the influence of land change on the fluvial system. This study can be built upon in the future to quantify river adjustment due to landuse, climate and other changes in the Pedernales River basin.

APPENDIX

Cross-sections, graphs, pictures

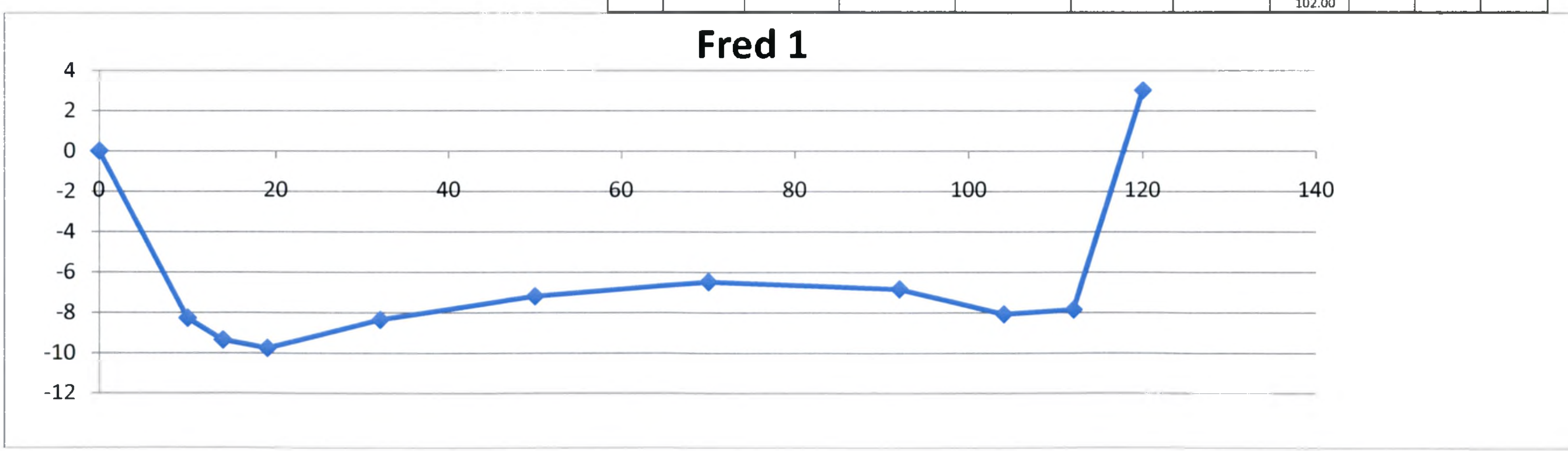
This appendix contains field data consisting of bankfull cross-sections, velocity cross –sections, charts of bankfull cross-sections, and pictures of the study sites. The Fredericksburg reach (Fred) contains cross-sections 1-10 and the Johnson City reach (JC) from 12-22.

Fred 1

L > R   Picts: 32-34

Notes	HI	HS	Corrected HS	US	LS	Distance	AZ
WL	5	13.08	8.28	13.12	13.02	10	200
		14.16	9.36	14.24	14.1	14	
		14.56	9.76	14.65	14.46	19	
		13.16	8.36	13.32	13	32	
		12	7.2	12.24	11.74	50	
		11.28	6.48	11.62	10.92	70	
		11.64	6.84	12.1	11.18	92	
		12.88	8.08	13.4	12.36	104	
WL		12.66	7.86	13.22	12.1	112	

	Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	Distance Total	D Each	A	V	Q	Q Total
1	0.00	0.00	0.00	0.00	102.00	0.00	0.00	0.00	0.00	159.89
2	0.92	3.02	1.25	1.94		12.75	38.48	1.60	61.38	
3	0.78	2.56	1.10	2.12		8.50	21.75	1.61	35.02	
4	0.62	2.03	1.55	2.10		8.50	17.29	1.83	31.55	
5	0.42	1.38	1.53	1.85		8.50	11.71	1.69	19.79	
6	0.28	0.92	1.12	1.54		8.50	7.81	1.33	10.39	
7	0.12	0.39	0.62	0.92		8.50	3.35	0.77	2.58	
8	0.04	0.13	0.34	0.00		8.50	1.12	0.17	0.19	
9	0.10	0.33	-0.10	0.00		8.50	2.79	-0.05	-0.14	
10	0.10	0.33	-0.08	0.00		8.50	2.79	-0.04	-0.11	
11	0.30	0.98	-0.13	-0.08		8.50	8.37	-0.11	-0.88	
12	0.54	1.77	-0.02	0.03		12.75	22.59	0.01	0.11	
13	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
							102.00			



Fred 1

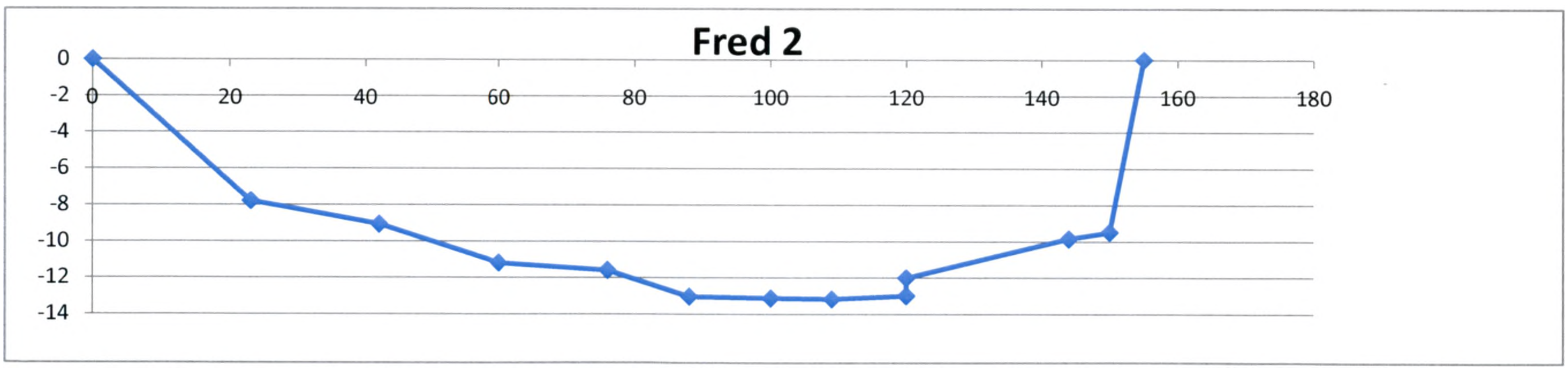
Fred 2

L > R

Notes	HI	HS	Corr. HS	US	LS	Distance
	5	12.3	7.8	12.41	12.18	23
		13.58	9.08	13.78	13.36	42
		15.7	11.2	16	15.4	60
WL		16.1	11.6	16.46	15.7	76
		17.55	13.05	18	17.12	88
		17.64	13.14	18.14	17.14	100
		17.68	13.18	18.23	17.14	109
		17.5	13	18.1	16.9	120
WL		16.52	12.02	17.16	15.96	120
		14.36	9.86	15.08	13.64	144
		14	9.5	14.76	13.26	150

Picts: 35 (54') 5.4' intervals

	Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
1	0.00	0.00	0.00	0.00	54.00	0.00	0.00	0.00	0.00	162.46
2	0.26	0.85	1.52	2.25		9.00	7.68	1.89	14.47	
3	0.40	1.31	2.65	3.25		6.00	7.87	2.95	23.23	
4	0.46	1.51	2.14	3.26		6.00	9.06	2.70	24.45	
5	0.44	1.44	1.89	3.39		6.00	8.66	2.64	22.87	
6	0.44	1.44	2.15	2.82		6.00	8.66	2.49	21.52	
7	0.44	1.44	1.97	2.66		6.00	8.66	2.32	20.05	
8	0.36	1.18	1.89	2.30		6.00	7.09	2.10	14.85	
9	0.42	1.38	1.46	1.93		9.00	12.40	1.70	21.02	
10	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
						54.00				



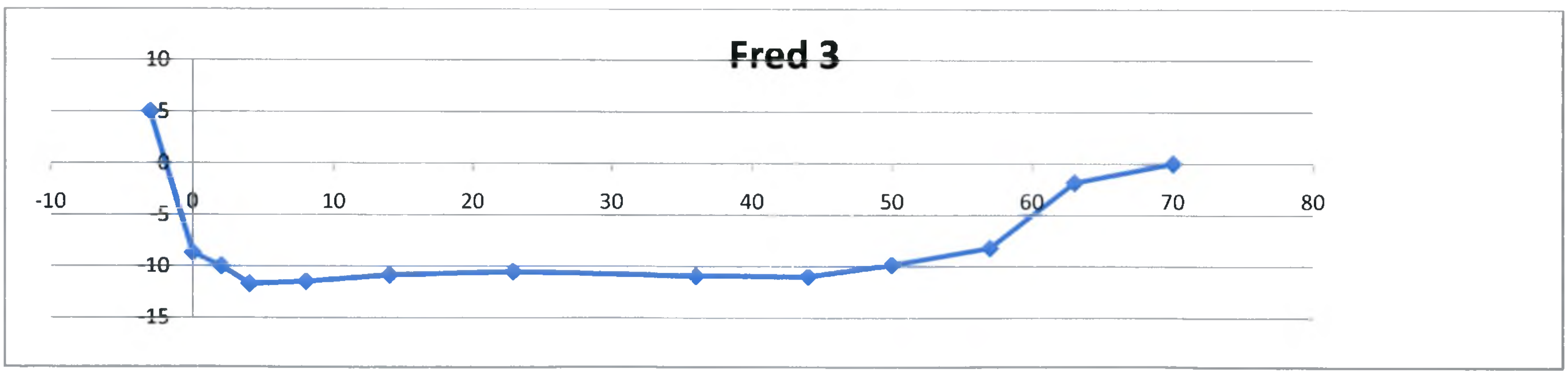
Fred 2

Fred 3

L > R Picts:36-38 GPS:50-60 (54')-5.4' intervals

Notes	HI	HS	Corrected HS	US	LS	Distance	AZ
WL	**5**	**13.5**	**8.7**	**13.9**	**13.2**	**70**	**323**
		14.78	9.98	15.14	14.46	68	
		16.5	11.7	16.84	16.18	66	
		16.3	11.5	16.6	15.8	80	
		15.65	10.85	15.94	15.38	56	
		15.32	10.52	15.56	15.09	47	
		15.74	10.94	15.9	15.56	34	
		15.78	10.98	15.9	15.64	26	
WL		14.64	9.84	14.76	14.56	20	
		13	8.2	13.8	12.93	87	
		6.64	1.84	6.67	6.6	7	

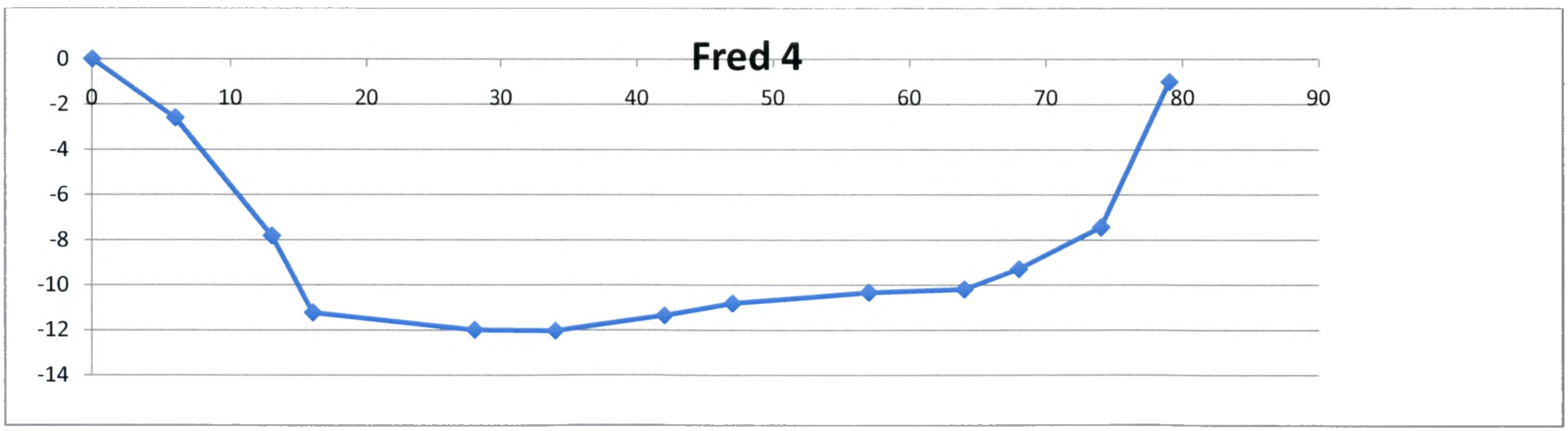
	Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
1	**0.00**	**0.00**	**0.00**	**0.00**	**54.00**	**0.00**	**0.00**	**0.00**	**0.00**	**143.34**
2	0.76	2.49	2.15	2.90		7.00	17.45	2.53	44.07	
3	0.66	2.17	1.95	3.10		5.00	10.83	2.53	27.34	
4	0.58	1.90	2.09	2.79		5.00	9.51	2.44	23.22	
5	0.50	1.64	1.47	3.04		5.00	8.20	2.26	18.50	
6	0.44	1.44	1.79	2.96		5.00	7.22	2.38	17.14	
7	0.46	1.51	-0.02	0.01		5.00	7.55	-0.01	-0.04	
8	0.54	1.77	0.12	0.08		5.00	8.86	0.10	0.89	
9	0.62	2.03	0.87	1.14		5.00	10.17	1.01	10.22	
10	0.60	1.97	0.01	0.66		5.00	9.84	0.34	3.30	
11	0.40	1.31	-0.12	-0.16		7.00	9.19	-0.14	-1.29	
		12.00	0.00	0.00						



Fred 3

Fred 4

						L > R			Picts:39-41	GPS:61-71		(60')/6' int						
Notes	HI	HS	Corrected HS	US	LS	Distance	AZ		Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
	5	7.14	2.6	7.17	7.11	6	159	1	0.00	0.00	0.00	0.00	60.00	0.00	0.00	0.00	0.00	187.32
WL		12.36	7.82	12.42	12.29	13		2	0.80	2.62	1.11	2.61		9.00	11.81	1.86	21.97	
		15.78	11.24	15.86	15.7	16		3	1.80	5.91	2.30	3.02		6.00	35.43	2.66	94.25	
		16.54	12	16.68	16.4	28		4	0.98	3.22	1.11	2.26		6.00	19.29	1.69	32.51	
		16.58	12.04	16.75	16.41	34		5	0.80	2.62	1.10	1.38		6.00	15.75	1.24	19.53	
		15.9	11.36	16.1	15.68	42		6	0.64	2.10	0.90	1.00		6.00	12.60	0.95	11.97	
		15.36	10.82	15.59	15.12	47		7	0.50	1.64	0.42	0.66		6.00	9.84	0.54	5.31	
		14.88	10.34	15.19	14.62	57		8	0.38	1.25	0.09	0.43		6.00	7.48	0.26	1.94	
		14.74	10.2	15.06	14.42	64		9	0.36	1.18	0.09	0.07		6.00	7.09	0.08	0.57	
WL		13.84	9.3	14.18	13.5	68		10	0.34	1.12	-0.08	-0.21		9.00	5.02	-0.15	-0.73	
		11.98	7.44	12.34	11.6	74		11	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	

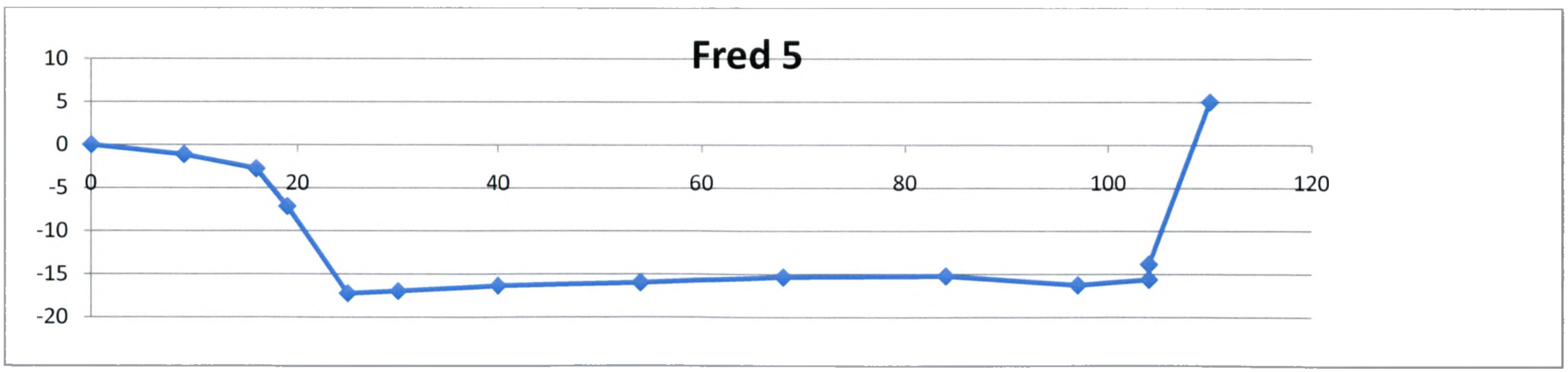


Fred 4

Fred 5

L > R   Picts:42-43   GPS:72-82   (84') - 8.4' int

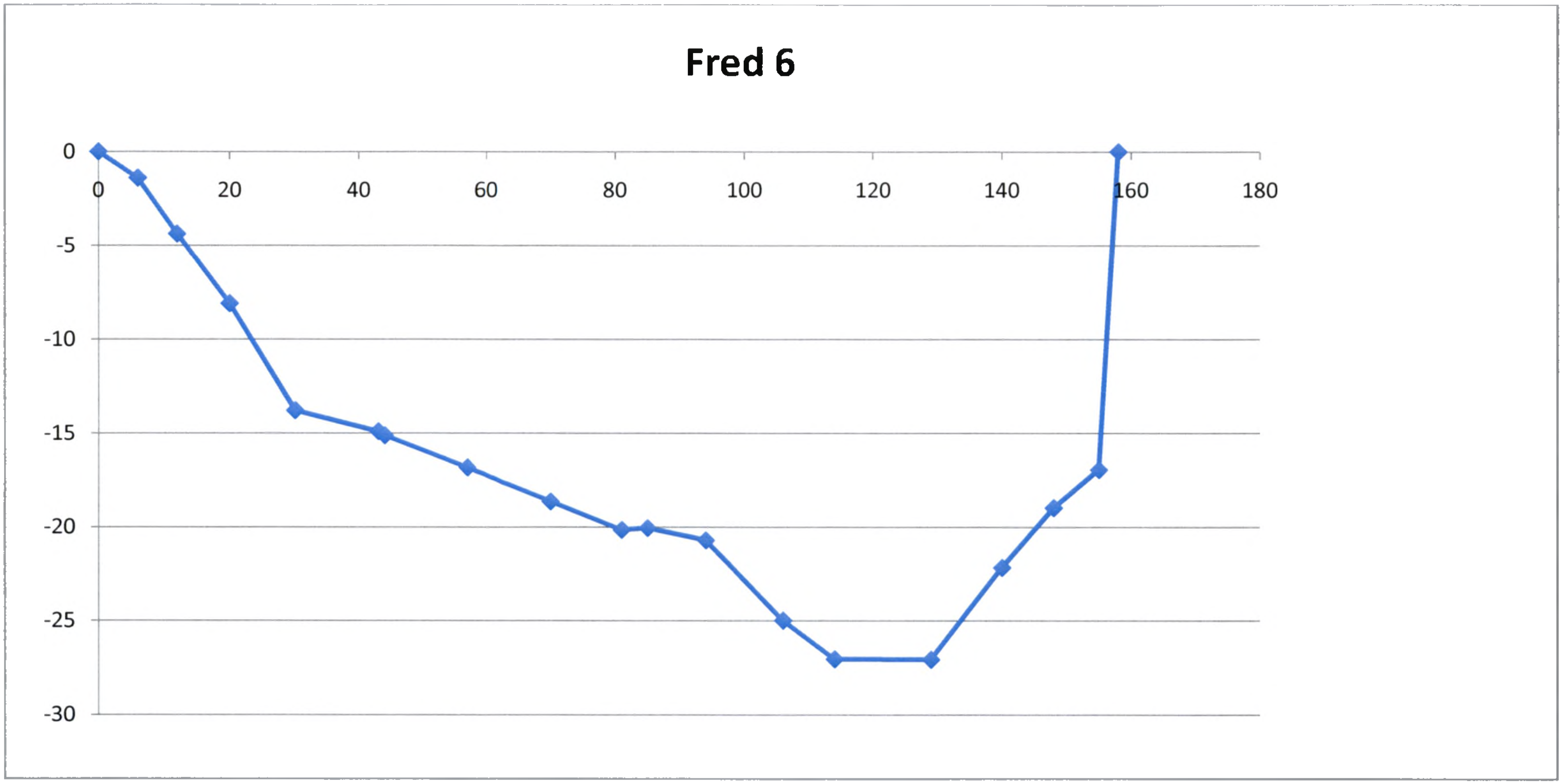
Notes	HI	HS	Corrected HS	US	LS	Distance	AZ		Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
	4	4.68	1.14	4.73	4.64	9	170	1	0.00	0.00	0.00	0.00	84.00	0.00	0.00	0.00	0.00	133.94
		6.32	2.78	6.4	6.24	16		2	0.70	2.30	0.25	0.67		10.50	24.11	0.46	11.09	
		10.72	7.18	10.81	10.62	19		3	0.78	2.56	0.53	0.50		7.00	17.91	0.52	9.23	
WL		20.8	17.26	22.4	19.5	20		4	0.80	2.62	0.65	0.88		7.00	18.37	0.77	14.06	
		20.54	17	27.2	23.6	360		5	0.72	2.36	0.78	1.08		7.00	16.54	0.93	15.38	
		19.92	16.38	21.6	19.69	191		6	0.64	2.10	1.10	1.10		7.00	14.70	1.10	16.17	
		19.55	16.01	19.82	19.28	54		7	0.52	1.71	1.03	1.30		7.00	11.94	1.17	13.91	
		18.9	15.36	19.24	18.56	68		8	0.38	1.25	1.02	1.36		7.00	8.73	1.19	10.39	
		18.78	15.24	19.2	18.36	84		9	0.50	1.64	0.95	1.19		7.00	11.48	1.07	12.29	
		19.84	16.3	19.32	18.35	97		10	0.42	1.38	1.05	1.25		7.00	9.65	1.15	11.09	
		19.18	15.64	19.7	18.66	104		11	0.38	1.25	0.53	0.95		7.00	8.73	0.74	6.46	
WL		17.42	13.88	20.02	18.98	104		12	0.48	1.57	0.63	1.05		10.50	16.54	0.84	13.89	



Fred 5

Fred 6 L > R Picts:44-47

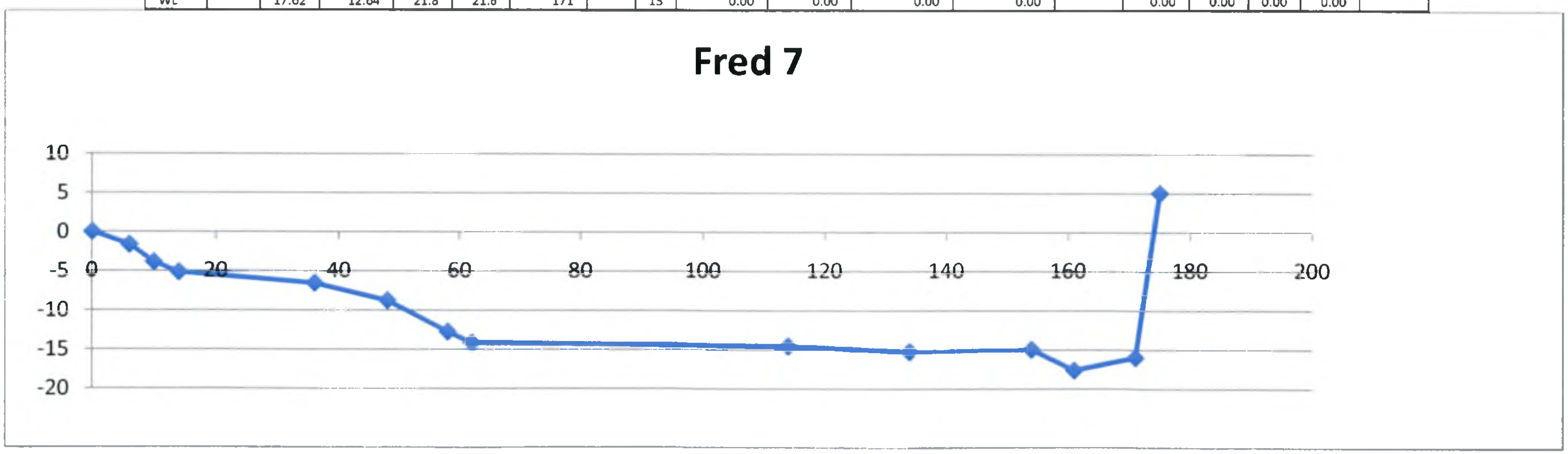
Notes	HI	HS	Corr. HS	CHS2	US	LS	Distance		AZ	Neg heights
		4.66	0	0			0	0	450	0
	4.66	6.06	1.4	1.4	6.1	6.04	6	6		-1.4
		9.03	4.37	4.37	9.09	8.97	12	12		-4.37
		12.76	8.1	8.1	12.86	12.66	20	20		-8.1
		18.44	13.78	13.78	18.58	18.28	30	30		-13.78
		19.56	14.9	14.9	19.77	19.34	43	43		-14.9
		19.78	15.12	15.12	19.98	19.54	44	44		-15.12
15.12	5.26	5.26	0	15.12			0	44		-15.12
		6.96	1.7	16.82	7.04	6.91	13	57		-16.82
		8.77	3.51	18.63	8.9	8.64	26	70		-18.63
		10.28	5.02	20.14	10.47	10.1	37	81		-20.14
		10.18	4.92	20.04	10.37	10.005	36.5	85		-20.04
		10.84	5.58	20.7	13.1	12.6	50	94		-20.7
		15.12	9.86	24.98	15.44	14.82	62	106		-24.98
		17.18	11.92	27.04	18.56	16.81	175	114		-27.04
		17.2	11.94	27.06	17.48	16.63	85	129		-27.06
		12.3	7.04	22.16	12.8	11.84	96	140		-22.16
		9.1	3.84	18.96	9.62	8.58	104	148		-18.96
		7.08	1.82	16.94	7.63	6.52	111	155		-16.94
								158		0


Fred 6
0
-5
-10
-15
-20
-25
-30
0
20
40
60
80
100
120
140
160
180

Fred 6

Fred 7

						L > R			Picts:48-51	GPS:105 - 115		(113') - 10' int						
Notes	HI	HS	Corr. HS	US	LS	Distance	AZ		Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
	4.98	6.61	1.63	6.64	6.58	6	245	1	0.00	0.00	0.00	0.00	113.00	0.00	0.00	0.00	0.00	123.82
		8.84	3.86	8.9	8	90		2	0.24	0.79	0.20	0.32		15.00	11.81	0.26	3.07	
		10.12	5.14	10.19	10.05	14		3	0.44	1.44	0.37	0.51		10.00	14.44	0.44	6.35	
		11.54	6.56	11.71	11.35	36		4	0.52	1.71	0.38	0.58		10.00	17.06	0.48	8.19	
		13.76	8.78	14	13.52	48		5	0.48	1.57	0.50	0.64		10.00	15.75	0.57	8.98	
WL		17.72	12.74	18	17.42	58		6	0.56	1.84	0.52	0.80		10.00	18.37	0.66	12.13	
		19.14	14.16	19.56	17.84	172		7	0.70	2.30	0.53	0.72		10.00	22.97	0.63	14.35	
		19.52	14.54	20.1	18.96	114		8	0.80	2.62	0.66	0.73		10.00	26.25	0.70	18.24	
		20.22	15.24	20.9	19.56	134		9	0.78	2.56	0.69	0.70		10.00	25.59	0.70	17.79	
		19.94	14.96	20.7	19.16	154		10	0.72	2.36	0.46	0.72		10.00	23.62	0.59	13.94	
		22.6	17.62	21.8	19.46	234		11	0.78	2.56	0.24	0.73		10.00	25.59	0.49	12.41	
		20.98	16	21.8	21.6	171		12	0.84	2.76	0.37	0.39		8.00	22.05	0.38	8.38	
WL		17.62	12.64	21.8	21.6	171		13	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	

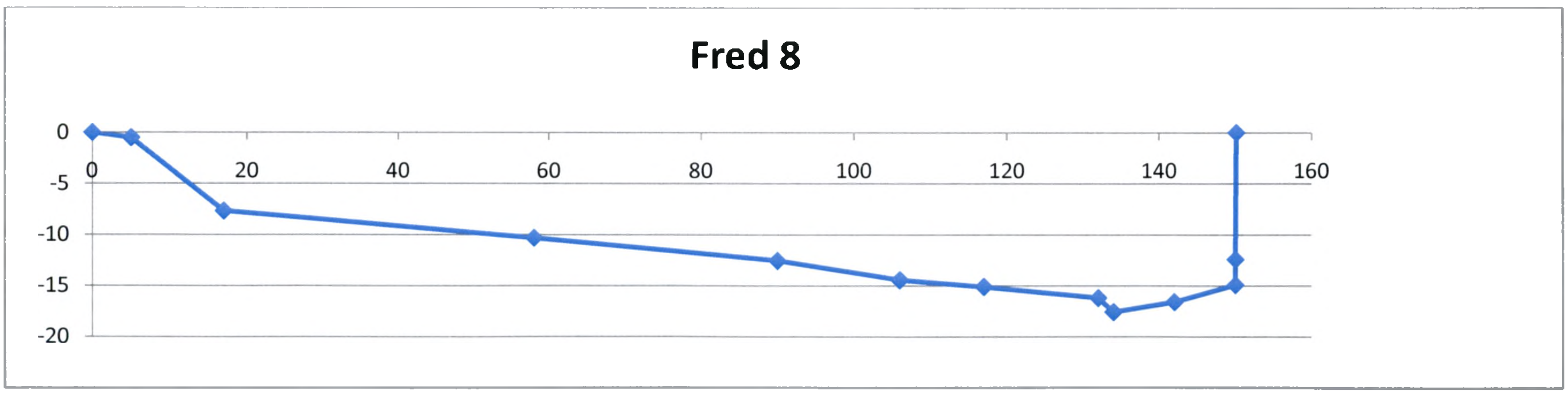


Fred 7

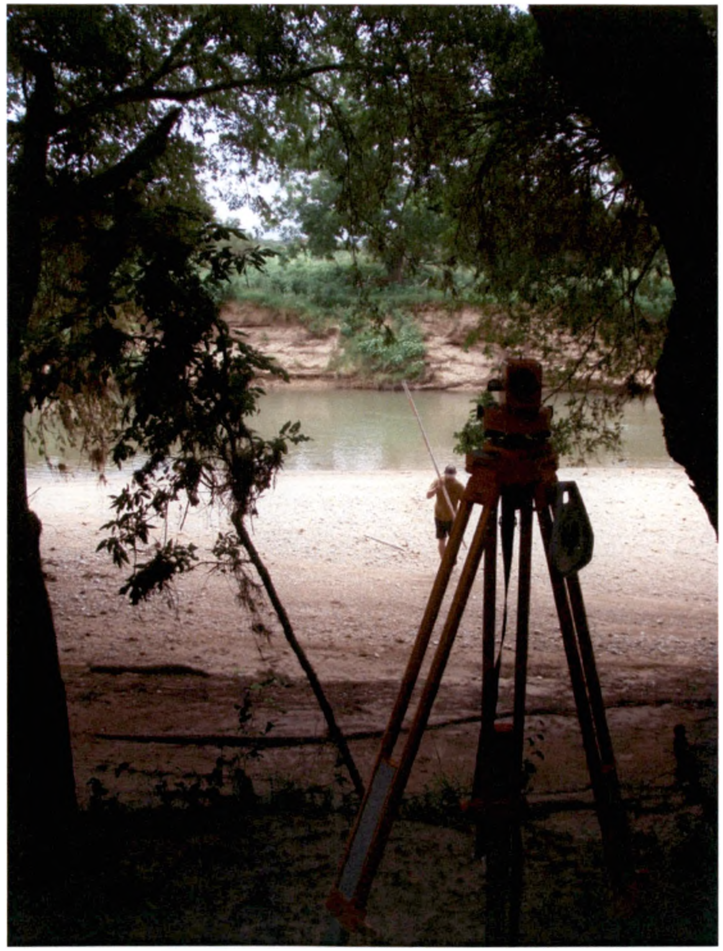
Fred 8

L > R Picts:52 GPS:116-126 (60') - 6' int

Notes	HI	HS	Corr. HS	US	LS	Distance	AZ		Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	60% V	D Total	D Each	A	V	Q	Q Total
	5.4	5.91	0.51	5.94	5.89	5	325	1	0.00	0.00	0.00	0.00		60.00	0.00	0.00	0.00	0.00	130.39
		13.1	7.7	13.19	13.02	17		2	0.38	1.25	0.14	0.13			9.00	11.22	0.14	1.51	
		15.74	10.34	16.02	15.44	58		3	0.58	1.90	0.22	-0.01			6.00	11.42	0.11	1.20	
WL		17.96	12.56	18.42	17.52	90		4	0.74	2.43	0.33	0.02			6.00	14.57	0.18	2.55	
		19.86	14.46	20.38	19.32	106		5	0.80	2.62	0.58	0.64			6.00	15.75	0.61	9.61	
		20.52	15.12	21.1	19.93	117		6	0.82	2.69	0.90	0.78			6.00	16.14	0.84	13.56	
		21.62	16.22	22.3	20.98	132		7	1.16	3.81	0.89	0.84			6.00	22.83	0.87	19.75	
		23	17.6	23.74	22.4	134		8		4.56			1.07		4.50	20.52	1.07	21.96	
		22	16.6	22.74	21.32	142		9		4.24			1.24		4.50	19.08	1.24	23.66	
		20.34	14.94	21.14	19.64	150		10	1.12	3.67	0.60	1.06			12.00	44.09	0.83	36.60	
WL, cliff		17.84	12.44	21.14	19.64	150		11	0.00	0.00	0.00	0.00			0.00	0.00	0.00	0.00	



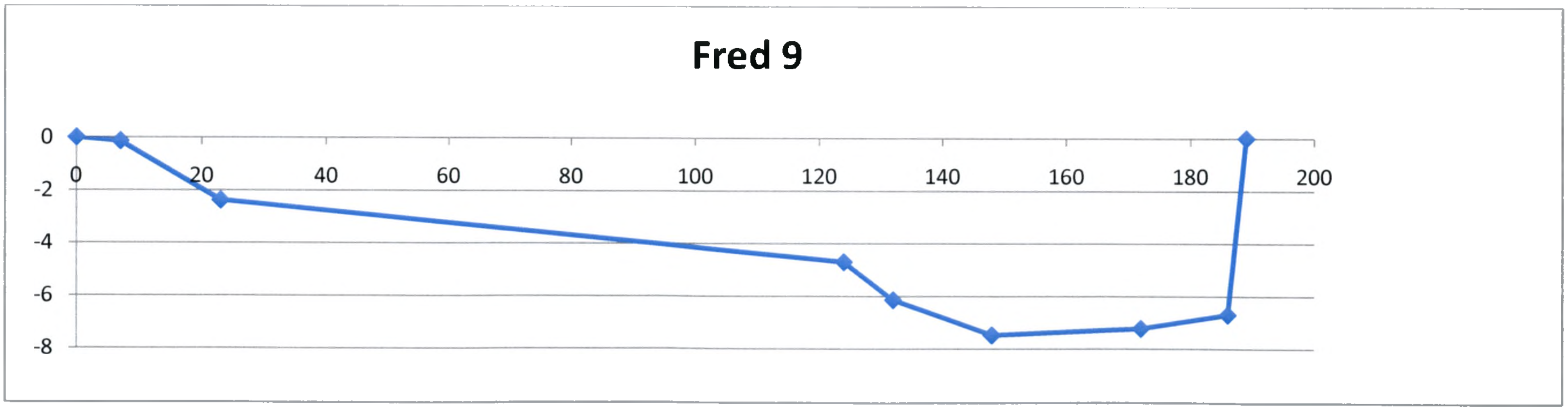
Fred 8



Fred 9

R>L   Picts:58-60   GPS:127-137   (57') - 6' int

Notes	HI	HS	Corrected HS	US	LS	Distance		Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
	4.9	5.04	0.14	5.08	5.01	7	1	0.00	0.00	0.00	0.00	54.00	0.00	0.00	0.00	0.00	130.20
		7.28	2.38	7.41	7.18	23	2	0.16	0.52	1.16	1.70		8.00	4.20	1.43	6.01	
		9.6	4.7	10.22	8.98	124	3	0.32	1.05	1.38	2.45		6.00	6.30	1.92	12.06	
WL		11.04	6.14	11.7	10.38	132	4	0.42	1.38	1.78	2.90		6.00	8.27	2.34	19.35	
		12.38	7.48	13.12	11.64	148	5	0.34	1.12	2.34	3.27		6.00	6.69	2.81	18.77	
		12.13	7.23	13	11.28	172	6	0.48	1.57	2.48	2.99		6.00	9.45	2.74	25.84	
WL	verticle wall	11.6	6.7	12.52	10.66	186	7	0.36	1.18	1.64	2.65		6.00	7.09	2.15	15.20	
							8	0.34	1.12	1.68	2.95		6.00	6.69	2.32	15.49	
							9	0.32	1.05	1.47	2.28		6.00	6.30	1.88	11.81	
							10	0.18	0.59	1.05	1.69		7.00	4.13	1.37	5.66	
							11	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
													57.00				

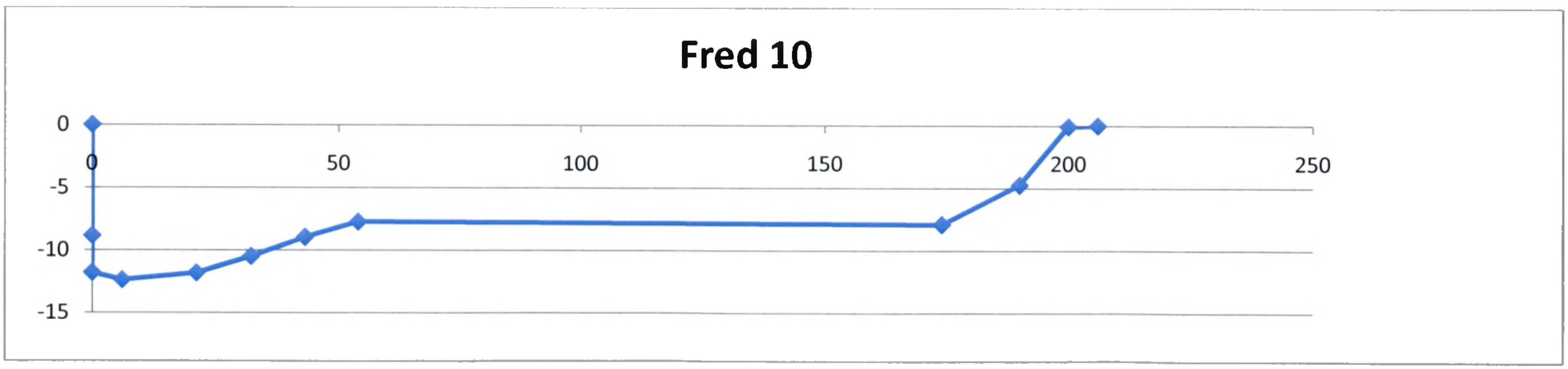


Fred 9

Fred 10

L > R — Picts: — GPS:138-148 — (51') -5' INT

Notes	HI	HS	Corrected HS	US	LS	Distance	AZ			Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
2.96		13.68	8.84				300	5' BANK	1	0.00	0.00	0.00	0.00	46.00	0.00	0.00	0.00	0.00	264.90
WL	4.8	16.64	11.8	17.64	15.58	206			2	0.92	3.02	2.28	1.81		7.50	11.32	4.13	46.71	
		17.22	12.38	18.22	16.22	200			3	0.96	3.15	2.45	2.81		6.00	18.90	6.88	130.10	
		16.66	11.82	17.58	15.73	185			4	0.90	2.95	1.75	2.18		5.00	14.76	3.82	56.32	
		15.34	10.5	16.22	14.48	174			5	0.88	2.89	1.43	1.34		5.00	14.44	1.92	27.66	
WL		13.81	8.97	14.62	12.99	163			6	0.86	2.82	0.32	0.83		5.00	14.11	0.27	3.75	
		12.58	7.74	13.34	11.82	152			7	0.68	2.23	-0.10	0.16		5.00	11.15	-0.02	-0.18	
		12.75	7.91	12.9	12.58	32		6' INT	8	0.50	1.64	-0.21	-0.29		5.00	8.20	0.06	0.50	
		9.59	4.75	9.67	9.51	16			9	0.12	0.39	-0.15	-0.17		7.50	1.48	0.03	0.04	
		4.91	0.07	4.94	4.88	6			10	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
															46.00				



Fred 10

JC 12 L > R Picts:64-65

Notes	HI	HS	Corr. HS	US	LS	Distance	AZ
	5	5.82	0.8	5.92	5.7	22	336
		6.94	1.92	7.22	6.66	56	
WL		8.24	3.22	8.54	7.92	62	
		10.13	5.11	10.56	9.7	86	
		10.53	5.51	11.08	9.98	110	
		11.83	6.81	12.43	11.23	120	
		10.46	5.44	11.16	9.76	140	
		10.06	5.04	10.9	9.24	166	
		11.82	6.8	12.74	10.9	184	
		11.54	6.52	12.63	10.44	219	
		12.32	7.3	13.58	11.06	252	
		13.26	8.24	14.6	12.94	166	
		13.62	8.6	15.1	12.18	292	
		12.96	7.94	13.53	10.36	317	
		12.1	7.08	13.84	10.4	344	
		13.28	8.26	15.14	11.44	370	
WL		8.3	3.28	10.2	6.4	380	
		6.49	1.47	8.42	4.54	388	


JC 12
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-1
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-3
-4
-5
-6
-7
-8
-9
-10
0
50
100
150
200
250
300
350
400
450

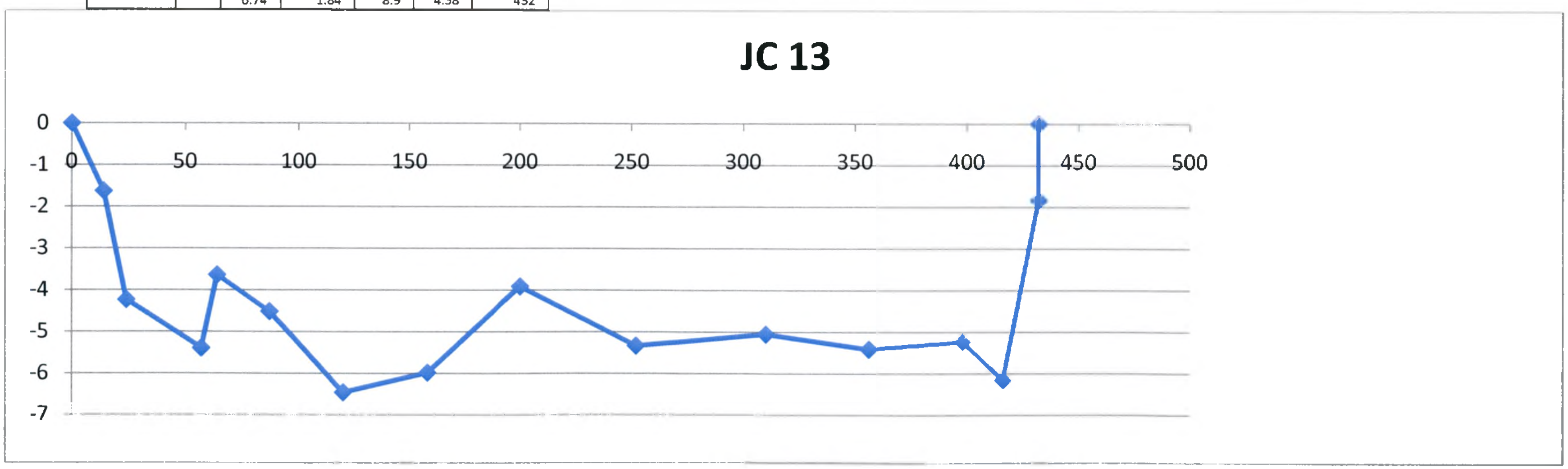
JC 12

JC 13

L > R Picts:66-68 GPS:11-21 392' 35.5'

Notes	HI	HS	Corr. HS	US	LS	Distance	AZ
	4.9	6.53	1.63	6.6	6.46	14	327
WL		9.14	4.24	9.26	9.02	24	
		10.3	5.4	10.59	10.02	57	
		8.54	3.64	8.86	8.22	64	
		9.42	4.52	9.85	8.98	87	
		11.36	6.46	11.96	10.76	120	
		10.89	5.99	11.68	10.1	158	
		8.82	3.92	9.82	7.82	200	
		10.24	5.34	11.5	8.98	252	
		9.96	5.06	11.5	8.4	310	
		10.32	5.42	12.1	8.54	356	
		10.14	5.24	12.12	8.14	398	
WL		11.06	6.16	13.14	8.98	416	
		6.74	1.84	8.9	4.58	432	

Change Int.		Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
	1	0.00	0.00	0.00	0.00	392.00	0.00	0.00	0.00	0.00	461.22
	2	0.50	1.64	2.73	2.52		56.00	45.93	2.63	120.57	
	3	0.22	0.72	-0.15	0.15		35.00	25.26	0.00	0.00	
	4	0.36	1.18	0.99	1.29		35.00	41.34	1.14	47.13	
23	5	0.68	2.23	1.59	1.68		35.00	78.08	1.64	127.67	
30	6	0.38	1.25	0.10	0.35		35.00	43.64	0.23	9.82	
55	7	0.30	0.98	0.65	1.00		35.00	34.45	0.83	28.42	
25	8	0.18	0.59	1.08	1.67		35.00	20.67	1.38	28.42	
60	9	0.18	0.59	2.17	2.47		35.00	20.67	2.32	47.95	
47	10	0.22	0.72	1.30	1.35		35.00	25.26	1.33	33.47	
25	11	0.30	0.98	-0.70	1.99		56.00	27.56	0.65	17.78	
18	12	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
							392.00				

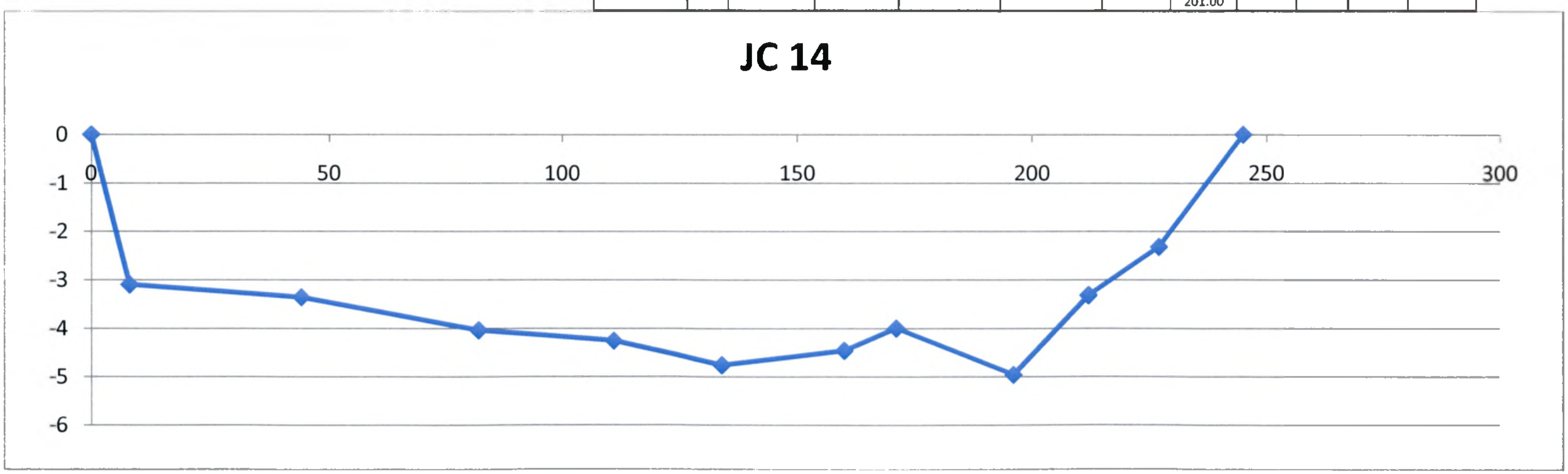


JC 13

JC 14

L > R Picts:68-71 GPS:22-32 201 18' int

Notes	HI	HS	Corr. HS	US	LS	Distance	AZ	Change Int.		Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
	4.9	8.02	3.1	8.06	7.98	8	282		1	0.00	0.00	0.00	0.00	201.00	0.00	0.00	0.00	0.00	349.79
WL		8.28	3.36	8.5	8.06	44			2	1.00	3.28	1.03	1.28		28.00	45.93	1.16	53.05	
		8.96	4.04	9.36	8.54	82			3	0.18	0.59	1.38	1.67		18.00	10.63	1.53	16.21	
		9.18	4.26	9.74	8.63	111			4	0.22	0.72	0.98	1.41		18.00	12.99	1.20	15.53	
		9.68	4.76	10.35	9.01	134			5	0.30	0.98	2.01	2.22		18.00	17.72	2.12	37.47	
		9.38	4.46	10.18	8.58	160			6	0.22	0.72	1.57	2.07		19.00	13.71	1.82	24.96	
		8.92	4	9.77	8.06	171			7	0.28	0.92	2.62	3.33		18.00	16.54	2.98	49.19	
		9.88	4.96	10.86	8.9	196			8	0.52	1.71	1.59	2.36		18.00	30.71	1.98	60.65	
		8.24	3.32	9.3	7.18	212			9	0.24	0.79	2.77	3.03		18.00	14.17	2.90	41.10	
WL		7.24	2.32	8.37	6.1	227			10	0.66	2.17	1.09	1.00		18.00	38.98	1.05	40.73	
		4.92	0	6.15	3.7	245			11	0.42	1.38	0.07	1.06		28.00	19.29	0.57	10.90	
								19	12	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
															201.00				



JC 14

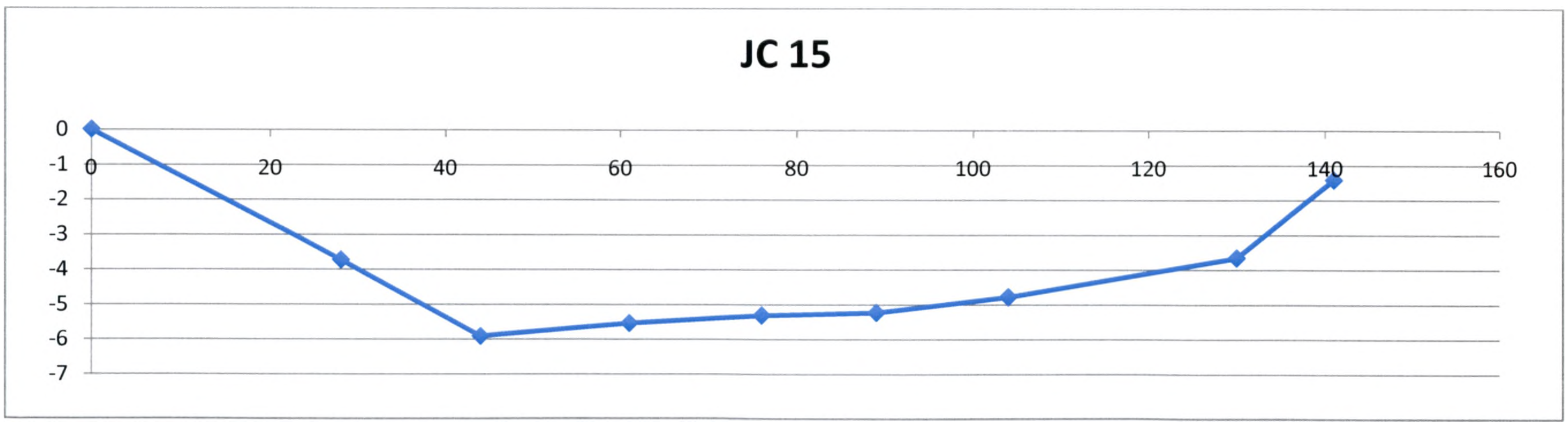
JC 15

L > R

Notes	HI	HS	Corr. HS	US	LS	Distance
WL	5	8.73	3.73	8.87	8.59	28
		10.9	5.91	11.13	10.69	44
		10.5	5.54	10.84	10.23	61
		10.3	5.31	10.69	9.93	76
		10.2	5.23	10.68	9.79	89
		9.78	4.78	10.3	9.26	104
WL		8.66	3.66	9.3	8	130
		6.42	1.42	7.12	5.71	141

Picts:72-73 GPS:33-43 101' 10' int

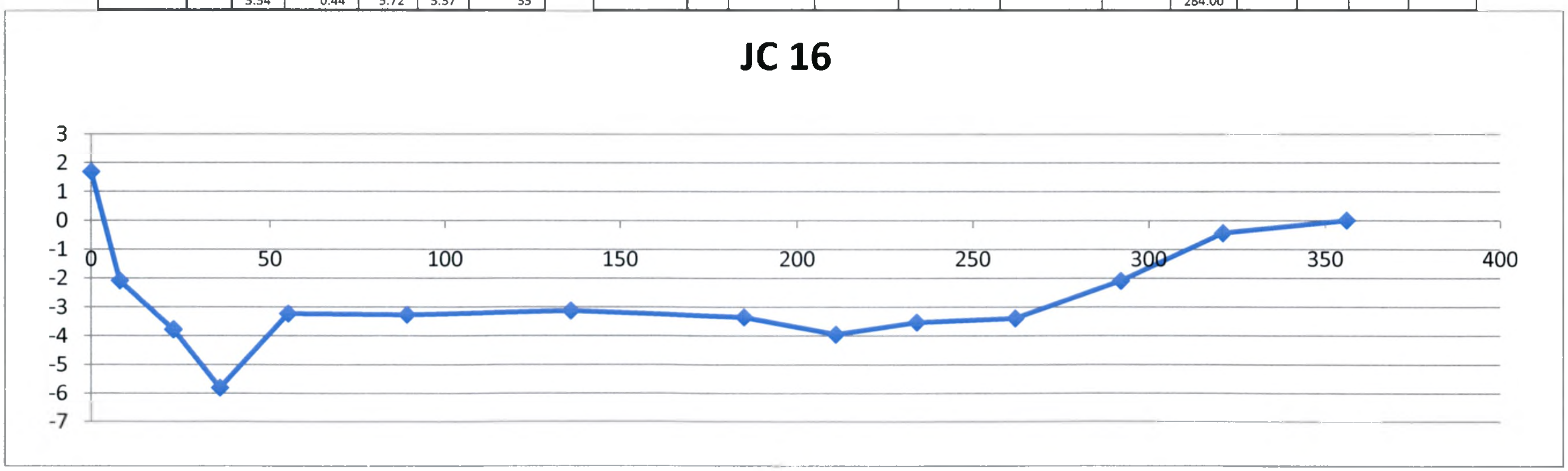
Change Int.		Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
	1	0.00	0.00	0.00	0.00	101.00	0.00	0.00	0.00	0.00	325.72
	2	0.64	2.10	1.42	1.80		15.00	31.50	1.61	50.71	
	3	0.76	2.49	2.07	2.67		10.00	24.93	2.37	59.09	
	4	0.64	2.10	2.61	3.33		10.00	21.00	2.97	62.36	
	5	0.54	1.77	2.76	3.05		10.00	17.72	2.91	51.47	
	6	0.48	1.57	2.17	2.79		11.00	17.32	2.48	42.96	
	7	0.50	1.64	1.80	2.05		10.00	16.40	1.93	31.58	
	8	0.34	1.12	1.40	2.04		10.00	11.15	1.72	19.19	
	9	0.24	0.79	0.32	0.53		25.00	19.68	0.43	8.37	
20	10	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	



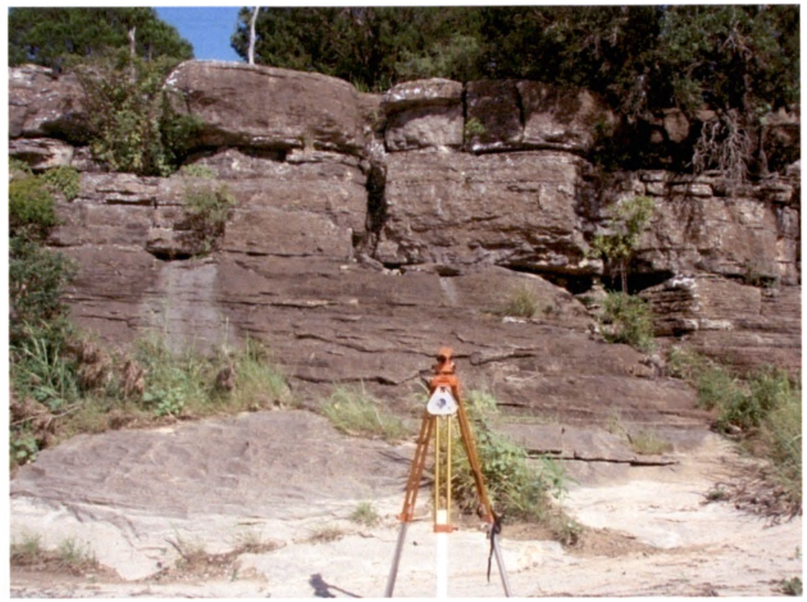
JC 15

JC 16

Notes	HI	HS	Corr. HS	US	LS	Distance	AZ	Change Int.		Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
						L > R		Picts:74-76	GPS:44-54		284'	28.4' int							
	5.1	3.42	-1.68	5.2	1.64	356	296		1	0.00	0.00	0.00	0.00	284.00	0.00	0.00	0.00	0.00	328.41
		7.2	2.1	8.94	5.46	348			2	0.50	1.64	0.52	0.72		33.50	54.95	0.62	34.07	
		8.89	3.79	10.55	7.22	333		17	3	0.32	1.05	0.71	1.01		22.50	23.62	0.86	20.31	
		10.9	5.82	12.52	9.32	320			4	0.40	1.31	0.58	0.96		28.00	36.75	0.77	28.29	
		8.34	3.24	9.85	6.84	301			5	0.38	1.25	0.62	0.55		28.00	34.91	0.59	20.42	
		8.38	3.28	9.71	7.04	267			6	0.38	1.25	0.42	0.52		28.00	34.91	0.47	16.41	
		8.24	3.14	9.34	7.14	220			7	0.32	1.05	0.94	1.13		28.00	29.40	1.04	30.43	
		8.46	3.36	9.31	7.6	171			8	0.38	1.25	0.86	1.17		28.00	34.91	1.02	35.43	
		9.06	3.96	9.79	8.34	145			9	0.46	1.51	0.71	1.28		28.00	42.26	1.00	42.05	
		8.64	3.54	9.24	8.02	122			10	0.44	1.44	1.20	1.55		28.00	40.42	1.38	55.58	
		8.5	3.4	8.98	8.04	94			11	0.42	1.38	0.93	1.13		32.00	44.09	1.03	45.42	
		7.2	2.1	7.52	6.88	64			12	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
		5.54	0.44	5.72	5.37	35									284.00				



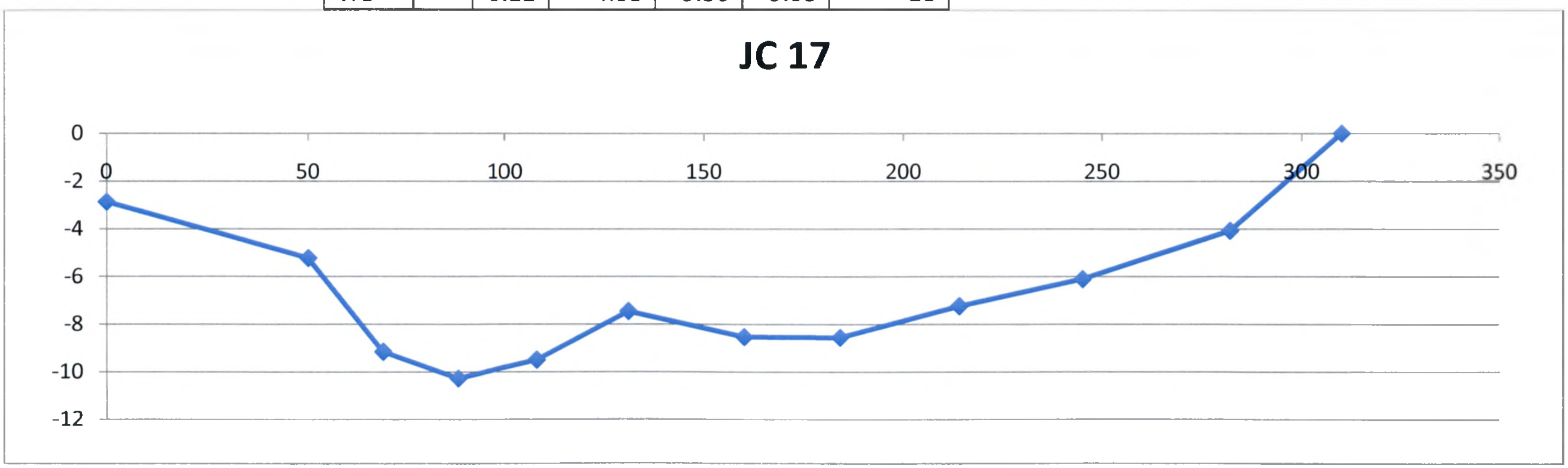
JC 16



Picts:77-78 GPS:55-65

JC 17 L > R

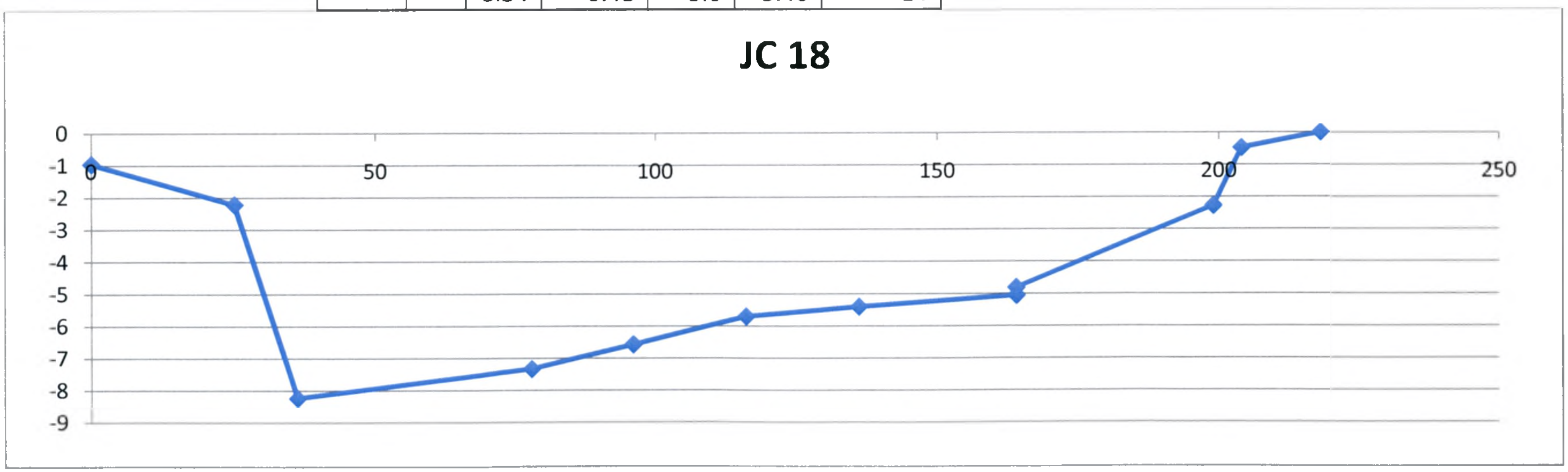
Notes	HI	HS	Corr. HS	US	LS	Distance	AZ
	5.1	8.01	2.87	9.56	6.46	310	0
WL		10.4	5.23	11.66	9.06	260	
		14.3	9.16	15.5	13.09	241	
		15.4	10.28	16.54	14.32	222	
		14.6	9.5	15.66	13.64	202	
		12.6	7.46	13.5	11.71	179	
		13.7	8.53	14.42	12.92	150	
		13.7	8.56	14.32	13.06	126	
		12.4	7.24	12.86	11.9	96	
		11.3	6.11	11.57	10.92	65	
WL		9.22	4.08	9.36	9.08	28	



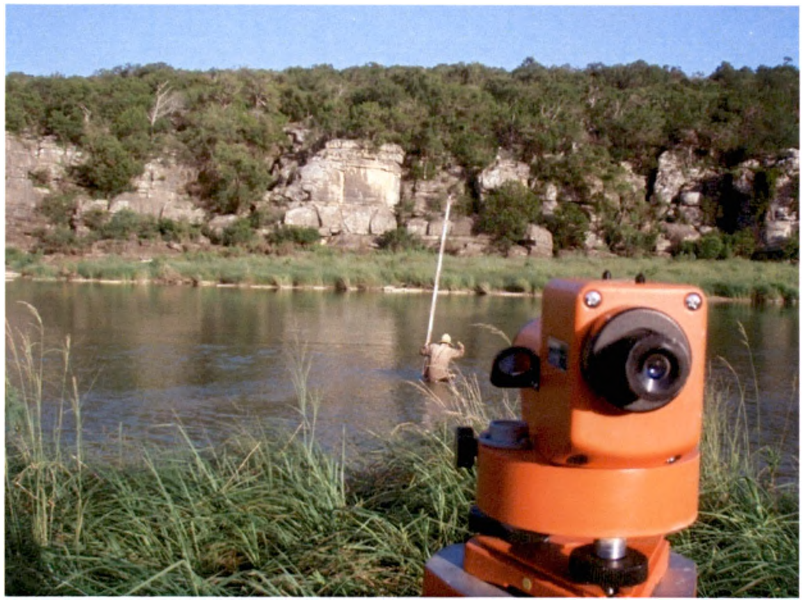
JC 17

JC 18 L > R Picts:81-82 GPS:66-76

Notes	HI	HS	Corr. HS	US	LS	Distance	AZ
	5.1	6.02	0.96	7.11	4.93	218	290
WL		7.28	2.22	8.24	6.31	193	
		13.3	8.24	14.2	12.38	182	
		12.4	7.34	13.1	11.7	140	
		11.6	6.58	12.24	11.02	122	
		10.8	5.71	11.28	10.26	102	
		10.5	5.41	10.88	10.06	82	
		10.1	5.06	10.41	9.87	54	
		9.88	4.82	10.26	9.72	54	
WL		7.34	2.28	7.43	7.24	19	
		5.54	0.48	5.6	5.46	14	



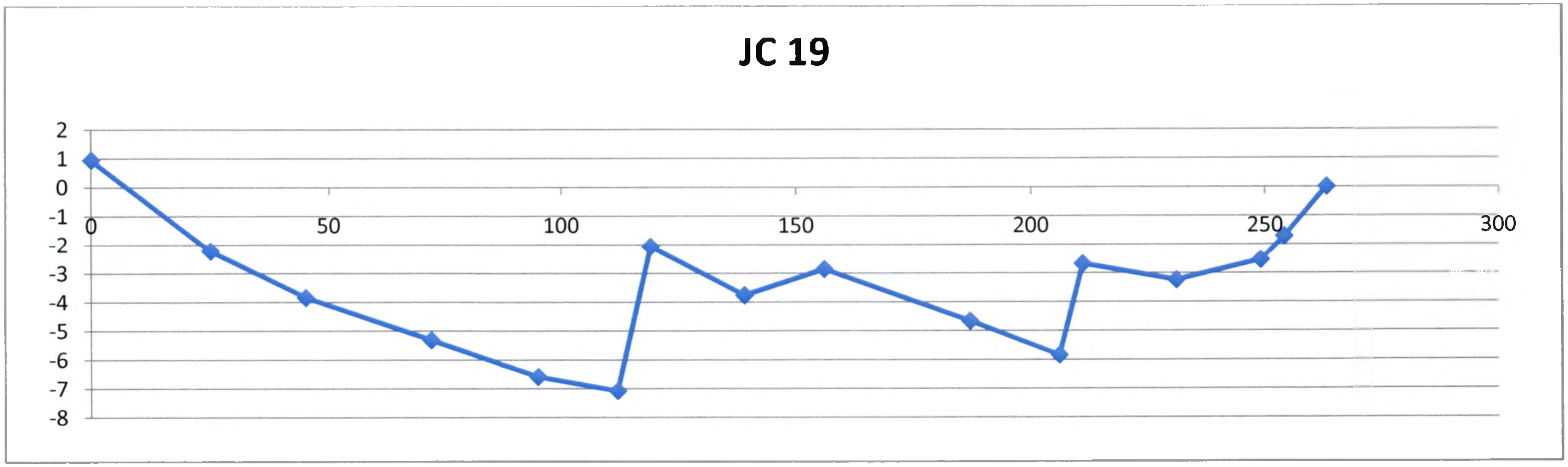
JC 18



JC 19

L > R Picts:85-86 GPS:77-87 224' int 22.4' int

Notes	HI	HS	Corr. HS	US	LS	Distance	AZ	Change Int.		Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
	5.1	4.18	-0.94	5.5	2.87	263	334	0	1	0.00	0.00	0.00	0.00	224.00	0.00	0.00	0.00	0.00	609.42
WL		7.34	2.22	8.54	6.16	238		11	2	0.36	1.18	0.80	0.89		27.50	32.48	0.85	27.45	
		8.96	3.84	10.06	7.88	218	22	to rock										0.00	
		10.4	5.31	11.39	9.48	191		33	3	1.20	3.94	0.49	1.41		27.00	106.30	0.95	100.98	
		11.7	6.59	12.55	10.87	168		21		0.68	2.23	0.38	0.82		34.50	76.97	0.60	46.18	
		12.2	7.08	12.96	11.45	151	32	to rock										0.00	
		7.18	2.06	7.9	6.46	144	42	end of rock										0.00	
		8.88	3.76	9.5	8.26	124		48	4	0.44	1.44	1.86	2.32		42.00	60.63	2.09	126.72	
		7.98	2.86	8.51	7.44	107	16	to front of rock										0.00	
		9.78	4.66	10.16	9.4	76	21	to back of rock										0.00	
		11	5.84	11.25	10.68	57		36	5	1.60	5.25	1.21	1.72		33.50	175.85	1.47	257.62	
		7.8	2.68	7.34	6.82	52		31	6	1.00	3.28	0.62	0.51		28.50	93.50	0.57	52.83	
		8.36	3.24	8.52	8.2	32		26	7	0.58	1.90	-0.07	-0.01		31.00	58.99	-0.04	-2.36	
WL		7.66	2.54	7.73	7.59	14	to bank	37	8		0.00	0.00	0.00		0.00	0.00	0.00	0.00	
		6.84	1.72	6.89	6.8	9		243							224.00				


JC 19
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
0
50
100
150
200
250
300

JC 19

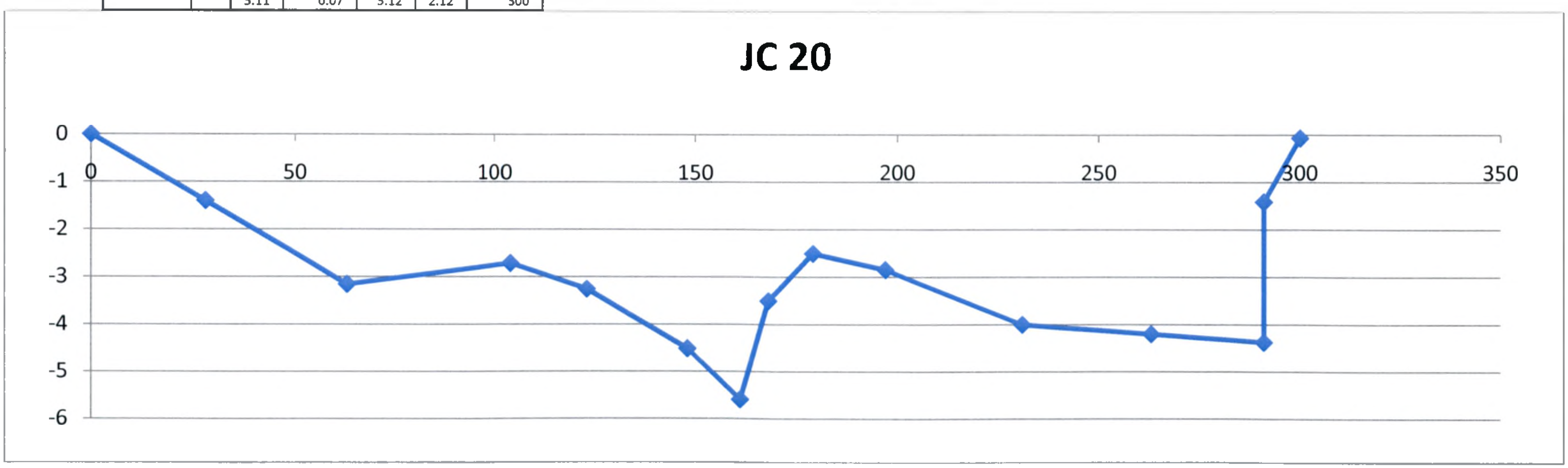
JC 20

L > R

Notes	HI	HS	Corr. HS	US	LS	Distance
WL	5	6.44	1.4	6.58	6.3	28
sandy		8.2	3.161	8.52	7.89	63
sandy		7.76	2.72	8.28	7.24	104
br		8.3	3.26	8.92	7.69	123
		9.56	4.52	10.3	8.82	148
		10.6	5.6	11.47	9.86	161
		8.55	3.51	9.39	7.71	168
		7.55	2.51	8.45	6.66	179
		7.89	2.85	8.88	6.91	197
		9.05	4.01	10.21	7.9	231
		9.25	4.21	10.57	7.94	263
WL- 2.96		9.42	4.38	10.88	7.97	291
WL			1.42	10.88	7.97	291
		5.11	0.07	5.12	2.12	300

Picts:89-90 GPS:88-98 263' int 26.3' int

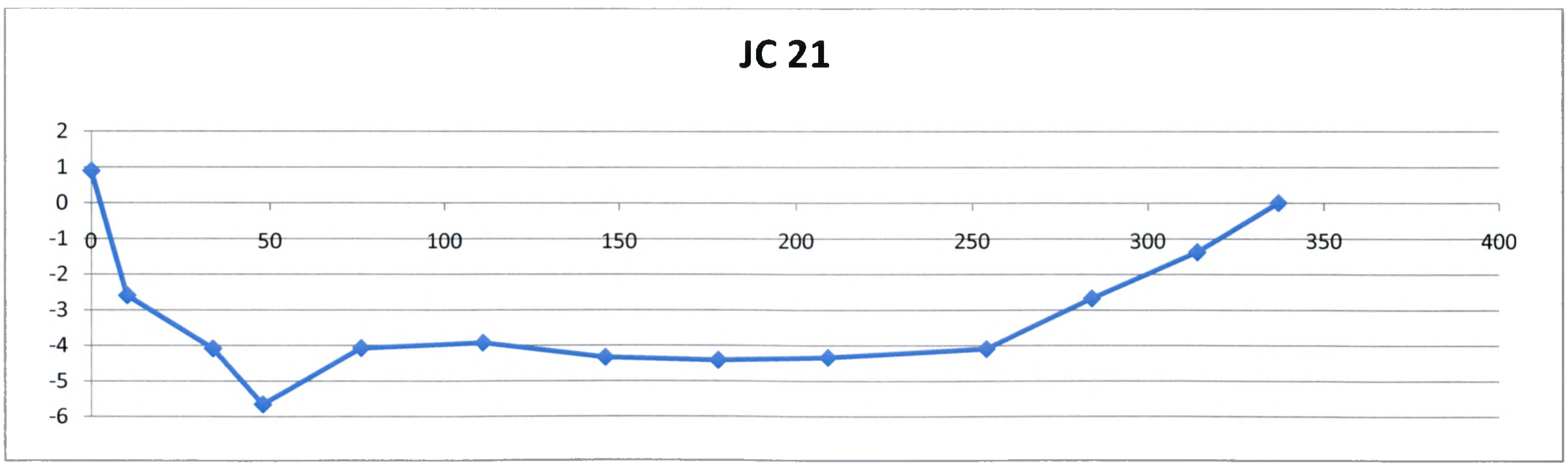
Change to Int.		Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
	1	0.00	0.00	0.00	0.00	263.00	0.00	0.00	0.00	0.00	295.80
sand	2	0.50	1.64	0.32	0.50		39.00	63.98	0.41	26.23	
sand	3	0.50	1.64	0.61	0.91		26.00	42.65	0.76	32.41	
	4	0.42	1.38	0.27	0.62		26.00	35.83	0.45	15.94	
br	5	0.78	2.56	0.20	0.23		26.00	66.54	0.22	14.31	
br shelf	6	1.12	3.67	0.18	0.25		26.00	95.54	0.22	20.54	
	7	0.60	1.97	0.33	0.38		26.00	51.18	0.36	18.17	
	8	0.54	1.77	0.51	0.68		26.00	46.06	0.60	27.41	
	9	0.76	2.49	0.59	0.81		26.00	64.83	0.70	45.38	
	10	0.90	2.95	0.77	0.88		26.00	76.77	0.83	63.34	
	11	0.94	3.08	0.59	0.71		16.00	49.34	0.65	32.07	
10' to bank	12	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
							263.00				



JC 20

JC 21

						L > R		Picts:92-95	GPS:99-109		274' int	27.4' int							
Notes	HI	HS	Corr. HS	US	LS	Distance	AZ			Depth (m)	Depth (ft)	Vel 20% (cfs)	Vel 80% (cfs)	D Total	D Each	A	V	Q	Q Total
	5.3	4.37	-0.89	6.05	2.68	337	45		1	0.00	0.00	0.00	0.00	274.00	0.00	0.00	0.00	0.00	363.67
WL		7.86	2.6	9.49	6.22	327			2	0.74	2.43	0.05	0.58		40.50	98.33	0.32	30.97	
		9.35	4.09	10.87	7.84	303			3	0.48	1.57	0.50	0.73		27.00	42.52	0.62	26.15	
		10.9	5.66	12.36	9.47	289	sandy		4	0.40	1.31	0.75	0.92		27.00	35.43	0.84	29.59	
		9.34	4.08	10.64	8.03	261	island upstream		5	0.54	1.77	1.83	2.91		27.00	47.83	2.37	113.37	
		9.19	3.93	10.32	8.06	226			6	0.56	1.84	0.59	1.51		27.00	49.61	1.05	52.09	
		9.6	4.34	10.55	8.64	191			7	0.64	2.10	0.45	0.54		27.00	56.69	0.50	28.06	
		9.68	4.42	10.48	8.89	159			8	0.46	1.51	0.83	1.13		27.00	40.75	0.98	39.93	
		9.6	4.34	10.24	8.96	128			9	0.20	0.66	0.23	1.82		27.00	17.72	1.03	18.16	
		9.36	4.1	9.78	8.95	83	br		10	0.18	0.59	0.90	1.22		40.50	23.92	1.06	25.35	
WL		7.94	2.68	8.2	7.67	53			11	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
		6.64	1.38	6.75	6.52	23									270.00				



JC 21

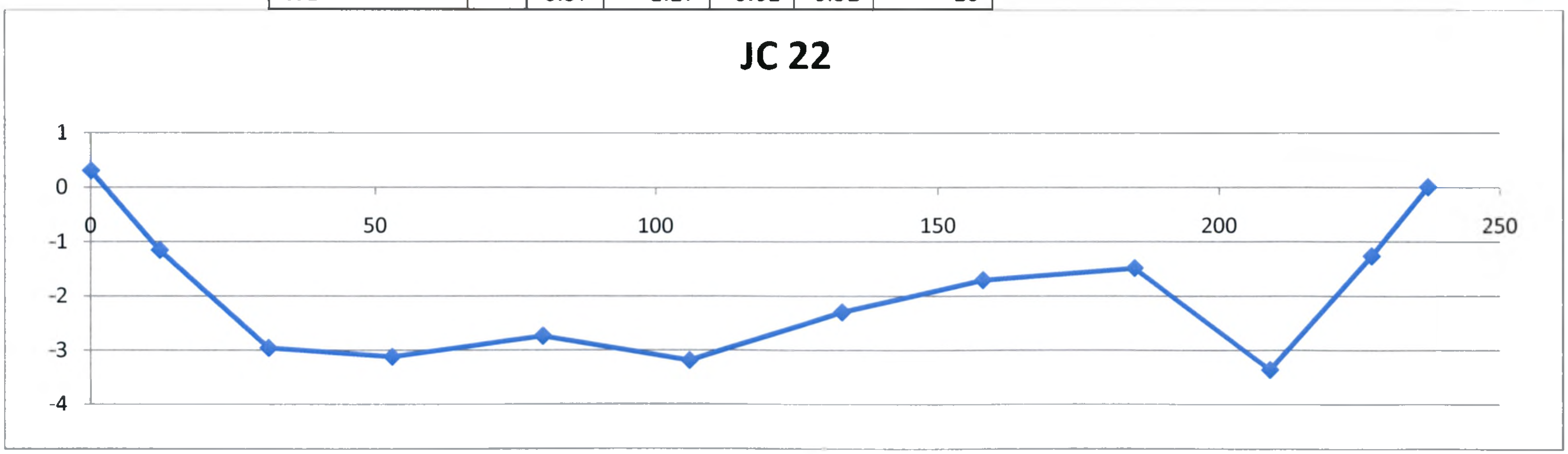
JC 22

L > R

Picts:96-97

GPS:110-120

Notes	HI	HS	Corr. HS	US	LS	Distance	AZ
	5.3	5	-0.3	6.19	3.82	237	35
WL		6.46	1.16	7.58	5.33	225	
		8.26	2.96	9.29	7.23	206	
Back side of Island		8.42	3.12	9.34	7.5	184	
Island point		8.04	2.74	8.82	7.25	157	
		8.49	3.19	9.15	7.84	131	
		7.6	2.3	8.12	7.08	104	
		7.01	1.71	7.4	6.61	79	
		6.79	1.49	7.05	6.53	52	
		8.66	3.36	8.8	8.52	28	
WL		6.57	1.27	6.62	6.52	10	



JC 22

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VITA

Benjamin Thomas Warden was born in Austin, Texas, on May 24, 1983, the son of Sharron Kay Warden and Dayton Reed Warden. After completing his work at Florence High School, Florence, Texas in 2001, he entered Texas State University-San Marcos. He received the degree of Bachelor of Science from Texas State in May 2006. In September 2006, he entered the Graduate College of Texas State University-San Marcos. Yes, he has been going to school all of his life and is being cut-off from his parents in May 2008. From here he shall roam the planet with the title Benjamin Warden, Master of SCIENCE.

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