KVICHAK RIVER RISEC PROJECT

Resource Reconnaissance & Physical Characterization

Final Report

Kvichak River, Vicinity of Igiugig, Alaska

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES (Included on CD and FTP Site)

1.0 EXECUTIVE SUMMARY

1.1 Introduction

During the summer and fall of 2011 TerraSond Ltd. (TerraSond) completed a bathymetric survey and hydrokinetic energy assessment of the Kvichak River at Igiugig, Alaska. The purpose of this work was to characterize the initial site conditions for the design and installation of a hydrokinetic turbine to provide electric power for the village.

There were six distinct phases of work for this project. The first was a literature review and investigation of prior surveys and hydrologic studies done in the area. This included collection of Alaska State Land Surveys, data sheets for existing National Geodetic Survey, (NGS) control, and Alaska Community Development Maps. The primary source for surface water hydrology was the USGS Water Resources Office in Anchorage, Alaska. The USGS operated a gaging station on the Kvichak River at Igiugig from 1967 to 1987. They provided copies of the discharge measurement field notes, rating curves, and original descriptions of the gage site. There was also a hydrologist on staff at the Anchorage office that operated and maintained the original USGS gage. He was generous with his time and was able to provide excellent firsthand accounts of the gage operations methods.

The second, third, fourth, and fifth phases consisted of four field expeditions conducted over the summer and fall of 2011. The first expedition was from 9 to 13 June 2011. The purpose of this trip was to do an initial area reconnaissance for future hydrographic surveys, establish a local control network, and attempt to recover existing monumentation that might be useful for the planned hydrographic surveys. The second expedition spanned 17 to 26 June 2011. During this trip the field crew completed the first multibeam bathymetric survey, 10 flow velocity measurements, one discharge measurement, and a survey of water levels along the river to determine the water surface slope. The third expedition was from 26 August to 2 September 2011. During this trip the crew did a second bathymetric survey, completed 11 flow velocity measurements, and a discharge measurement. They also collected 10 sediment samples from the river bed. The fourth expedition was from 11 to 14 October 2011. The main purpose of Expedition IV was to complete detailed flow velocity studies. The field crew completed 35 velocity profiles and one discharge measurement. The final phase of the project was complete data reduction, and preparation of this report with its accompanying map sheets and data packages.

1.2 Synopsis of Findings

1.2.1 Control

During the first expedition a local control network consisting of five monuments was established. Three Continuously Observed Reference Stations, (CORS) were included in the final network adjustment. This network was the basis of control for all of the future survey activities. TerraSond also developed a provisional water level datum for this project based on current discharge measurements, Global Positioning System, (GPS) water level surveys, and the USGS stage and discharge record. The new datum is called the Kvichak River Igiugig Provisional Datum of 2011, (KRIGIPVD11).

An attempt was made to recover any existing NGS monuments in the area. These monuments were placed in1946. After an extensive search using GPS and a magnetometer the crew was unable to locate any of these monuments. The crew also tried to locate remnants of the USGS gage station and reference monuments. No confirmed remains of the gage station could be found.

1.2.2 Bathymetry

The data from the first bathymetric survey was not satisfactory. Therefore, it was discarded and the data acquired on Expedition III was used for preparation of the bathymetric surface and analysis of the river bed.

The Kvichak River bed is comprised mainly of gravel and cobbles. There is little sand or silt. There are also occasional boulders with a volume of one cubic meter or greater. Inspection of the bathymetric surface reveals 44 dangers to navigation and 10 hazards for construction in the project area. There are also a few areas of shoaling that pose a danger to navigation. The locations and coordinates of these features are given in the accompanying map sheets in Appendix 1. The river bathymetry varies considerably from the mouth to the downstream extent of the project area. At the mouth there is a small field of sand waves to the left and a shoal on the right. The shoal continues downstream to the vicinity of the Fish and Game Boat Landing. Over this same stretch the main channel forms a well defined thalweg in the middle. About half way downstream in the project site by the Fish and Game Boat Landing the channel bifurcates around the first island. The right channel narrows and forms a sharp central thalweg as part of an inverted triangular profile. The bed drops rapidly through this area. Then the central part of the channel fills and a trapezoidal profile emerges. This profile continues for the remainder of the project area. Consideration of the moving bed tests and the sampled bed materials indicate that the river bed is quite stable. Nonetheless it should not be considered immutable. Movement of small material below the limit of instrument detection as well as localized scour patterns that develop around various fixed objects can cause some bed load transport.

1.2.3 Hydrokinetic Energy

Analysis of the Acoustic Doppler Current Profiler, (ADCP) data from Expeditions II and III indicates that there are three areas of the river that offer the most potential for development of a hydrokinetic facility. These areas are designated as Site 6, 9, and 10. Their locations are depicted on the accompanying map sheets in Appendix 1. All three locations have a well defined and stable zone of high energy density the ranges between 4.5 to 7 kW/ m^2. Site 6 has shown the most promise for immediate development. This site has a good zone of energy density. The channel is large and can thus accommodate a turbine while leaving ample room for navigation. It is also close to the current generator facility. This reduces the cost and effort required to connect to the power grid. Sites 9 and 10 have excellent energy density characteristics. However, the channel at site 9 is less accommodating to a turbine and navigation. Further, they are up to 1 km downstream from the electric power facility and nearly 150 meters from the village side shore.

1.2.4 Recommendations

Site 6, 9, and 10 show the most promise for future hydrokinetic development. Presently Site 6 offers the best constellation of features. There is good energy density. The site is close the power generation facility. The channel dimensions are generous and the zone of high energy density is offset from the thalweg. However, there appears to be more seasonal variability of energy density at this site compared to the other sites. Its proximity to the river mouth also makes it susceptible to problem with floating debris and ice. Site 9 has a very high energy density that appears more stable. However, the channel is smaller and the high energy density zone is centered in the thalweg. The channel morphology may also be more dynamic at this site. It is further away from the power generation facility. Thus connection to the existing power infrastructure is more difficult and expensive. Site 10 has a large and deep channel. This site could accommodate multiple turbines on the surface as well as the bottom. The energy characteristics of the river are very favorable. The only drawback to this site is its distance from the existing power infrastructure.

The work presented in this report is the first detailed field investigation for a future hydrokinetic facility in Igiugig. More investigation is required to help ensure the success of this effort. There is a need for more detailed studies of flow dynamics. These studies would increase the knowledge of temporal and spatial flow patterns in the river. They would also determine the stability of the flow patterns and determine if there is migration of the thalweg. Installation of a new gage station is crucial to future planning and design of a turbine system for this river. Quality gage data will provide timely information of flow velocities and discharge. It will be invaluable for assessment, and operation of any turbine system. A gage station should be established in the vicinity of the planned turbine trial site. It should be installed before the turbine is placed in the river.

A good qualitative and quantitative assessment of the ice condition on the river is crucial to the future success of this endeavor. Currently there are only limited anecdotal accounts of ice conditions. Every effort should be made to establish an ice observation system in Igiugig as soon as possible.

2.0 SITE DESCRIPTION

2.1 Introduction

Igiugig, Alaska is located on the left bank of the Kvichak River, (N59^{o} 19’, W155^{o} 54’). It is situated at the mouth of the river, Figures 1, 2. The year round population is about 50 people. It is not on the road system. Normal access is by plane or boat. There is no rail service. Goods and fuel are brought to the village by barge and plane.

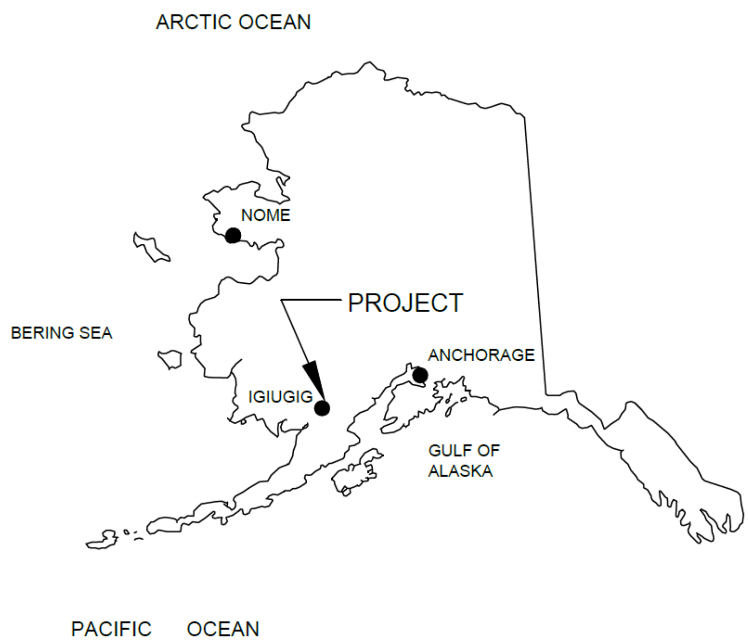

Figure 1 – Igiugig project location map.

Figure 2 – Aerial view of the project site from the west.

2.2 Kvichak River

The main source for the Kvichak River is drainage from Iliamna Lake. In the vicinity of Igiugig there are no other significant tributaries or diversions to the river. The river flows past Igiugig and continues on for 110 km to its outlet in Kvichak Bay. The total drainage basin for the river is 16,835 km^2 and it has a mean elevation of 546 meters. Approximately 20% of the basin is storage in the form of lakes and ponds. Transitional forest comprises about 64% of the basin, and the remainder it primarily wetlands. The average annual precipitation is 101.6 cm. Average annual snowfall in the basin is 178 cm. The record high and low temperatures for Igiugig are 31^o C and -42^o C. The average annual high and low temperatures are 26^o C and -33^o C. Typical summer temperatures range from -1^o C to19^o C. Winter temperatures are between -16^o C and -1^o C.

The average flow velocity is 1.37 m/s (σ = 0.26 m/s). In some particularly fast reaches the surface velocity can approach 3.0 m/s in the central channel. The river level can rise and fall over a range of two meters. The average annual range of water levels is 1.1 meters. The smallest and larges annual ranges are 0.59 and 1.48 meters. Peak stages and discharges occur in the fall during September and October. The lowest stages and discharges are in the spring during April and May. The average annual high discharge rate in the USGS gage data for this site is 815 m^3 /s, (σ = 213 m^3 / s). And the average reported low discharge is 293 m^3 /s, (σ = 81 m^3 / s). The daily average discharge rate from the USGS data is 500 m^3 /s, (σ = 201 m^3 / s).

The water is extremely clear. During most of the year the bed can be seen at depths to 5 meters. However, there are some times when the sediment load increases and visibility drops. This is typically during periods of high wind from the east and extended duration rain. The surrounding area is transitional forest and tundra. There are few large trees. Thus there is rarely any substantial amount of drifting materials in the water. The river usually does not experience a major freeze. However, some ice may form from November to February. The mild climate and rapid flow normally prevent persistence of the ice. During break up in March to May ice from the lake is driven into the river by wind. This ice is typically about 1 meter thick. It can be present in the river for two to three weeks.

2.2 Infrastructure

Igiugig may be reached by boat and plane. There is no rail or road access. The village has a good local network of improved dirt and gravel roads. The state of Alaska maintains a 3000 foot x 75 foot gravel runway. Adjacent to the runway is a generous apron and a hangar with three large bay doors. The Federal Aviation Administration maintains a weather station with two web cameras at the airport. The lake and river offer ample opportunities for float plane operations. Large goods including construction equipment and materials can be brought to the village by cargo planes and barges, Figure 3, 4. There is regular air taxi service from Anchorage.

Full service lodging for work crews is available at a work camp that is owned and operated by Iliamna Lake Contractors, (ILC). ILC can also provide four-wheelers, Jon boats, pickup trucks, gasoline, and diesel fuel, an assortment of heavy construction equipment, barge service, and basic mechanic support.

Figure 3 – Flexibarge on the Kvichak River near the Fish and Game boat landing.

Figure 4 – FAA weather station with webcams.

3.0 SURVEY ACTIVITIES

3.1 Introduction

Prior to commencing field activities TerraSond completed a detailed study of existing land survey data, USGS stream gage records, prior hydrokinetic energy assessments and the community profile. This preparatory research was used to plan the subsequent field expeditions. These expeditions took place on 9 to 13 June 2011, 17 to 26 June 2011, 26 August to 2 September 2011, and 11 to 14 October 2011.

3.2 Literature Research

Several literature resources were obtained by TerraSond for the purpose of planning and executing the survey activities presented in this report. The land survey data assembled consisted of Alaska State Land Surveys, (ASLS), and Easement Vacations, (EV), National Geodetic Survey, (NGS) control monuments, GPS sites in the NGS Continuously Observed Reference Stations, (CORS), system, Alaska State Community Development Maps, USGS 15 minute topographic maps, and a site specific digital orthorectified image. Stream gage data was collected by the USGS in the vicinity of the project site from 1967 to 1987. Prior hydrokinetic assessments were published by the Electric Power Research Institute, (EPRI), and the Alaska Center for Energy and Power, (ACEP).

TerraSond obtained digital copies of ASLS AS91-111, AS91-111A, and EV EV - 2-541. These documents were used to identify property boundary lines and status as well existing monuments in the area. These surveys were not used for any of the hydrographic analysis in this report. Digital copies of these surveys were placed in Appendix 6 of this report.

The NGS online database was searched for control monuments within a radius of five miles, (8 km) from the approximate center of the project site. Three records were returned. The PID's were UV7630, UV7631, and UV 7632. Horizontal orders for these monuments were First, Third, and Second respectively. No vertical order was reported for these monuments in the NGS database. An attempt was made to recover these monuments during Expedition I. Unfortunately they could not be located. All of these monuments were set in1946. In light of their age and the manner of placement it is believed that they have been lost. Current copies of the NGS datasheets for the monuments were placed in Appendix 5 of this report.

Three Continuously Observed Reference Stations (CORS) stations were identified within 100 km of the project site. The CORS ID's for these stations were AB22, AC24, and AC27. The sites were located in the vicinity of Iliamna, King Salmon, and the McNeil River Game Refuge respectively. These stations were used as fixed control for the adjustment of the local control network established by TerraSond for this project. The data sheets for these CORS sites were placed in Appendix 5 of this report.

Digital copies of the Alaska State Community Development Maps were obtained from the Alaska Department of Commerce, Community, and Economic Development Community and Regional Affairs. These maps were used to gain an initial impression of the river dynamics on a decadal scale. They were also used to identify land status and village infrastructure. Copies of these maps are in Appendix 6 of this report.

A USGS digital raster graphic of the Iliamna B-8 15 minute topographic map and a site specific orthorectified image were used to do the initial planning of survey efforts. Comparison of the USGS map and the orthorectified image was also used to gain an indication of river morphodynamics on a decadal scale. The digital orthorectified image was used as a background in final map sheets.

An extensive investigation of the USGS historical gage data for this site was completed. This included a visit to the USGS Water Resources Office in Anchorage, Alaska. Copies of the original USGS records for the station were obtained. The following documents were obtained: USGS Gage Station Descriptions, USGS Discharge Measurement Notes, Rating Curve Plots. All of the online gage data for the gaging site was downloaded from the USGS web page. Personal interviews were also conducted with a member of the USGS staff that operated the gage site for a portion of the time that it was active. This data was used to assess historic discharge, flow velocities, and approximate times of peak and minimum discharge. The collected data items were placed in Appendix 3 of this report.

The Electric Power Research Institute, (EPRI) completed two assessments of the hydrokinetic potential for the Kvichak River. The first was *System Level Design, Performance, Cost and Economic Assessment – Alaska In-Stream Power Plants*, and the other was *River In-Stream Energy Conversion (RISEC) Characterization of Alaska Sites*. These reports were used for an initial estimate of the river's potential for development of a hydrokinetic power generation facility. Their assessment was based on the historical record from USGS Gage Site 15300500. The information contained in these reports was one source of guidance for the planning of the field surveys completed this year.

3.3 Field Expeditions

Four field survey expeditions were completed for this project. The goals of the first expedition were to complete an initial site reconnaissance and establish a local control network. The three subsequent expeditions were used to complete a multibeam bathymetric survey, and progressively develop a detailed assessment of hydrokinetic energy potential.

3.3.1 Field Expedition I

Expedition I spanned 9 to 13 June 2001. During this expedition five control monuments were set and surveyed with multiple static GPS sessions. The static GPS session data was then post processed and adjusted with a precise ephemeris to determine the final adjusted coordinates for the control network. In addition to the GPS survey a detailed site reconnaissance was completed. This included a general tour of the village and introductions to members of the village council and the village corporation. The field team also dedicated approximately 1 ½ days to locating USGS reference monuments, and NGS control monuments. The team searched using the available descriptions from the respective agencies, GPS coordinates, and local inquiries. None of the monuments could be recovered. During this field expedition the team also completed an initial boat transit of the proposed hydrographic study area.

3.3.2 Field Expedition II

Expedition II was conducted on 17 to 26 June 2011. The primary activity during this trip was the completion of the first hydrographic surveys. These included a multibeam bathymetric survey, 10 ADCP transects, an ADCP discharge measurement, four ADCP moving bed tests, and a water line survey with RTK GPS to estimate the water surface slope of the river.

3.3.3 Field Expedition III

Expedition III spanned 26 August to 2 September 2011. During this trip the crew completed one ADCP moving bed test, an ADCP discharge measurement, 10 ADCP transects, and collected 10 bottom grab samples. They also completed a second multibeam survey. Six of the ADCP transects were completed in the extended project area. This expanded area reached down stream an additional 1.3 km beyond the original proposed project boundary. Near surface flow velocity measurements were made at select points along each of the ADCP transects.

3.3.4 Field Expedition IV

Expedition IV started on 11 October 2011 and ended on 14 October 2011. During this time 34 ADCP transects, an ADCP discharge measurement, and four moving bed tests were completed. Near surface flow velocity measurements were made at select points along each of the ADCP transects. The ADCP transects were positioned to develop detailed estimates of energy density at Sites 5, 6, 9, and 10. An additional transect was also run on Station 17.

4.0 SURVEY CONTROL

4.1 Introduction

During Expedition I TerraSond established a control network for the project site. This network consisted of five monuments that were set and surveyed using static GPS methods. Several redundant occupations were made using Leica 1200+ series dual frequency GPS GNSS units. The collected occupation data for the network was then adjusted using Trimble Geomatics Office Version 1.63. Three CORS stations were included in the network adjustment. All monuments were set on the left bank of the river. The monument locations and coordinates have been depicted on the accompanying map sheets in Appendix 1.

ADCP river discharge measures and RTK GPS Surveys of the water level collected during Expedition II, III, and IV were used to determine the water level datum. The discharge measurements were referenced to the USGS rating curves for the site. This provided a coarse basis for comparison of the current river stage with the historical record. This was then used to estimate where the current stage was compared to the recorded lowest stage. The water surface ellipsoid height that was slightly below the corresponding ellipsoid height of the estimated historical low ellipsoid height was selected. This chosen value was 25.00 meters.

4.2 Control Network Establishment

After assessing the field site the survey crew determined that the best location for the primary control monument was in the vicinity of the Fish and Game Boat Landing. This location was selected because of its central location in the project area, ease of access, good line of site for broadcast of RTK correction signals, and stable soils. Two monuments were set at this location. The first monument was designated "*HK-1*." It was a 36 inch x ¾ inch piece of rebar with a domed 3 ¼ inch aluminum cap stamped "*IGIUGIG HK-1 TERRASOND 2011*." The selected location was a grassy section on the side of a knoll between the upper parking area and the boat landing. The final set was 0.4 feet below grade. Figures 5, 6. The second monument was set for vertical reference. It has been designated as "*HK-V*". It was comprised of four sections of ½ inch x 4 foot steel drive rod with a bullet head center threaded at the top. The rod was driven until met with refusal at approximately 16 feet. This monument was set 0.2 feet below grade at the top of the hill on the east shoulder of the road leading from the school to the boat landing, Figure 7, 8. A group of small sized cobbles with one large cobble were set around and over both monuments for protection.

Figure 5 – Monument HK-1.

3 ¼ inch aluminum cap on rebar.

Figure 6 – View across the Kvichak River from HK-1.

Figure 7 – Monument HK-V.

Figure 8 – View from HK-V.

View to the northwest across the road toward the Fish and Game boat landing and HK – 1.

Three additional monuments were set for the purpose of monitoring the river water level and as possible base station locations. Monument "*HK-2*" was established with a 3¼ inch domed aluminum cap marked "*IGIUGIG HK-2 TERRASOND 2011*" on 36 inch x ¾ inch rebar. It was set three quarters of the way down the bank from the west fence corner of the fuel tank containment by the electric generation plant, Figures 9, 10. Sloughing of the bank that occurred between 2 September and 11 October 2011 has destroyed this monument.

Figure 9 – Monument HK-2.

3 ¼ inch aluminum cap on rebar. (Destroyed.)

Figure 10 – View to the northwest across the Kvichak River from HK-2.

(HK-2 was Destroyed.)

Monument "*HK-3*" was placed on a level spot at the base of a 3 meter bluff of moderate repose on the left bank in the vicinity of the Kvichak River mouth. It was topped with a 3 ¼ inch aluminum cap that was stamped "*IGIUGIG HK-3 TERRASOND 2011*" The final placement was 0.4 feet below grade. It was concealed under several medium cobbles, Figures 11, 12.

Figure 11 – Monument HK-3.

3 ¼ inch aluminum cap on rebar.

Figure 12 – View toward downstream witness tree from HK-3.

The final monument was placed near the downstream extent of the initial project area. Two pieces of ½ inch x 4 foot drive rod were driven and topped with a bullet head. It has been designated "*HK-4*". The monument was established in a small level clearing approximately 35 feet shoreward of the left bank. Figure 13, 14.

Figure 13 – Monument HK-4.

½ inch x 8 foot steel rod with bullet top.

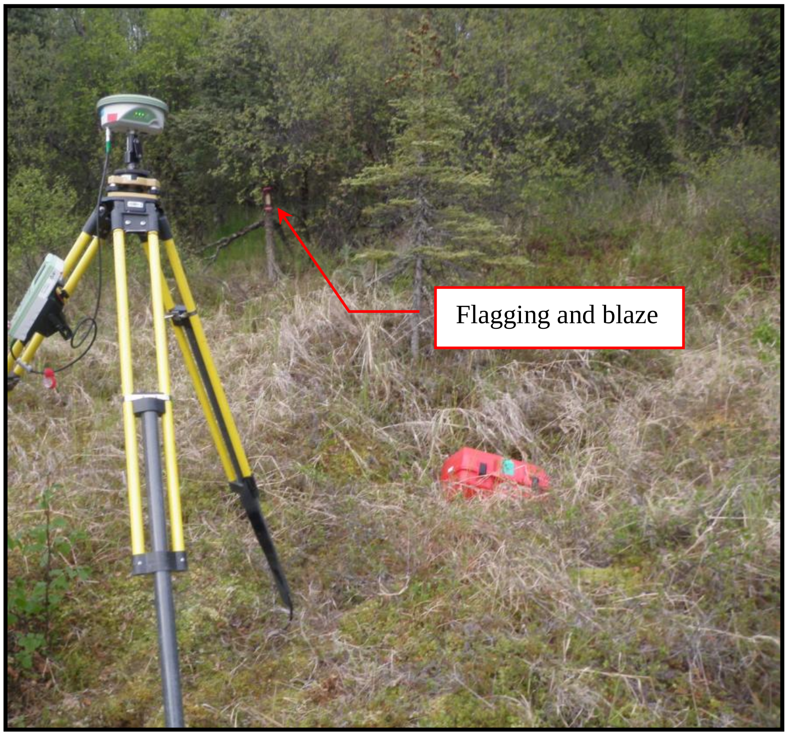

Figure 14 – View of upstream bearing tree from monument HK-4.

4.3 Network Adjustment

Trimble Geomatics Office (TGO) version 1.63 was used to process the static GPS data and adjust the control network. Three CORS sites were included in the network adjustment, Table 1. These stations were held fixed and the newly placed control monument locations were adjusted horizontally and vertically.

CORS ID	PID	Latitude	Longitude	Ellipsoid Ht. (m)	Geoid Ht. (m)
AB22	DL6678	N 59° 53' 57.55673"	W 154° 41' 53.64393"	199.318	13.03
AC24	DL7656	N 58° 40 53.66665	W 156° 39' 09.83425"	35.814	13.72
AC27	DM7487	N 59° 15' 09.03078"	W 154° 09' 46.28667"	417.006	12.36
Datum NAD 83 Geoid heights based on the NGS 2009 geoid model GEOID09 AK					

Table 1 – CORS used for Kvichak River control network adjustment.

Preliminary processing was done in June 2011. Final coordinate processing with precise ephemeris files was completed in October 2011. The TGO project coordinate system was set to UTM AK Zone5 NAD 83 and used the NGS 2009 Geoid model for Alaska, (GEOID09 AK). Final project coordinates were transformed to Alaska State Plane Coordinate System Zone 5. (Note: The horizontal datum for this system is NAD 83, and the horizontal units are U.S. Survey Feet). The final adjusted coordinates have been given on the included map sheet and in Table 2.

Monument	Latitude	Longitude	Northing	Easting	Ellipsoid Ht.	Orthometric Ht.
HK-1	N 59° 19' 40.20931"	W 155° 54' 06.65546"	1951306.55	1285272.68	102.46	57.58
HK-V	N 59° 19' 39.97861"	W 155° 54' 05.33396"	1951281.18	1285340.55	107.15	62.28
HK-2*	N 59° 19' 38.96916"	W 155° 53' 53.47837"	1951161.19	1285952.49	93.14	48.27
HK-3	N 59° 19' 42.64454"	W 155° 53' 12.33824"	1951473.56	1288096.69	95.14	50.26
HK-4	N 59° 19' 10.74202"	W 155° 55' 00.87362"	1948396.64	1282374.74	93.96	49.08
Datum NAD 83, Alaska State Plan Coordinate System Zone 5 US Survey feet. Orthometric height is based on NGS geoid model of 2009 GEOID09 AK *HK-2 was destroyed						

Table 2 – Final adjusted values for Kvichak River RISEC local control network.

4.4 Establishment of the Project Water Level Datum

Water levels are constantly changing. Therefore, establishment of a water level datum can be problematic. Nonetheless it is necessary to establish a reasonable and useful datum from which water depth may be reckoned. The choice of a water level datum is particularly difficult for inland waters. These water bodies lack the stabilizing influence of the ocean reservoir with its regular and predictable tide cycles. A three month water level record at a coastal tide station is typically sufficient to obtain the requisite knowledge of water level extremes and sinusoidal constituents for the determination of the station datum and prediction of future water levels. Water level fluctuations on inland water bodies do not behave in a manner that is sufficiently regular and predictable for the development of dependable water level models analogous to those used for tide predictions. Inland waters levels are subject to any manner of seasonal and secular fluctuations. In some cases years of observation may be required to determine a suitable datum level for a particular river or lake.

For non-tidal water the vertical datum, should be selected such that at least 95% of the time the water is above this level. Ideally no single daily mean water level should ever fall more than about 0.2 meters below the datum level. Further, the water level datum for a river must recognize that the surface of the water is sloped. Therefore, a series of water levels must be measured along the many reaches of the river to determine an appropriate water surface level slope. Then the datum level is adjusted with respect to this slope along the course of the river. In this manner the water level datum will always appropriately reflect the state of the river during its usual low stages.

A fully developed water level datum has not been established for the Kvichak River. TerraSond has created a provisional water level datum to meet the needs of this project. The Kvichak River Igiugig Provisional Datum of 2011 has been designated as KRIGIPVD11. The datum definition and description given in this report and its accompanying map sheets supersede all other datum descriptions previously issued for this project. In particular it supersedes the description given for 11 RISECVD that was issued in the interim report dated 3 October 2011and its associated documents and map sheets.

TerraSond did not have a long term river gage record that was tied to a true vertical datum. The USGS gage data record was referenced to an arbitrary height. It was not determined with respect to any accepted vertical reference. All of the RM's for the USGS gage station have been lost. Therefore, it was impossible to make a physical tie of the current water level data to the USGS record. However, it was possible to make some coarse but reasonable assumptions in the pursuit of a suitable selection for the KRIGIPVD11 water level datum.

The datum level for the KRIGIPVD11 datum was established by referencing a current discharge measurement and RTK GPS water level measurement to the original USGS rating curve. The USGS gage data for this site indicated that the lowest annual river stages typically occur between the second week of March and the second week of April. Using their rating curve the USGS estimated that the lowest discharge for the recorded history was 181 m^3/s (6400 ft^3/s). This discharge corresponded to a USGS gage height of 15.10 ft. (4.60 m). On 21 June 2011 an ADCP discharge measurement was made in the approximate location of the previous USGS discharge measurements. The total discharge was 335 m^3/s, (11,830 ft^3/s). This discharge would correspond with a USGS gage height of 16.95 ft. (5.17 m). The river water level at the Fish and Game Boat Landing, (the origin of the KRIGIPVD11 datum) was measured using RTK GPS at about the same time that the discharge measurement was made. The water level ellipsoid height was found to be 25.90 m, (84.97 ft.). Using the USGS rating curve as a basis for comparison reveals that the difference in gage height for these two discharges would have been about 1.85 feet, (0.56m). Thus a rough assumption could be made that the corresponding ellipsoid height of the water surface at the origin of KRIGIPVD11 for the USGS's historical low discharge would have been about 25.34 meters, (83.14 ft). Based on this rough correspondence between the USGS gage height and the measured ellipsoid height, it was determined that an ellipsoid height of 25.00 meters would be a reasonable value for the provisional datum. This value makes allowance for some extra range in the water levels to ensure that the river does not drop to a stage that is below the established datum for determining water depth, Figure 15.

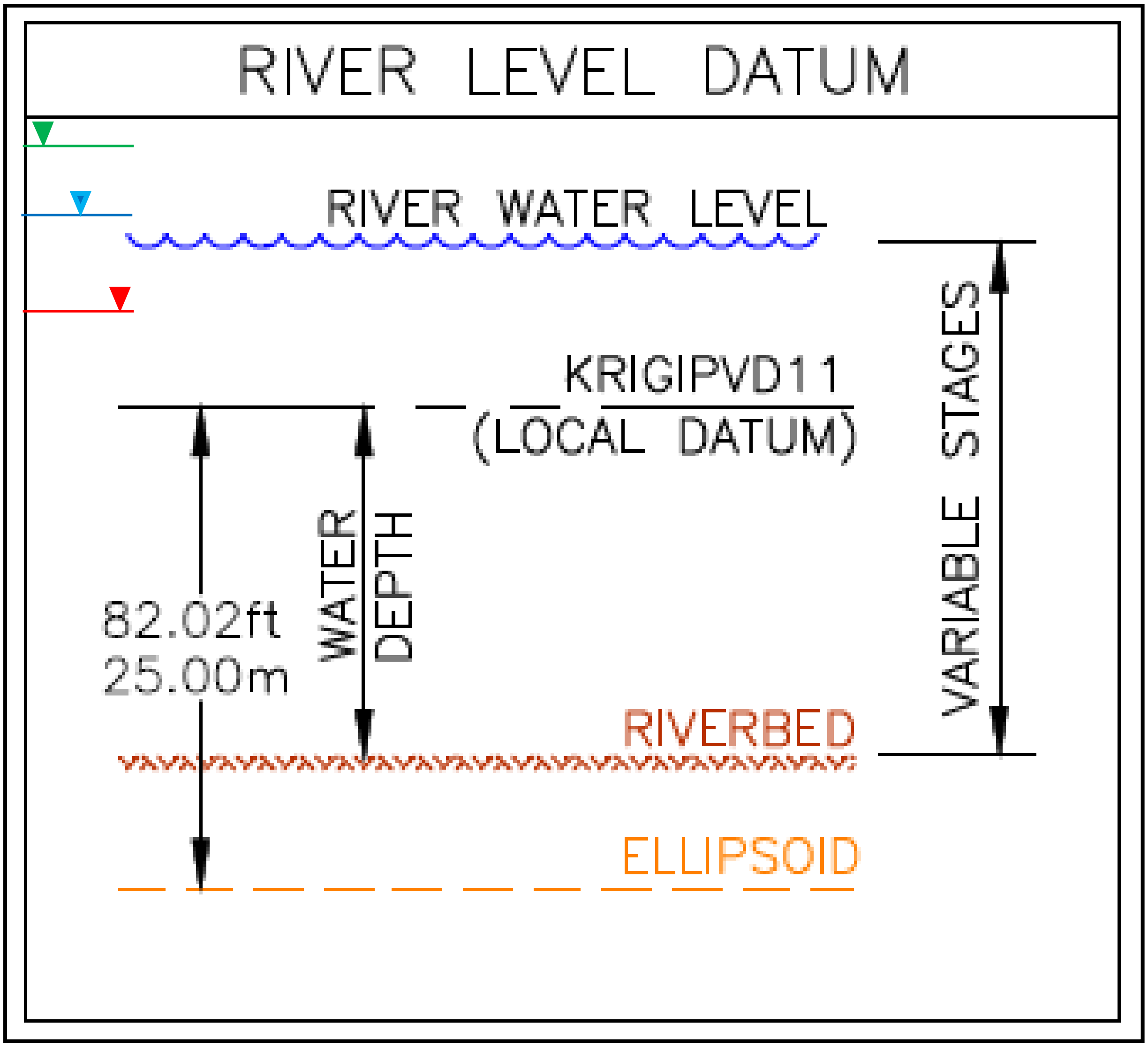

Figure 15 – Relationships of the KRIGIPVD11 datum.

(NOT TO SCALE)

— Mean annual high water height (1.86 m above KRIGIPVD11)
— Mean daily water height (1.27 m above KRIGIPCD11)
— Mean annual low water height (0.79 m above KRIGIPVD11)

The KRIGIPVD11 datum is used for the bathymetric surface presented in this report. The depths represented on this surface are the distance in feet from the level of the KRIGIPVD11 datum to the river bed. Because KRIGIPVD11 was selected to be slightly below an estimated extreme of low water, the given depths should be a rather conservative estimate. Further, the water depths given on this surface have not been adjusted for the slope of the river surface. Given the close proximity of the project area to the origin of the KRIGIPVD11 datum, and the provisional status of this datum it was determined that such a fine adjustment was premature.

It is important to remember that the KRIGIPVD11 datum was selected to represent a water level that is extreme for the river. This level was chosen because it is unlikely that the river stage would drop below this datum. Therefore, water depths that are referenced to this datum can be considered a worst case shallow water situation. This convention for depth determination gives a conservative view with respect to navigational considerations.

Water depth must never be confused with river stage. River stage refers to the vertical movement of the water surface. The river stage is continuously changing. The established datum is fixed and by implication the surveyed depth of the river is also fixed. Further, the river stage can be given with respect to any reference. The reference may have specific physical significance or it can be arbitrary. The river stage is the basis for discharge estimates, and flood potential. Ideally the river should not drop to a stage that is below the level of KRIGIPVD11. It is also prudent to bear in mind that the KRIGIPVD11 datum is provisional. The depths referenced to this datum should not be considered definitive for purposes of navigation.

Levels and values for Mean Annual High water level, Mean Daily Water Level, and Mean Annual Low Water Level are given in Figure 15. The methods used to establish these values are given in section 10.4.

5.0 MONUMENT RECOVERY

5.1 Introduction

Approximately 1½ days of Expedition I were dedicated to locating existing monuments. There was particular interest in locating USGS reference monuments, (RM) that were associated with the gage station. An effort was also made to recover NGS survey monuments that were located on the right bank of the river.

5.2 USGS Gage 15300500 Reference Monuments

The USGS operated a gaging station on the Kvichak River from June 1967 to September 1987. It was designated as USGS Gage Site 15300500. The associated RM’s were referenced to an arbitrary datum. The USGS determined water level with respect to this datum by leveling from the RM to the water. Recovery of these RM’s was necessary to establish a physical tie from the current survey to the historical USGS gage record. An attempt was made to locate the RM’s and any other items associated with this gaging station. TerraSond obtained the online record for this gage from the USGS web site. A visit was also made to the USGS Water Resources Office in Anchorage, Alaska. During this visit the USGS provided copies of the original gage descriptions, discharge notes and the rating curves. There was also a hydrologist on staff at this office that was responsible for operation and maintenance of the gage when it was active. He was able to answer questions about the gage’s operational methods, and the locations of its associated RM’s.

The field crew used the USGS descriptions and coordinates to locate any features of the original USGS gage that might have remained at the site. Inquiries were also made with local people in Igiugig. The local people had little recollection of the gage. No reference monuments were located by the field crew. The crew found some items that they thought may have been associated with the gage’s bubbler system. However, after consultation with the USGS it was determined that the items found were not associated with the gage. After this investigation it was concluded that any items from the gage station that could be used to establish a sound physical tie to the original gaging data have been lost.

The documents copied from the USGS and the data obtained from the USGS web sites are included in Appendix 3 of this report.

5.3 NGS Control Monuments

There were three NGS monuments recorded within a radius of five miles from the approximate center of the project site, Table 3, the current NGS data sheets for these monuments were included in Appendix 5 of this report.

PID	Designation	Latitude (NAD 83)	Longitude (NAD 83)
UV7631	IGIUGIG POST OFFICE E GABLE	N 59^{o} 19’ 46.49301”	W 155^{o} 54’ 00.67627”
UV7630	IGIUGIG	N 59^{o} 19’ 58.06078”	W 155^{o} 53’ 13.86006”
UV7632	IGIUGIG 1946 AZ MK	N 59^{o} 19’ 50.43518”	W 155^{o} 53’ 13.88539”

Table 3 – NGS control monuments recorded in the project area.

The monuments were set in 1946. The field crew made an attempt to locate all of these monuments. They used GPS positioning, in conjunction with a magnetometer. They were able to get to the reported locations and identify many of the references given in the NGS data sheets. However, none of the monuments were recovered. It would have been good to occupy one or more of these monuments with static GPS sessions and tie the project control network to existing monumentation. However, the lack of ability to do this was not deleterious to the final accuracy and precision of the surveys completed for the project.

6.0 MULTIBEAM HYDROGRAPHIC SURVEY

6.1 Introduction

TerraSond performed two multibeam echosounder (MBES) surveys for this project. The first one was completed during Expedition II. When the data from this survey was analyzed and processed in the office it was found to be unsatisfactory. Therefore, it was decided to discard this data and conduct a second survey during Expedition III. The second survey was conducted over 27 to 29 August 2011. The area of coverage started on Iliamna Lake about 0.12 km prior the mouth of the Kvichak River and extended downstream about 2.7 km of reach distance. The total area covered was approximately 0.8 km^2. The cleaned survey data was used to create two interpolated bathymetric surfaces with 0.5 and 1.0 meter cell size.

6.2 Instrumentation

All bathymetric data was acquired with an R2Sonic 2024 MBES equipped with a Valeport acoustic velocimeter to measure the speed of sound at the sonar face. An Odom Digibar Pro acoustic velocimeter was used to measure the speed of sound throughout the water column. Vessel position and attitude were determined with a Coda Octopus F-180 inertial motion unit, (IMU). The F-180 received RTK GPS correction messages from a Leica GPS 1200+ series base station located on HK-1. Bathymetric data acquisition, vessel position and navigation were managed with HYPACK MAX 2011. All software for the bathymetric survey was running on a Panasonic Toughbook model CF 30 field computer with Windows XP Professional. The survey platform for the bathymetric surveys was an 18 foot Lowe Jon boat with a 25 hp outboard engine. The MBES was mounted on a vertical pole off the port side of the boat The F-180 and its GPS antennas were mounted on the same pole directly above the MBES. The draft of the MBES head was 0.44 meters.

6.2 Instrument Calibration

All calibrations and checks were done according the specifications provided in the respective manufacturer's technical manuals. The detailed steps required for each procedure may be obtained from the appropriate manuals. The MBES and the F-180 were calibrated on Iliamna Lake. Two sets of MBES calibration data (commonly called a "Patch Test") were acquired for this survey. One patch test was done on 27 August 2011 and the other on 29 August 2011. The data was processed with the Caris HIPS and SIPS calibration routines. The calibration results were then applied to the vessel configuration file. Comparison of the two patch test results confirmed that the MBES head position remained constant throughout the survey.

6.3 Hydrographic Data Acquisition and Processing

Hydrographic data acquisition was managed with HYPACK MAX 2011. HYPACK received data streams from the F-180 and the MBES. The sound velocity at the MBES head was supplied by the Valeport velocimeter. Daily sound velocity profiles were collected with the Odom DigiBar Pro. Vessel navigation was also managed with HYPACK MAX. Raw survey data was then post processed using Caris HIPS and SIPS 7.1.

The Expedition III MBES acquisition was accomplished on 27 to 29 August 2011. TerraSond acquired a precise high density bathymetric data set that could be used as a base DEM surface for multiple products. The project goals for the MBES data set were to determine the geomorphology of the riverbed, a reference baseline surface for future comparisons, a surface for 1D - 3D numerical modeling, and an obstruction detection program. Geologic interpretation was beyond the scope of this project, however, the data set is informative for geologic interpretation and the dataset should be referenced when this interpretation is required.

MBES data was acquired in all locations of the project area that permitted safe operation of the vessel and equipment. The MBES physical dimensions, sensor capabilities and boat maneuverability were the main factors that determined which areas of the river could be safely surveyed. The combination of instrument draft and minimum sensor range dictated a minimum operational water depth of at least 1.5 meters. At this depth the river bed was about 1 meter below the MBES head. The survey lines were run such that there was always significant swath overlap with the adjacent line. This overlap increases point density and ensures full coverage of the river bed. HYPACK displayed the swath coverage on the navigation monitor in real time. The real time display allowed the survey crew to verify full bottom coverage while still on the water.

During post processing Caris HIPS and SIPS is used to apply vessel offsets, sound velocity, vessel position and attitude to the raw MBES data. Application of these values orthorectifies the sounding to water surface. Because of the high data rate and constant vessel movement there is a large amount of noise in all of the data streams. The data streams are inspected and cleaned of noise and spurious values. Then the soundings are adjusted to the project vertical datum. The final step is to inspect the corrected sounding that will be used to create the base surface. In this step the entire set of soundings is carefully checked to insure that they are actually bottom soundings. Spurious values that resulted from noise or environmental interference with the MBES beam are removed from the final data set. The average horizontal and vertical total propagated uncertainty of the soundings used to prepare the final surface is 0.25, and 0.1 meters respectively. This cleaned data set is then used to interpolate a final bathymetric surface with a cell size of 0.5 meters.

Every effort has been made to insure the accuracy and precision of the bathymetric data products for this report. However, the purpose of this survey was to prepare a data product for use in the design and placement of an in stream turbine. It was not prepared to be a navigation product. It should not be used for vessel navigation.

There were a few locations where small gaps exist in the sounding data. None of them posed a critical problem for the overall quality of the bathymetric surface. The interpolation functions of Caris HIPS and SIPS were used to fill the gaps. The locations of these gaps have been depicted as white polygons in Figure 16.

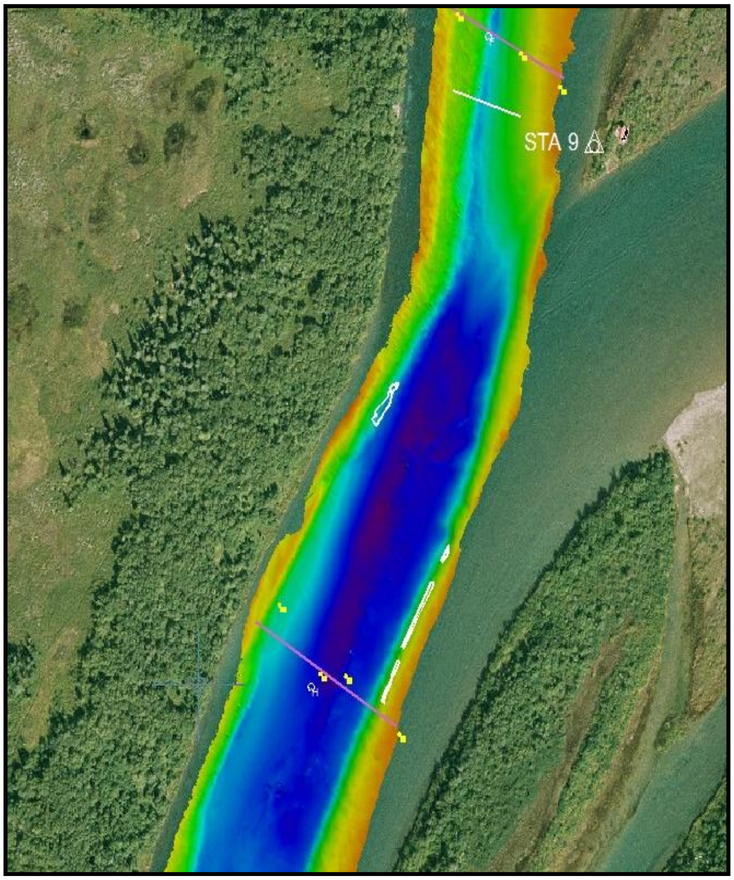

Figure 16 – Minor data gaps depicted in white.

7.0 ACOUSTIC DOPPLER CURRENT PROFILING

7.1 Introduction

The principle aim of this study was to characterize the hydrokinetic energy of the Kvichak River. TerraSond used a Workhorse Sentinel 1200kHz acoustic Doppler current profiler, (ADCP) to survey flow velocities and estimate discharge. The instrument was manufactured by Teledyne RD Instruments, (TRDI) of San Diego, California. ADCP studies were completed during Expedition II, III, and IV. On each of these expeditions the ADCP was used to test for a moving bed, estimate river discharge, and survey flow velocity across select transects.

7.2 ADCP Methods

7.2.1 Instrumentation

All ADCP measurements were done with a Teledyne RD Instruments 1200 kHz Workhorse Sentinel. It was equipped with a thermistor to measure water temperature, a flux gate compass tilt sensor, and Doppler bottom tracking. The same instrument was used for the entire study. ADCP data was collected using TRDI WinRiver II Version 2.07 running on a Dell Latitude E6400 XFR laptop computer with Windows XP professional operating system. The ADCP was powered by an external AC power source. Real time horizontal position and heading were supplied to WinRiver II by a Coda Octopus F-180 inertial motion unit. The F-180 received RTK GPS correction messages from a Leica 1200+ series base station located on monument HK-1. WinRiver II received the instrument’s roll and pitch from the ADCP’s internal flux gate compass tilt sensor. HYPACK MAX 2011 was used to manage boat navigation and mark key target points. HYPACK MAX received its horizontal positions from the F-180. The survey platform for the ADCP system was an 18 foot Lowe Jon boat. The ADCP was mounted vertically on the port side of the boat using a pole mount. The F-180 and its GPS antennas were mounted on the same pole directly above the ADCP. The transducer head of the ADCP was 0.5 meters below the water line. The instrument was programmed with a 25 cm blanking distance and 25 cm bins. The ping rate was 1 Hz and each ensemble consisted of a single ping. Flow data was collected using GPS and bottom tracking simultaneously. The speed of sound in water was computed by WinRiver II using the ADCP measured water temperature and a salinity of 0 ppt.

7.2.2 Instrument Calibration

All calibrations and checks were done according the specifications provided in the respective manufacturer’s technical manuals. The detailed steps required for each procedure may be obtained from the appropriate manuals.

Prior to starting the ADCP surveys the instrument’s flux gate compass was calibrated for hard and soft iron on shore in the vicinity of the project site. The ADCP was then installed on the boat pole mount. The boat transited to the lake and the remaining calibrations and checks were completed. On the lake the ADCP compass calibration was verified, and the head misalignment was determined. The F-180 was also calibrated on the lake. Prior to each survey session on the river the compass calibration was verified, head misalignment was determined, and the F-180 was calibrated.

7.2.3 Moving Bed Test

Moving bed tests were done at several locations in the project site. All of the tests were done using the stationary method as outlined in the USGS and TRDI methods. For each test the boat was held for a minimum of 10 minutes as close to a single point as possible using visual references and HYPACK MAX positioning. The boat movement as determined by bottom tracking was recorded during the session. The boat position and indicated upstream progress were then evaluated to assess the potential for the existence of a moving bed. Over the three expeditions a total of nine moving bed tests were completed. One moving bed test was done in conjunction with each of the discharge measurements. The additional tests were located at select points of interest in the study area. These locations were chosen based on their proximity to prospective turbine sites as well as changes in bed morphology and water flow that indicated a potential for the existence of a moving bed. All of the moving bed tests indicated that any bed movement that might be present was below the limit of detection for the instrument and method. Further, the use of RTK GPS for positioning of the ADCP obviated any potential bias in the discharge measurement that would have been introduced by a moving bed if bottom tracking was used. The locations of all moving bed tests have been depicted on the accompanying map sheets in Appendix 1.

7.2.4 Discharge Measurements

A discharge measurement was completed on Expeditions II, III, and IV. These measurements were done at Station 5. This location was selected for several reasons. First, it was in the same area that the USGS did their discharge measurements. This would allow the current discharge to have a reasonable basis for comparison to the USGS's data collection. Station 5 is located upstream from the first bifurcation in the river channel. There were no significant tributaries upstream of Station 5. Thus there was no division of flow or addition of flow associated with this station. Therefore, the discharge measurements represent the river flow that is received from the lake. Station 5 was also close to the current electric power generation facility. It was also thought to be a location with high energy density.

Discharge measurements were completed using the protocols recommended by the USGS and TRDI. A minimum of four transects consisting of two matched left - right pairs were run for each discharge measurement. The discharge values were computed by WinRiver II. The discharge of the individual transects was compared to the mean discharge for the set. None of the individual discharge values differed from the mean discharge by more than 5%.

7.2.5 ADCP Velocity Transects

Single transect velocity measurements were made at numerous locations on Expeditions II, III, and IV. There was a total of 54 transects completed over the three expeditions. Single transects were run at stations 1 to 4, and 6 to 12 on Expedition II. On Expedition III single transects were run at stations 6, 9 to 11, and 13 to 18. After evaluating the data from Expeditions II and III it was determined that the ADCP transects for Expedition IV should focus on areas in the vicinity of Stations 5, 6, 9, 10, 11, and 17. These areas were then designated as sites 5, 6, 9, 10, 11, and 17. The discharge measurement at Site 5 was used to fulfill the requirement for the single Site 5 velocity transect. Eleven transects were completed at Site 6. The first transect was located approximately 30 meters downstream of Station 5. The remaining 10 transects were the spaced at

20 meter intervals downstream. The eleventh transect was located about 120 meters downstream of Station 6. The Site 9 transects started about 90 meters upstream of Station 9. From this point a total of 10 transects were placed at approximately 20 meter intervals downstream. The Site 10 transects started about 20 meters downstream of the last transect of Site 9. The remaining 10 transects were then placed at successive 30 meter intervals downstream. Single transects were run at Site 11 and 17. Both of them were located at the respective stations. The locations of these transects have been depicted on the map sheets in Appendix 1.

Because of the instrument draft and blanking distance the first measurement bin spanned a zone that was between 75 and 100 cm below the surface. WinRiver II used an extrapolation algorithm to estimate the velocity and flow in the zone between the first bin and the surface. Nonetheless it was determined that there would be some value to measuring the flow speed in the zone above the first bin. A Marsh-McBirney FlowMate 2000 portable velocity flow meter was used to make a series of water speed measurement in this zone on all of the transects surveyed during Expeditions III and IV. The flow mate was placed on a vertical pole and fixed at a depth of 61 cm. The boat was held at select points on the transects by means of visual reference and GPS positioning using HYPAK MAX and the F-180. The positions and water speeds were compiled in a spreadsheet. The Marsh-McBirney sample positions and velocities collected during Expedition IV were depicted on the map sheets in Appendix 1. A spreadsheet with the measured velocities and positions was places in Appendix 2.

8.0 RIVER SLOPE ESTIMATE

8.1 Introduction

On 18 June 2011 a set of water level measurements were made using a Leica 1200+ series RTK GPS rover unit. The water levels and horizontal positions were placed in an Excel 2010 spread sheet and the ellipsoid heights were regressed to a line with respect to reach distance, Figure 17.

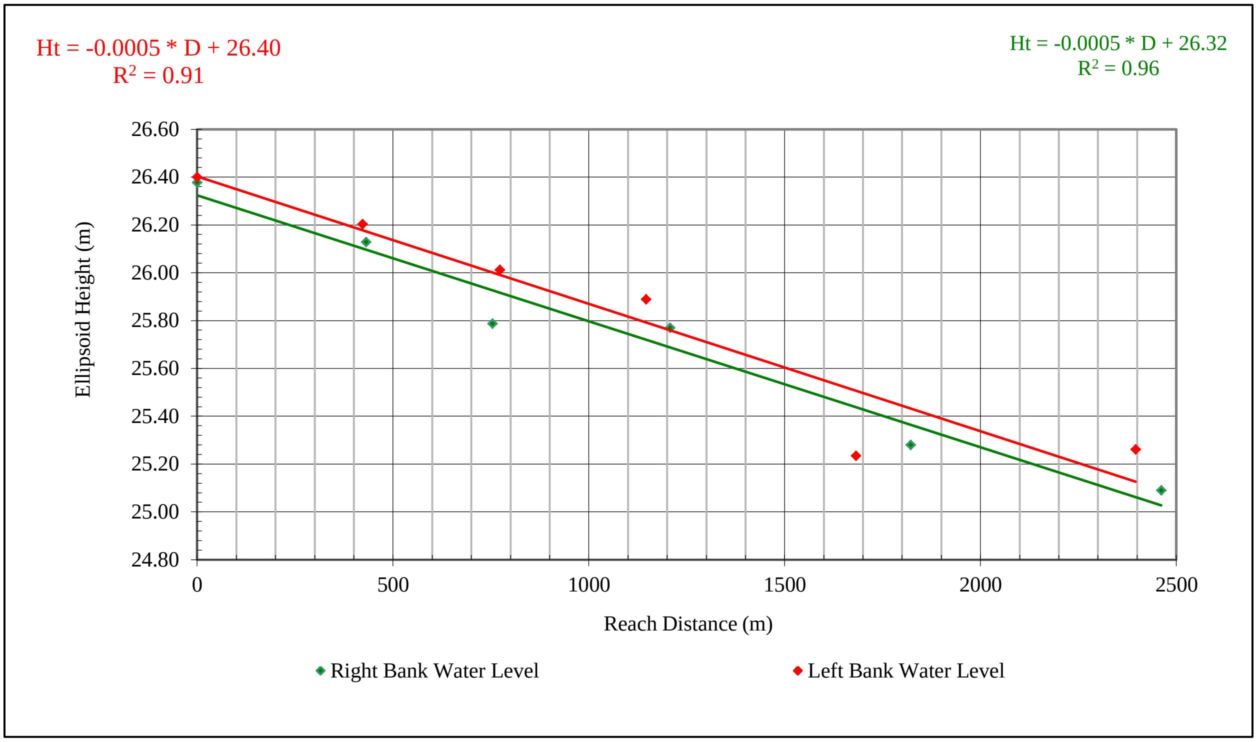

Figure 17 – Linear regression of water level slope.

8.2 Water Surface Level Slope Estimate

Corresponding left and right bank water levels were measured on 18 June 2011. These measurements were done using a Leica 1200+ series RTK GPS rover unit that was receiving correction messages from an RTK GPS base station set on HK-1. Measurements were made in the vicinity of Stations 1,3,5,8,9, and 12. The reach distance along each bank between points was computed. The ellipsoid heights with respect to the computed reach distances were then regressed to a line using Microsoft Excel 2010. This regression gave an estimated water surface slope of -0.0005 for both banks. The R^2 regression coefficients were 0.91 and 0.96 for the left and right banks respectively, Figure 17.

EQN 8.1 $Ht = S_{WL} * D + b$

Where: Ht = Ellipsoid height of the water surface in meters
S_{WL} = Water level slope
b = Height of the vertical intercept of the regression line at the putative river mouth

9.0 RIVER BED MATERIALS

9.1 Introduction

During the third expedition to Igiugig ten sediment samples were collected from the Kvichak River bed and Iliamna Lake. The collection dates were 27 and 30 August 2011. These samples were collected by dragging a cylindrical bed sampler several meters on the bottom. One drag was made for each sample. This yielded approximately four liters of bed material per sample. The sampled materials were classified by size using the scheme of Lane et. al as presented in Sediment Transport Theory and Practice by Yang (1996). This was a coarse characterization of materials based on simple inspection and measurement using calipers and the American Association of Petroleum Geologist's sedimentary size graph by George V. Chilingar. It was not intended to replace a more rigorous analysis using appropriate methods with standard sieves and hydrometry. The locations of the bed samples are depicted on the accompanying map sheets in Appendix 1.

9.2 Bed Samples

Sample ***Description***

A. The material is exclusively sand. The majority is coarse sand. The remainder consists of medium and fine sand. There is no frank presentation of gravel, cobbles, silt or clay.

B. There are some small cobbles. The predominant material is gravel. The full spectrum of gravel sizes is present. However, most of it is in the medium and fine range. Some sand is present in sizes from 0.25 to 2 mm. The majority of the sand is 0.5 to 1.0 mm. (coarse sand). There is a minor amount of clay/silt material. The sample has a pronounced odor of organic decay.

C. This material is substantially dominated by small cobbles. The small remainder consists of gravel and sand. The majority of the gravel is coarse and medium with a very small amount of fine gravel. The sand is mostly coarse. There are trace amounts of fine and very fine sand. There is no frank evidence of silt or clay. The sample has a mild aroma of organic decay.

D. This material is predominantly small cobbles and gravel. There is some very coarse and coarse gravel. The sample is dominated by medium and fine gravel. A small amount of very coarse sand is present. There is no obvious presence of material smaller than coarse sand.

E. The bed is predominantly gravel. The full spectrum of gravel sizes is present. There are some small cobbles. The minimal amount of sand present is primarily very coarse and coarse.

F. This sample is primarily medium and fine gravel. However, the full spectrum of gravel sizes is present. There are some small cobbles. The small amount of sand present is primarily coarse and very coarse. There is no clear evidence of finer sands, silt or clay.

G. The bed material is small cobbles and very coarse gravel. There are no significant amounts of any smaller materials.

H. The majority of material is small cobbles and very coarse gravel. The small remainder is coarse, medium and fine gravel. There is no evidence of finer material.

I. There are some small cobbles. The primary gravel is very coarse, and coarse. Some medium, fine, and very fine gravel is present. Finer material does not appear.

J. The material is small cobbles with very coarse, coarse, and medium gravel. There are no significant amounts of finer material.

Iliamna Lake and the Kvichak river waters are exceptionally clear. On the lake the bottom can be easily seen to a depth of five meters. In the general vicinity of the river mouth the lake bottom appears to be scattered cobbles, and small boulders on top of coarse sand. The river the bed is visible in almost all of the study area. The central part of the channel appears to be small to large cobbles and the occasional small boulder. At the water line by the mouth of the river the gravel and cobbles diminish and the beach consists primarily of fine and medium sands. There are occasional small areas with substantial silt or clay material. Further downstream the shore line presents infrequent small and medium boulders. The primary materials are large and small cobbles, with an assortment of gravel, and sand. There is relatively little organic material in the shoreline bed.

10.0 FINDINGS

10.1 Introduction

ADCP surveys were completed on Expeditions II, III, and IV. The effort had three primary goals. The first goal was to obtain discharge measurements at low medium and high stages. The second goal was to determine if there was a detectable moving bed at select points in the river. The final goal was to develop a detailed picture of the flow velocities and distribution of hydrokinetic energy density in the river.

A multibeam bathymetric survey was completed on Expedition II and III. The data from Expedition II was not satisfactory. It was discarded and a second survey was completed on Expedition III. The results of the second survey were the only ones included in this report. The purpose of the multibeam survey was to develop a detailed digital elevation model (DEM) of the river bed. Second, it established a baseline state of river bathymetry. It created a detailed 3-D data set suitable for future modeling requirements. Finally, the bathymetric survey was also used to identify dangers to navigation, and hazards for construction.

Ten bed samples were collected on Expedition III. These samples were intended to give a preliminary view of the typical bed material in the project site. They were not intended to be suitable for a detailed sediment study for the purpose of making a definitive assessment of bed stability and bed load transport.

None of the RM’s from the USGS gaging station were recovered. Nonetheless some coarse relationships were established. This was done by referencing current discharge measurements to the original USGS rating curve and then relating the gage heights to an ellipsoid height. This was then used to make some estimates of return even parameters, and extremes of flow and height conditions. These findings should be accepted with great caution. The river has changed over the decades since the USGS operated its gaging station. No physical tie to the USGS RM’s was possible. Therefore, the relationships established are based only on a rough estimate of water levels using a rating curve that is over two decades old.

10.2 ADCP Findings

TerraSond did ADCP surveys on Expeditions II, III, and IV. On each expedition a discharge measurement was completed at Station 5 in the vicinity of the electric power generator facility. A moving bed test was done in conjunction with each of these discharge measurements. On each occasion no moving bed was detected. Over the three expeditions a total of eight more moving bed tests were completed at other locations in the river. No moving bed was detected at any of these locations. The locations of the moving bed tests have been depicted on the accompanying map sheets. Fifty four single transects were completed over the course of the three expeditions. Nine single transects were done on Expedition II. The first of these was at the mouth of the river and the last was in the vicinity of the downstream extent of the original proposed survey area. This was about 2.5 km downstream. On Expedition III ten single transects were completed The first was at Station 5 and last was at Station 18. The transect at Station 18 was about 1.5 km downstream from Station 12. The total downstream extent of ADCP surveys was nearly 4 km of reach distance. After examination of the ADCP transects from Expeditions II and III it was decided that the best areas for further study were in the vicinity of Stations 5, 6, 9, 10, and 17. The area surrounding each of these stations was expanded to a study site. The sites were given a numerical designation that corresponded with the station that was the basis of the expanded area. ADCP efforts for Expedition IV aimed to develop a more detailed picture of the flow characteristics in these sites. The locations of the sites and the individual transects surveyed at each of these sites are depicted in the accompanying map sheets.

10.2.1 Discharge Measurements

A discharge measurement was done at Station 5 during each expedition. TerraSond attempted to time the discharge measurements to coincide with a low, medium, and high discharge. The first measurement was done on 21 June 2011. The second and third measurements were done on 27 August and 12 October 2011. The results of these measurements are in tables 4, 5, and 6.

21-Jun-11

Expedition II Discharge at Station 5

Transect	Total Q	Delta Q	Width	Total Area	Q/Area	Flow Speed
	m^3/s	%	m	m^2	m/s	m/s
PH3C002	334	-0.18	123	225	1.5	1.6
PH3C003	334	-0.13	124	222	1.5	1.6
PH3C004	337	0.78	127	227	1.5	1.6
PH3C005	333	-0.47	126	225	1.5	1.5
Average	335	0	125	225	1.5	1.6
Std Dev.	2	0.54	2	2	0.0	0.0

Table 4 – Expedition II ADCP discharge.

29-Aug-11

Expedition III Discharge at Electric Power Station

Transect	Total Q	Delta Q	Width	Total Area	Q/Area	Flow Speed
	m^3/s	%	m	m^2	m/s	m/s
PWRHSEDIS002	548	0.72	156	327	1.7	1.8
PWRHSEDIS003	540	-0.79	159	330	1.6	1.8
PWRHSEDIS004	544	-0.04	158	326	1.7	1.7
PWRHSEDIS005	545	0.11	158	327	1.7	1.8
Average	544	0	158	327	1.7	1.8
Std Dev.	3	0.62	2	2	0.0	0.0

Table 5 – Expedition III ADCP discharge.

12-Oct-11

Expedition IV Discharge at Electric Power Station

Transect	Total Q	Delta Q	Width	Total Area	Q/Area	Flow Speed
	m^3/s	%	m	m^2	m/s	m/s
SITE5-1001	548	0.47	170	334	1.6	1.7
SITE5-1002	548	0.55	167	330	1.7	1.7
SITE5-1003	552	1.24	170	333	1.7	1.8
SITE5-1004	533	-2.26	166	329	1.6	1.6
Average	545	0	168	332	1.6	1.7
Std Dev.	8	1.55	2	2	0.0	0.0

Table 6 – Expedition IV ADCP discharge.

The USGS operated a gaging station on the Kvichak River at this location from 1967 to 1987. It was designated Site 15300500. During this time they completed 39 discharge measurements and developed two rating curves. This rating curves were used by the USGS to make daily estimates of discharge. The USGS published these estimates from 1 January 1967 to 1 January 1987. Unfortunately the original RM's for the gaging station have been lost. Further, the river channel has experienced some changes in dimension and flow pattern over the last 24 years. Nonetheless the USGS gaging data has been of some utility in characterizing the current discharge. This data set shows that the typical low discharges have occurred between the middle of March and the middle of April, Figure 18. The high discharges have usually occurred between late August and early October.

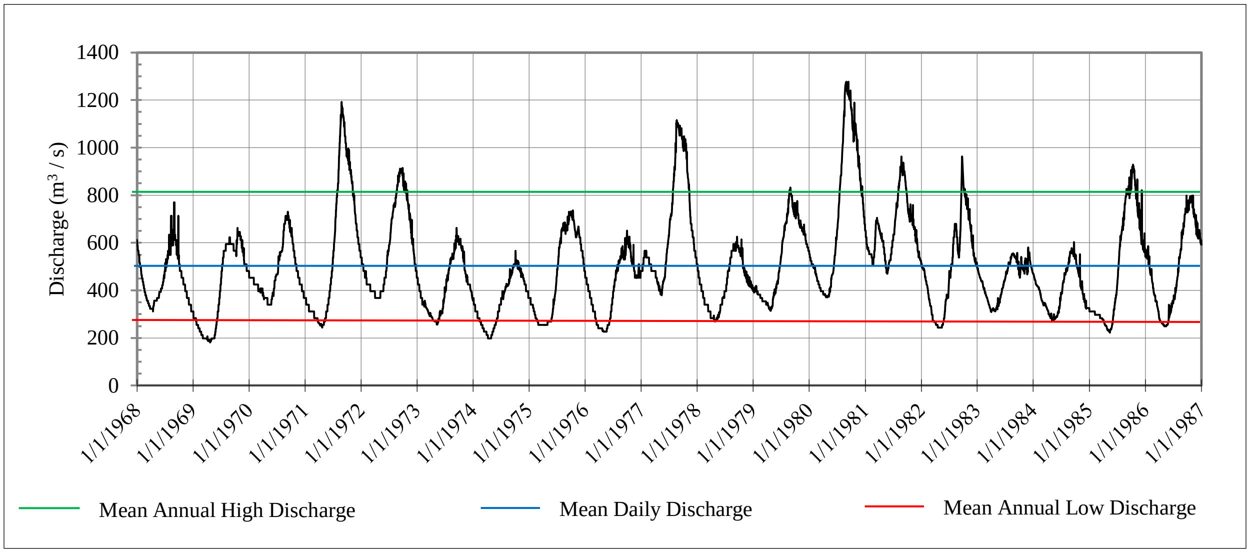

Figure 18 – USGS Site 15300500 daily discharge.

The USGS normally used a river year that corresponds with the U.S. fiscal year to define the period for selecting annual descriptive statistics. This approach was not useful for current analysis because it resulted in annual extremes being designated within weeks of each other in the same calendar year. Therefore it was decided to use the calendar year for river analysis in this report. The annual peak and minimum discharges that have been presented in Figure 19 were determined from the USGS gage data for the respective calendar years.

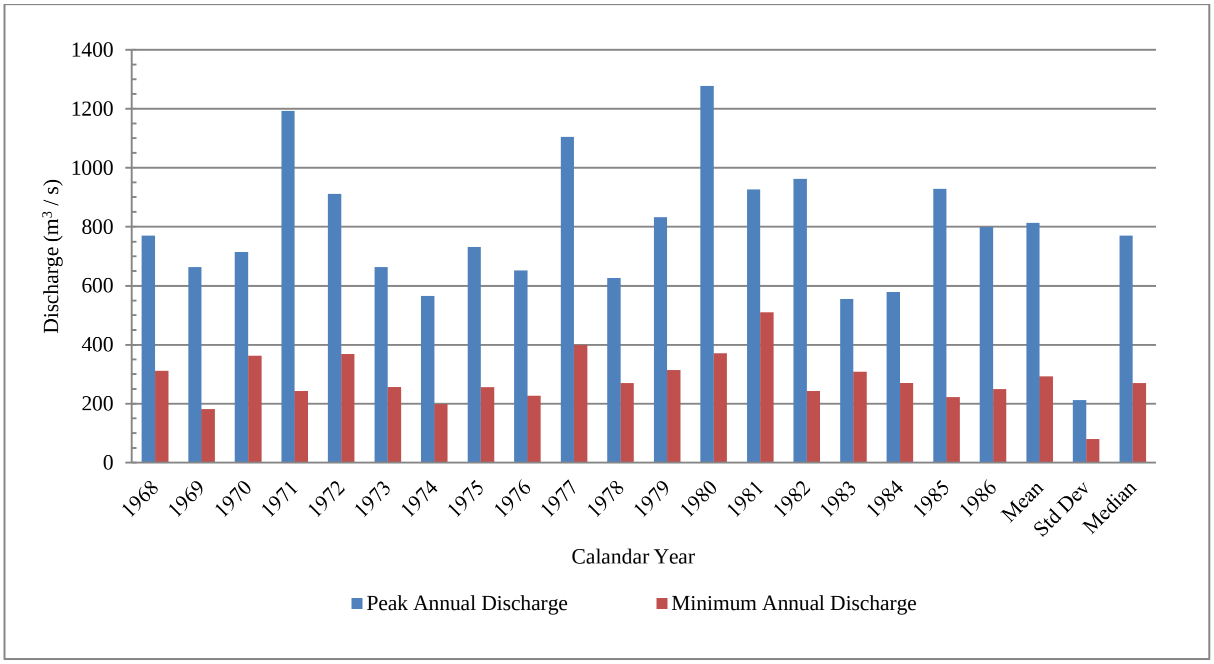

Figure 19 – USGS Site 15300500 annual maximum and minimum discharge.

The average daily discharge for the USGS record was 500 m^3/s ($\sigma = 201$ m^3/s). The maximum and minimum daily discharges reported were 1277 m^3/s and 181 m^3/s respectively. The average annual minimum and peak reported discharges were 293 m^3/s, ($\sigma = 81$ m^3/s), and 813 m^3/s, ($\sigma = 212$ m^3/s). The ADCP measured discharge on 21 June 2011 was 335 m^3/s. This value would have fallen in the 21st percentile of the USGS data set. The other two discharges measured on 27 August and 12 October 2011 were 544 and 545 m^3/s. These measurements fell into the 65th percentile of the USGS record. The USGS reported mean discharge for all of the June months was 405 m^3/s, ($\sigma = 90$ m^3/s). The minimum and maximum discharges reported in the USGS data set for the June months were 394 m^3/s and 524 m^3/s. The USGS reported daily mean discharge for all of the August months was 693 m^3/s, ($\sigma = 199$ m^3/s). The reported mean discharge for the October months was 699 m^3/s, ($\sigma = 181$ m^3/s). The minimum and maximum USGS discharge values October were 510 m^3 / s and 1189 m^3 /s. These parameters have been summarized in table 7. Several community members observed that this year seemed to have some of the lowest water levels that had been seen in the last 15 years. Comparison of the current ADCP discharge measurement to the USGS record has corroborated these observations.

Characteristic	Discharge (m^3/s)	Standard Deviation (1σ m^3/s)
USGS Mean Daily Discharge	500	201
USGS Maximum Daily Discharge	1277	****
USGS Minimum Daily Discharge	181	****
USGS Mean Annual Minimum Discharge	293	81
USGS Mean Annual Maximum Discharge	813	212
USGS Mean Daily Discharge June	405	90
USGS Maximum Discharge June	524	****
USGS Minimum Discharge June	394	****
USGS Mean Daily Discharge August	693	199
USGS Maximum Discharge August	1277	****
USGS Minimum Discharge August	413	****
USGS Mean Daily Discharge October	699	181
USGS Minimum Discharge October	510	****
USGS Maximum Discharge October	1189	****
RISEC Expedition II Discharge	335	2
RISEC Expedition III Discharge	544	3
RISEC Expedition IV Discharge	545	8

Table 7 – Summary discharge statistics.

10.2.2 Moving Bed Tests

Nine moving bed tests were done over the course of the three expeditions. One was done in conjunction with each of the discharge measurements at Station 5. The remaining ones were done at select points of interest in the river. None of these tests detected a moving bed.

The lack of a positive result for a moving bed does not mean that the bed is completely stable. There may be enough movement of the bed at rates below the instrument detection level to cause long term changes in the bed morphology. Further, modifications to flow patterns caused by objects place on the bed may cause substantial localized changes in the bed morphology.

10.2.3 Energy Density

ADCP velocity magnitude values were exported from WinRiver II for further evaluation using MatLAB Version 2008b. The velocity magnitude values were smoothed with a 3 x 3 ensemble average over the entire profile. The total hydrokinetic power density was computed by the following.

EQN 10.1 $P = 0.5 * \rho * V^3$

Where: P = Power density

ρ = Density of fresh water

V = water velocity magnitude

Images depicting the distribution of flow and hydrokinetic power were produced for every transect. The full collect has been placed in Appendix 2 of this report. The highlights of transects collected at Sites 5, 6 9 and 10 have been selected for discussion because they show the most promise for future development.

The depth shown in all of the ADCP transect graphics are those measured by the ADCP at the time of the survey. They have not been adjusted to the KRIGIPVD11 datum. The physical dimensions and acoustic properties of the ADCP prevent direct measurement of the entire channel. The TRDI WinRiver II software applies a series of extrapolation algorithms to estimate current velocities and discharge in the omitted areas. The results of these extrapolations are then added to the actual measured portion of the channel to determine the total discharge of the channel.

The TRDI WorkHorse Sentinel 1200 kHz ADCP used for this project was mounted vertically on a pole with the transducer head 0.5 meters below the water surface. When the transducers ping the sound is emitted in all directions. Thus there is a simultaneous return from the water column and the instrument housing. Because of this the instrument cannot distinguish between returns in the first 0.25 meters in front of the transducer head and the returns from the housing. Therefore no measurements are recorded for the region that extends from the transducer head to a point 0.25 meters distant. This distance is known as the blanking distance. The combined draft and blanking distance for the data presented here is 0.75 meters, (2.46 ft.). Therefore there are no direct measurements of current velocity recorded for the first 0.75 meters of the water column. A small portion of the bottom of the water column does not have direct current velocity measurements. This is due to issues with backscatter from the bottom and the need to use bottom tracking to determine vessel movement. In the data presented here the bottom gap is 0.75 m, (2.46). However, the ADCP does measure the actual depth to the river bed. Due to the instrument draft and blanking distance the ADCP cannot be maneuvered all the way to the shore. There must always be at least 0.75m (2.46) between the transducer heads and the river bed. Therefore, the profiles presented in this report represent the portion of the channel that was surveyed directly by the ADCP. There is a small sliver on each side of the channel that is omitted. In order to make an extrapolation to compute the discharge in the side slivers the ADCP is held in position for about 10 seconds as close as possible to the bank while also maintaining at least two good measurement bins below the instrument. Thus the shallowest water that this instrument configuration can measure is 1.30 m (4.26 ft). While holding position near the bank the distance from the instrument to the bank is measured and recorded in the data record. The sampled bins and the bank distance are used to extrapolate a value for discharge in the omitted sliver at each bank, Figure 20.

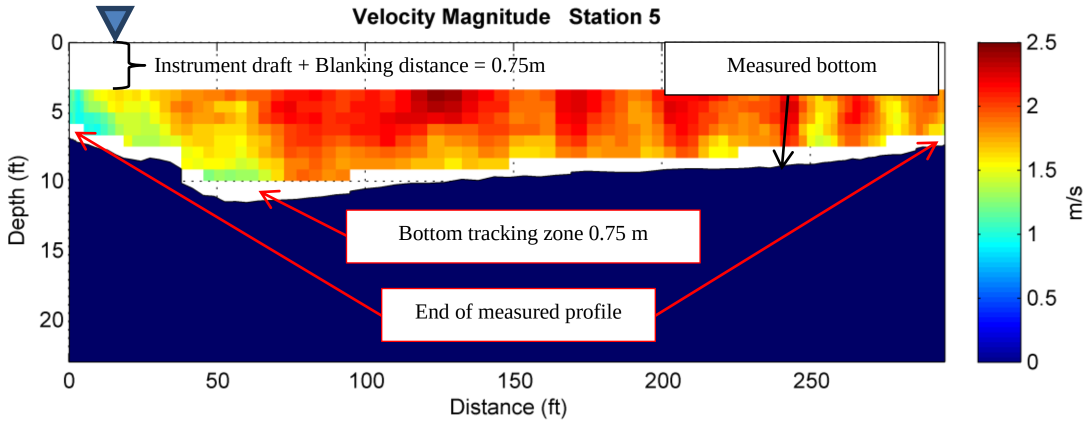

Figure 20 – Omitted zones of ADCP profiles.

10.2.3.1 Station 5

The June ADCP transect at Station 5 exhibits a zone of low to moderate power density that is centrally located in the channel. Its left extent is offset to the right of the thalweg by about 10 meters. From there it extends to the right of the channel such that it ultimately occupies the central two thirds of the river. The overall distribution of power at this station appears to remain the same at the higher discharge rates. Average velocity magnitude at Station 5 was 1.6 m/s on 21 June 2011, 1.8 m/s on 27 August 2011, and 1.7 on 12 October 2011. At the lower discharge the power density ranges from about 2 to 4 kW/m^2. At the higher discharge the range energy density in this zone is from approximately 4 to 6 kW/m^2 Figures 21, 22, 23.

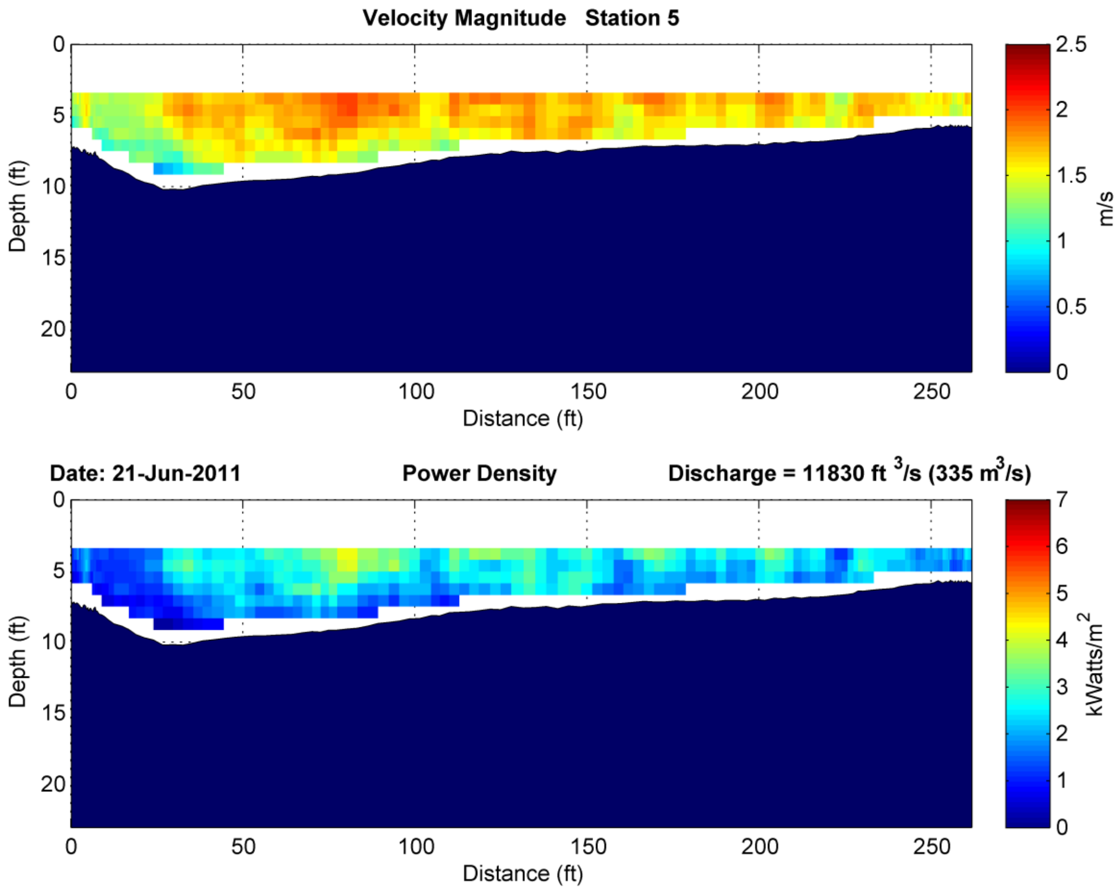

Figure 21 – ADCP transect at Station 5 Expedition II.

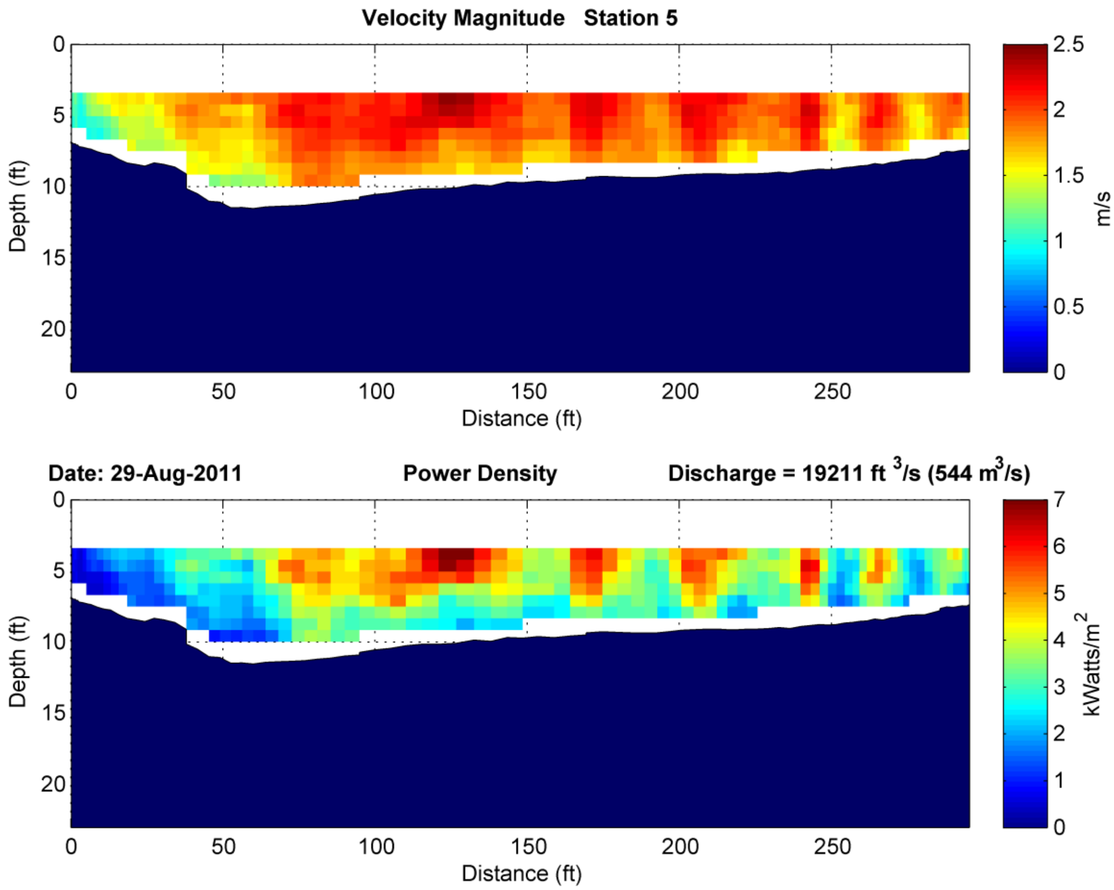

Figure 22 – ADCP transect at Station 5 Expedition III.

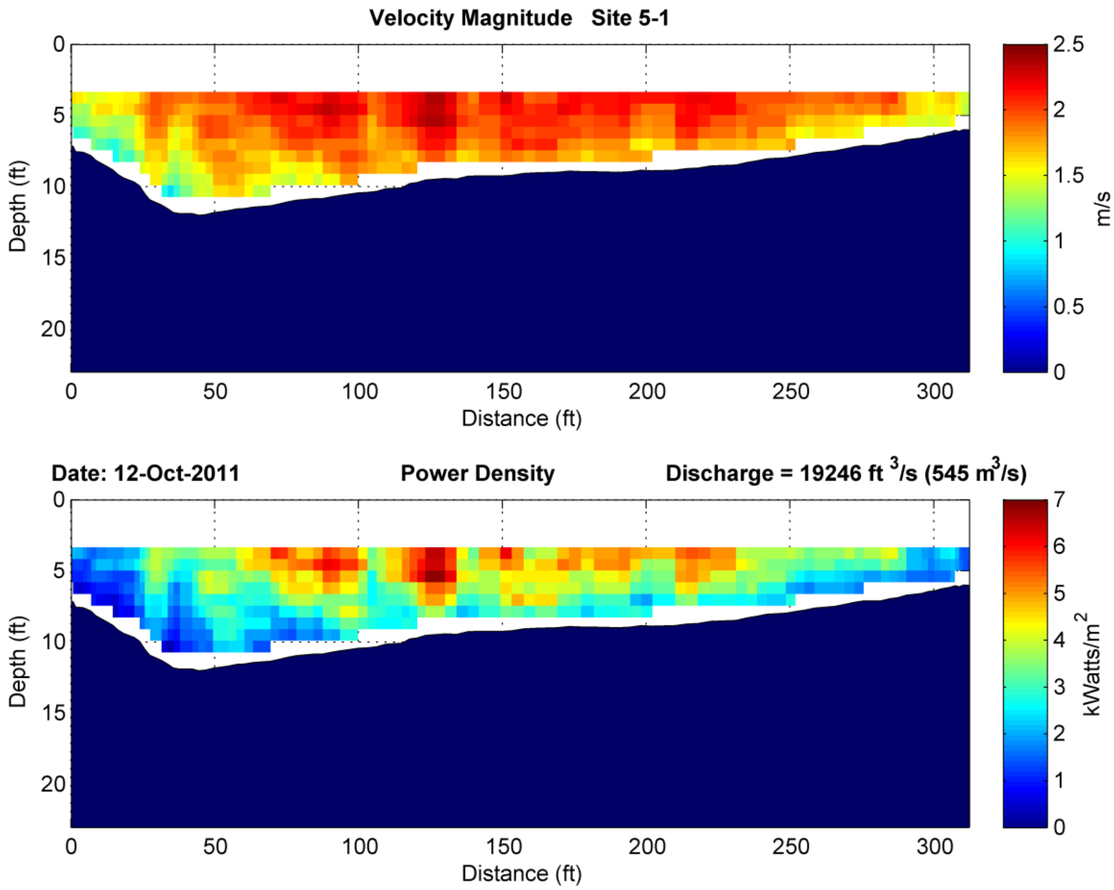

Figure 23 – ADCP transect at Station 5 Expedition IV.

10.2.3 Station 6

The energy is concentrated in the left half of the river at Station 6. In June it is at a moderate level of about 3.5 to 4.5 kW/m^2 Figure 22. The power increases considerably in August and October. At this higher discharge the power range in the left half of the channel is 5 to 7 kW/m^2, Figures 24, 25, 26. The average velocity magnitude at Station 6 for Expeditions II, III, and IV was 1.3, 1.6, and 1.9 m/s respectively. The overall distribution of power remains consistent through the seasons. At this station the power zone is wide. The thalweg is broad and less pronounced compared to other reaches. This location offers a wide high power zone while maintaining good depth and breadth for navigation.

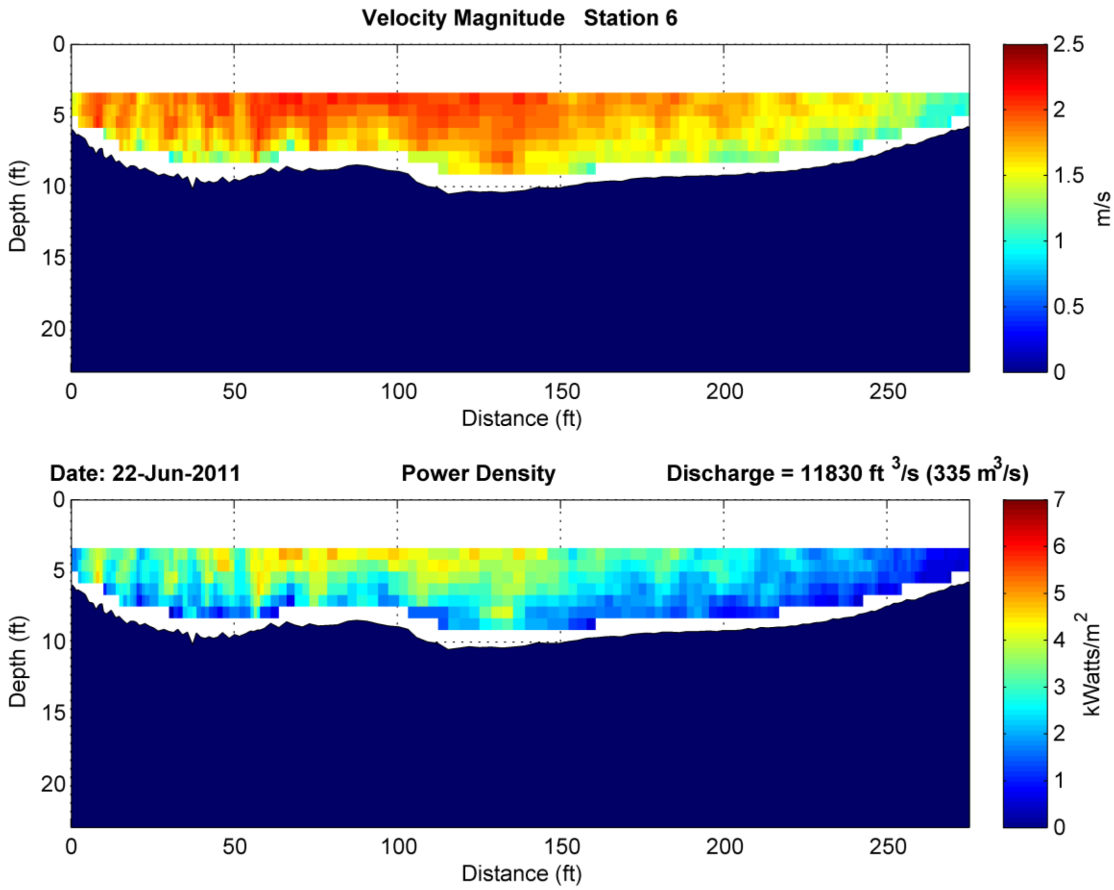

Figure 24 – ADCP transect at Station 6 Expedition II.

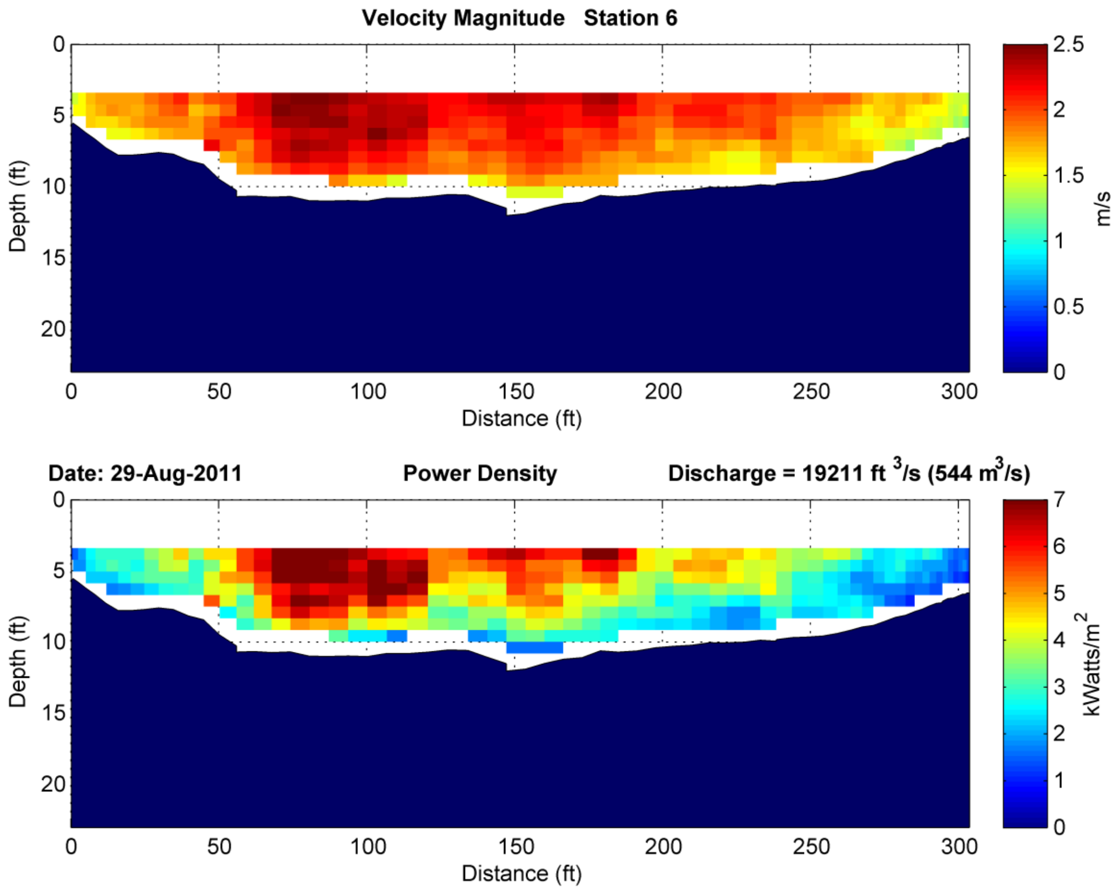

Figure 25 – ADCP transect at Station 6 Expedition III.

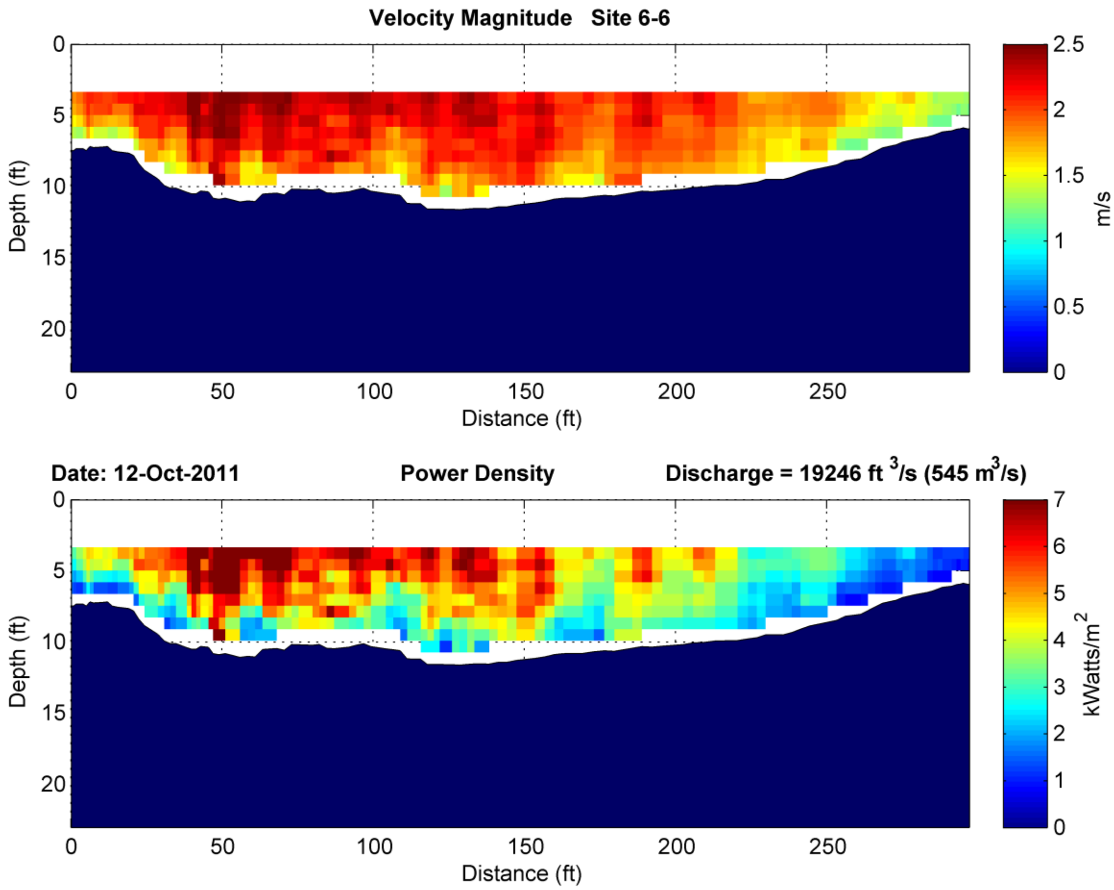

Figure 26 – ADCP transect at Station 6, (Site 6-6) Expedition IV.

10.2.3.1 Site 6

The initial ADCP data from Station 6 indicated that it would be one of the more favorable locations for a turbine. Therefore the scope of investigation was expended about this station. The expanded zone was designated as Site 6. A total of 11 ADCP transects were completed at this site during Expedition IV. The first was placed about 120 meters upstream of the original transect for Station 6. The remaining 10 transected were placed at 20 meter intervals downstream.

At Site 6 the power density distribution changes with the river morphology. From Site 6-1 to 6-2 the thalweg is expanded to the left and becomes less pronounced Figures 26, 27. Two zones of slightly elevated power density start to form at Site 6-2. At Site 6-3 some of the material returns to the left side of the thalweg and the right side is extended and widened, Figure 29.

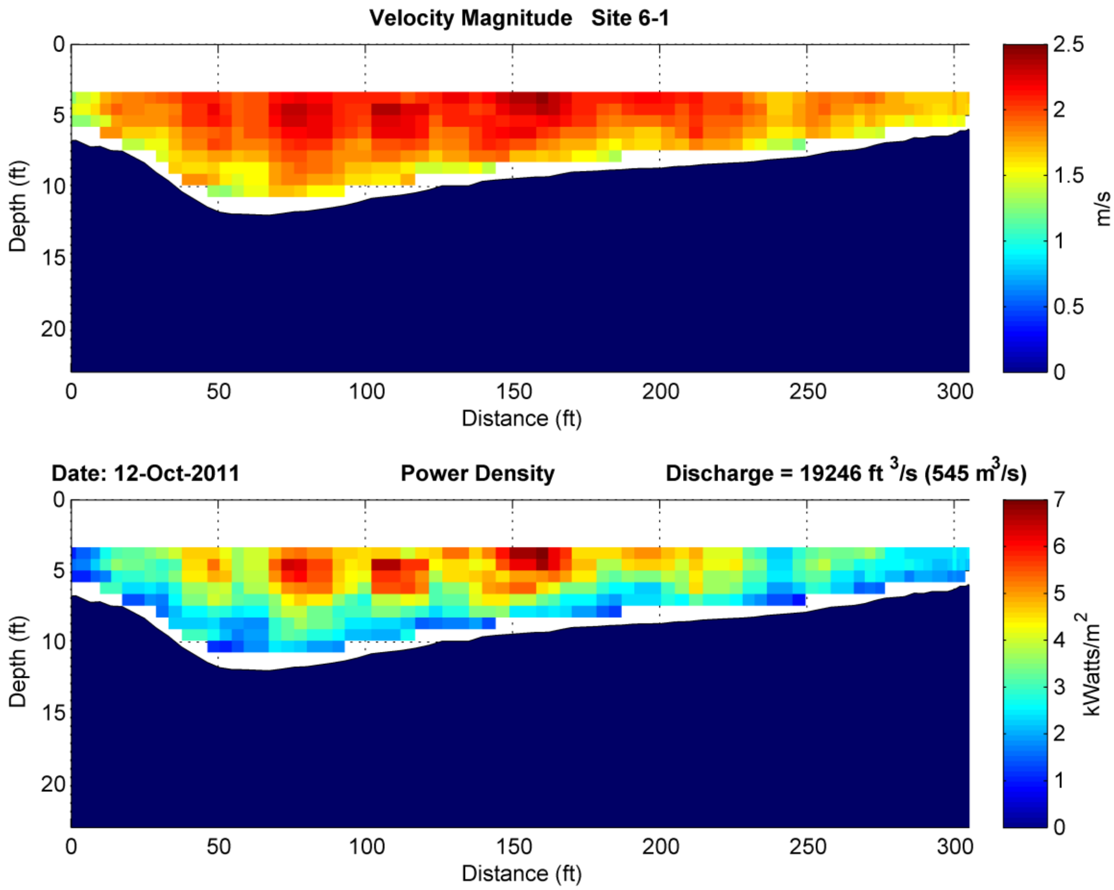

Figure 27 – ADCP transect Site 6-1.

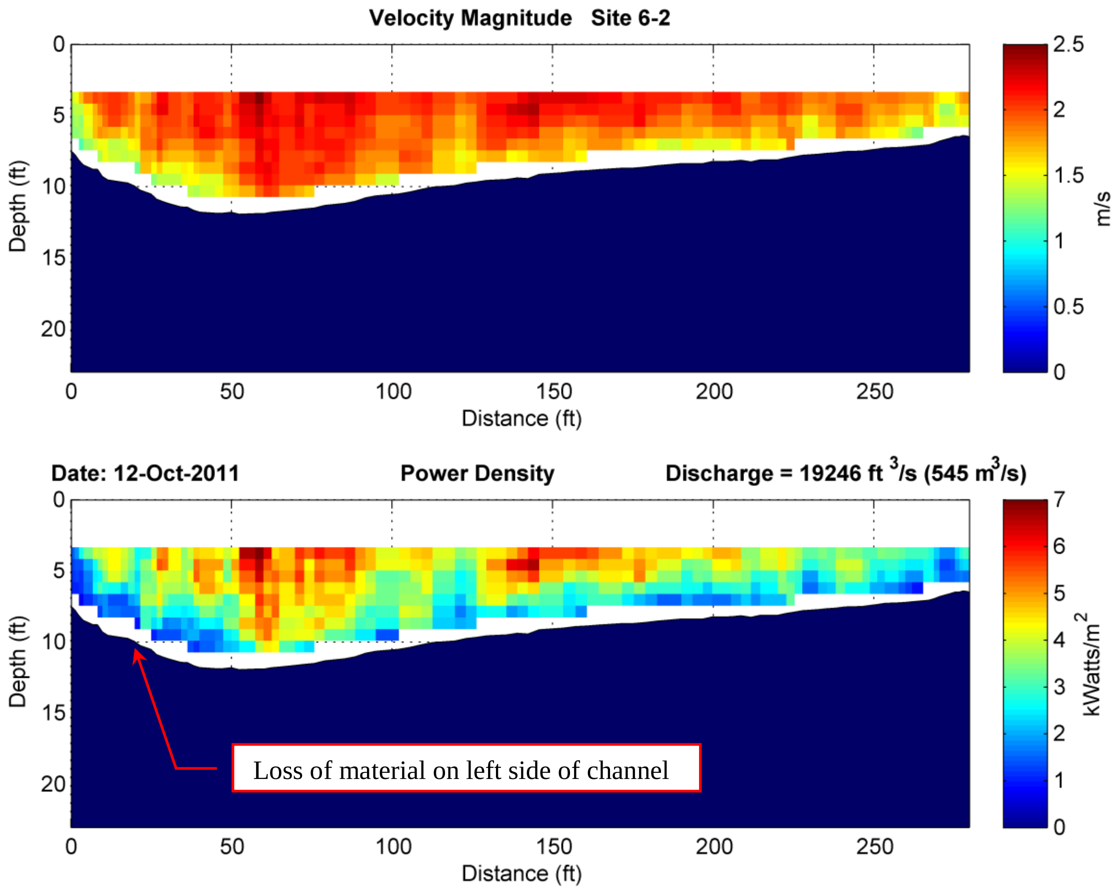

Figure 28 – ADCP transect Site 6-7.

A second zone of elevated energy density develops to the right of the thalweg.

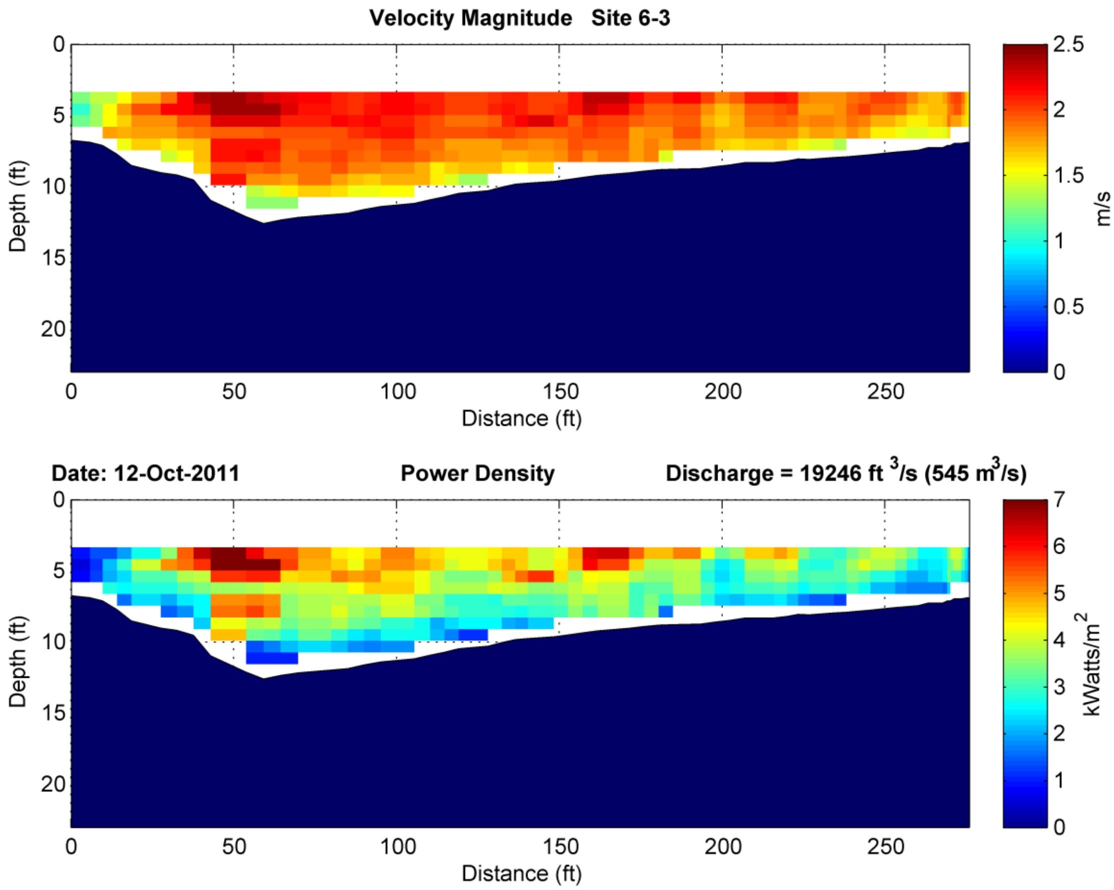

Figure 29 – ADCP Transect Site 6-3.

Some material returns on the left side and the right side continues to expand.

From Site 6-3 to Site 6-6 the thalweg expands to the right and the channel starts to develop a profile that has a steep slope from the left to a low point at 15 meters from the left bank. Then there is a gradual slope up to the right bank. A zone of elevated energy density develops on the left side of the river, Figures 29, 30, 31.

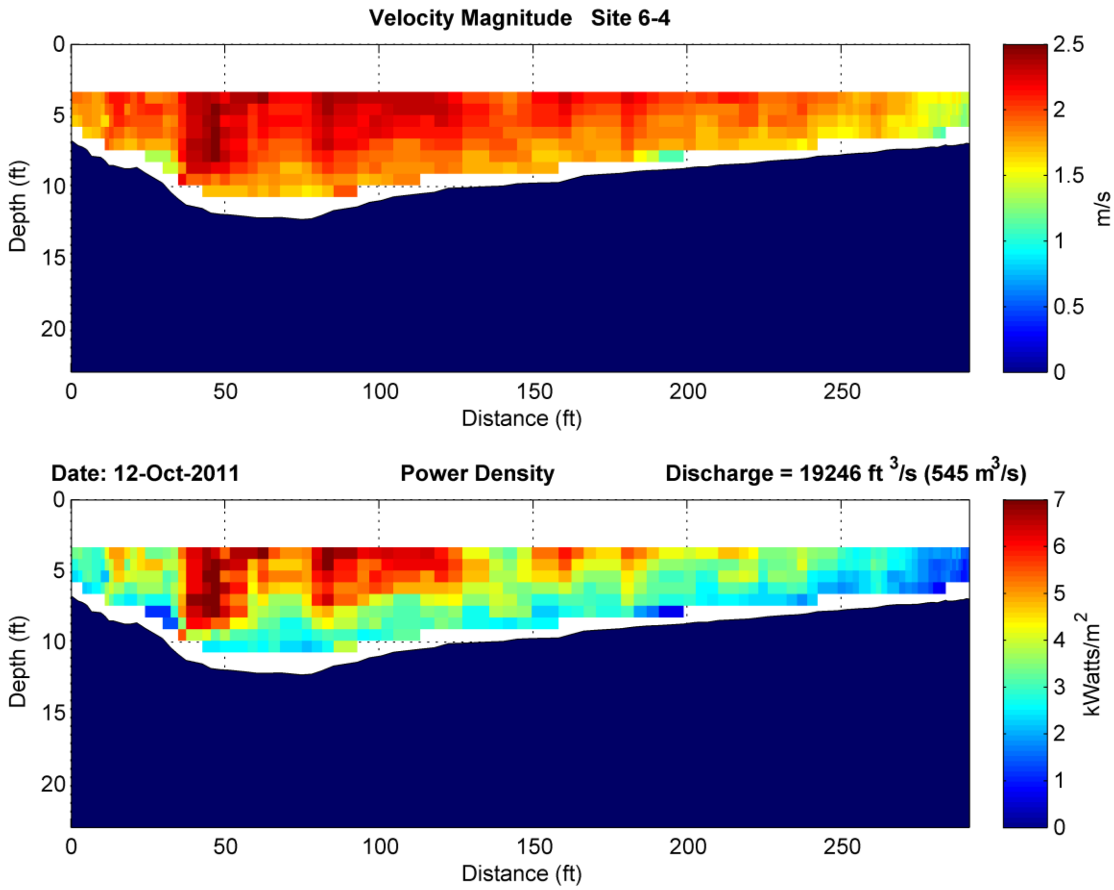

Figure 30 – ADCP transect Site 6-4.

The channel expansion continues and a zone of higher energy density develops in the vicinity of the thalweg.

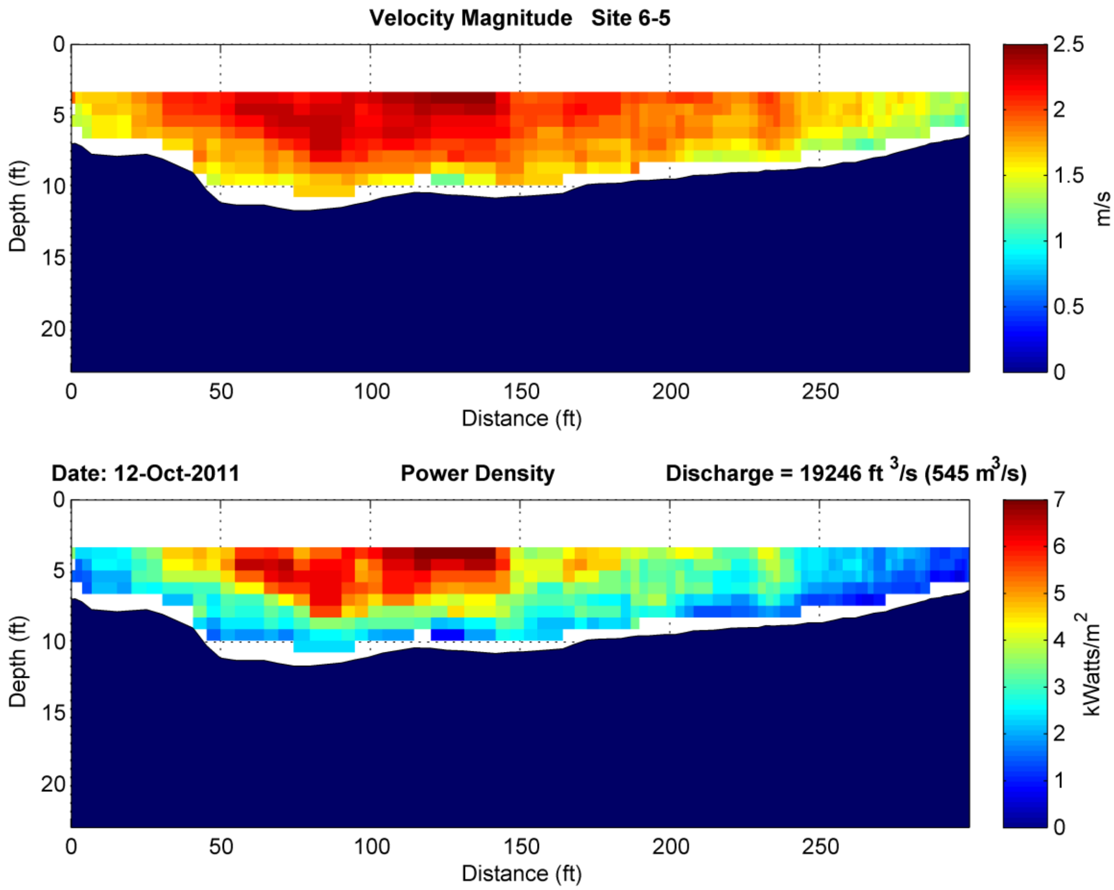

Figure 31 – ADCP transect Site 6-5.

Channel expansion continues and the zone of higher energy density consolidates in the vicinity of the thalweg.

At Site 6-6 the channel expands on the left and right side. The high energy density increases intensity and expands to occupy the majority of the left half of the channel. At Site 6-7 the channel is filled in on the left and continues to excavate on the right. The zone of elevated energy density remains largely the same as in the upstream transect. At Site 6-8 the left side is excavated again and the right side continues to be excavated. The overall profile has moderately steep slopes on the left and right with a flat bottom that comprises the central half of the channel. The elevated energy density persists to the left half of the channel, Figures 32, 33, 34.

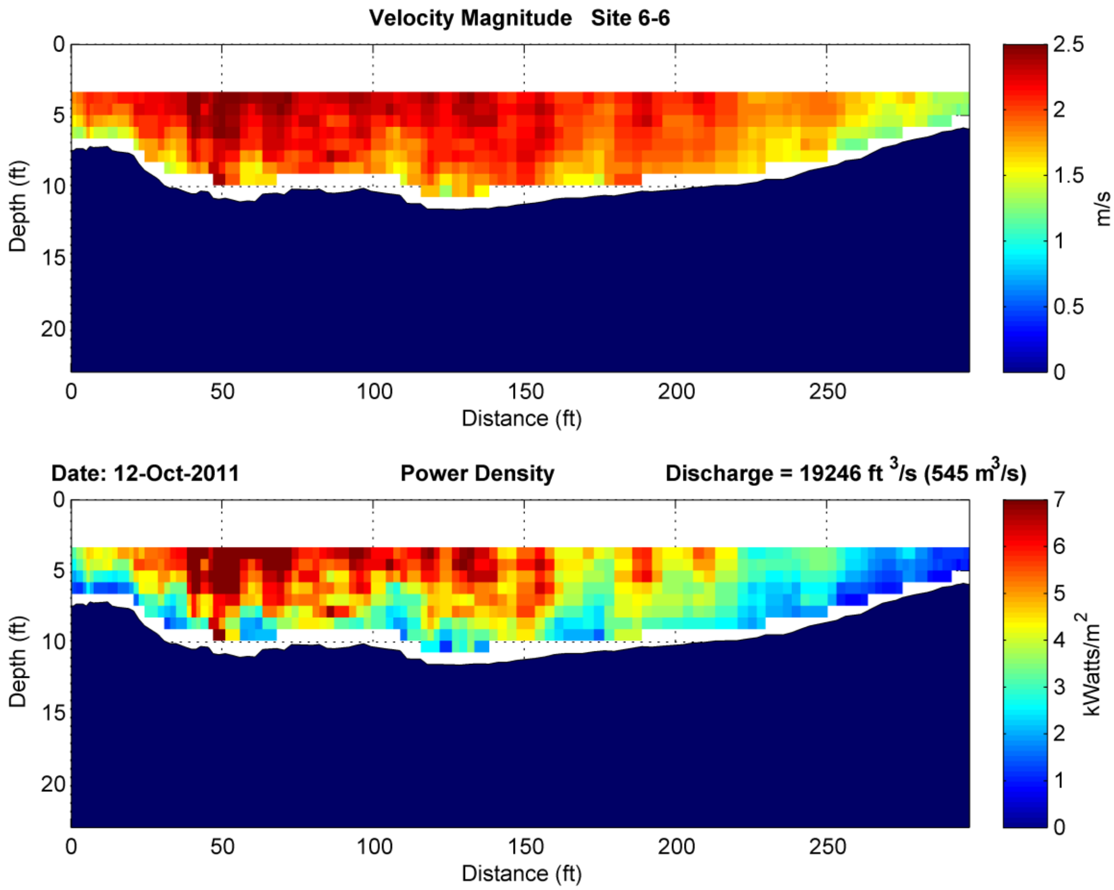

Figure 32 – ADCP transect Site 6-6.

The channel expansion continues and the zone of higher energy density expands to occupy the left half of the channel.

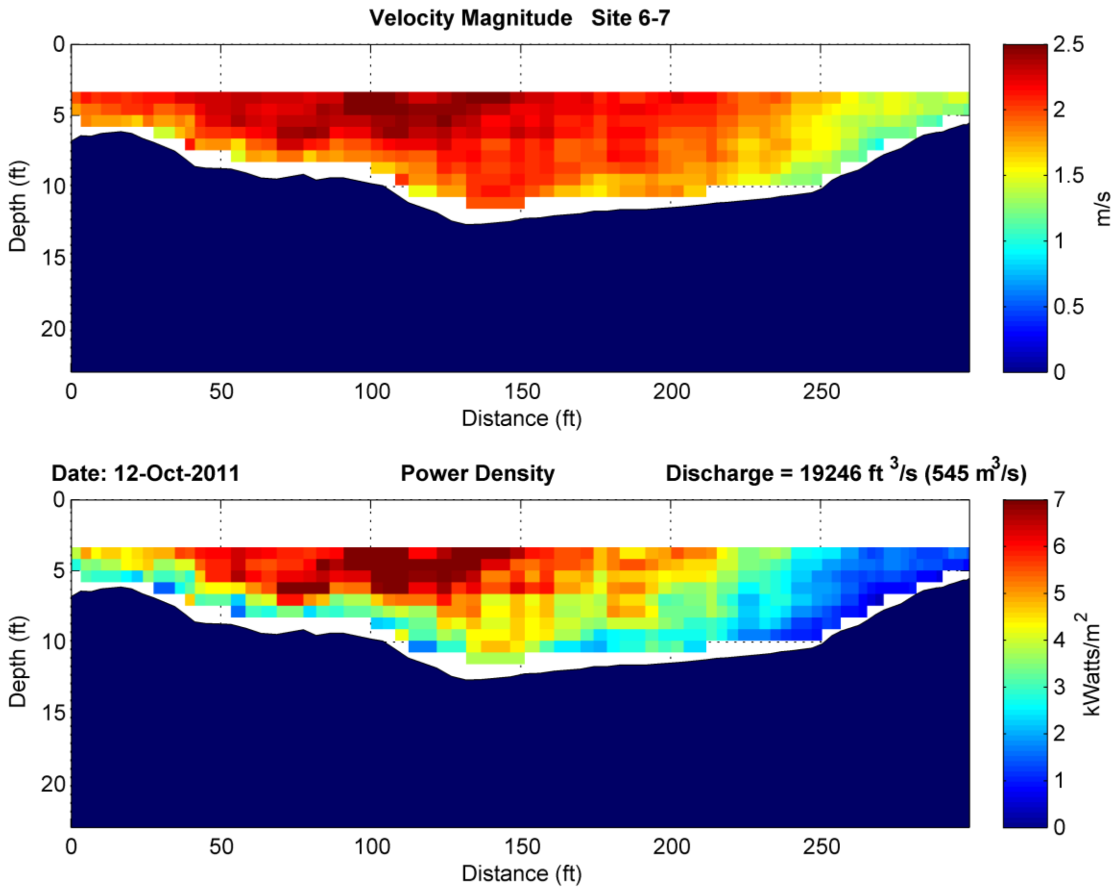

Figure 33 – ADCP transect 6-7.

At Site 6-7 the channel is filled in on the left and continues to be excavated on the right.

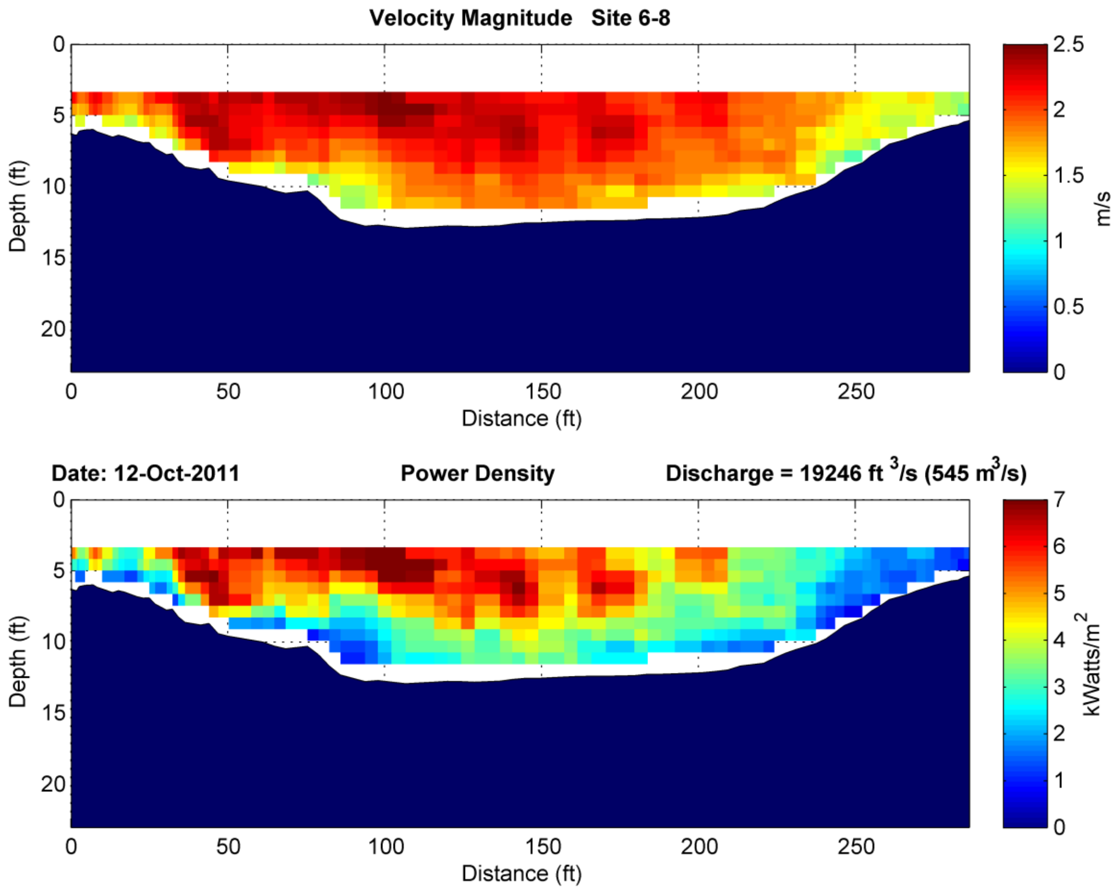

Figure 34 – ADCP transect 6-8.

At Site 6-8 the left side is excavated again and the right side continues to be excavated.

At Site 6-9 the left portion of the channel is filled again and the right side is still excavated. The flat portion of the channel is shifted slightly to right. The elevated energy density still trends to the left of the channel. However it has moved slightly to the right in response to the fill on the left, Figure 35.

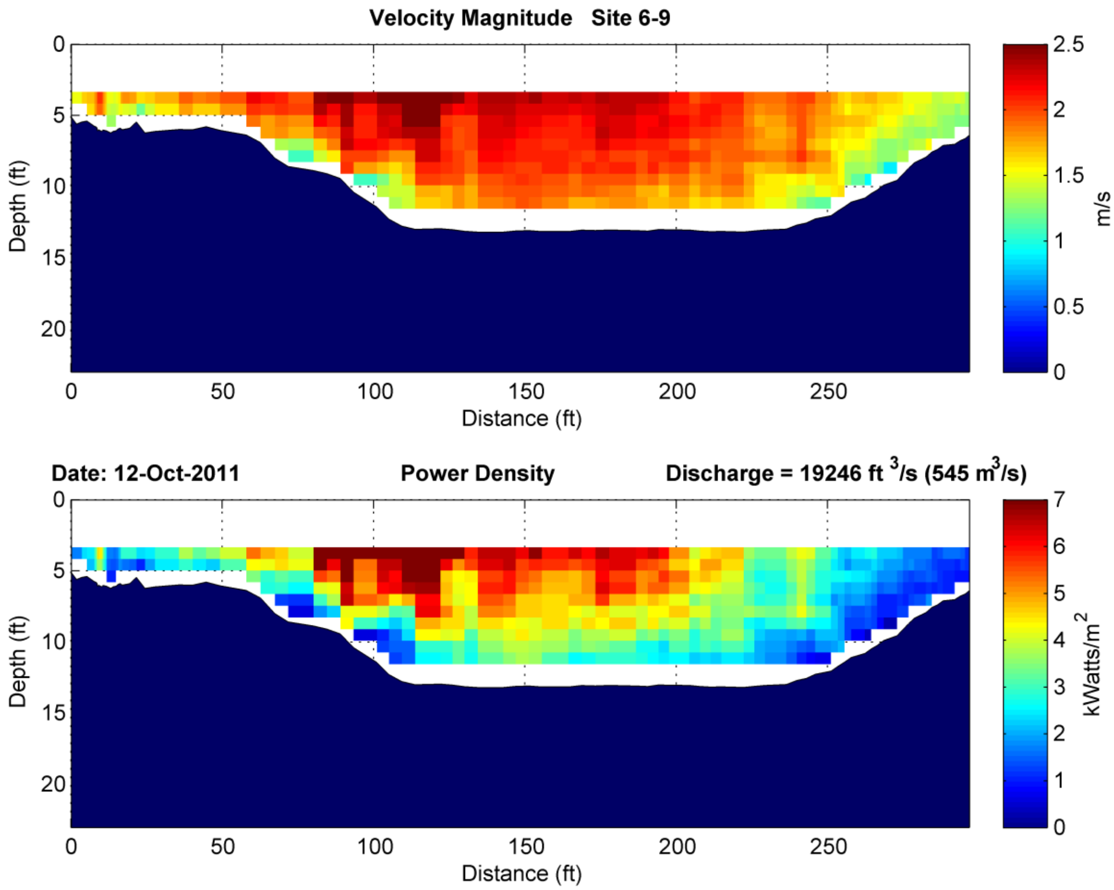

Figure 35 – ADCP Transect Site 6-10.

At Site 6-9 a trapezoidal profile starts to emerge.

The profile at Site 6-10 exhibits a reversal of the previous excavation and fill trend. The left side is substantially excavated and has a very short steep profile. The right side is filled in slightly. The channel profile is dominated by a broad flat section that favors the left side and has a slight dip to the right side. The high energy density zone is expanded over the majority of this broad flat portion of the channel, Figure 36.

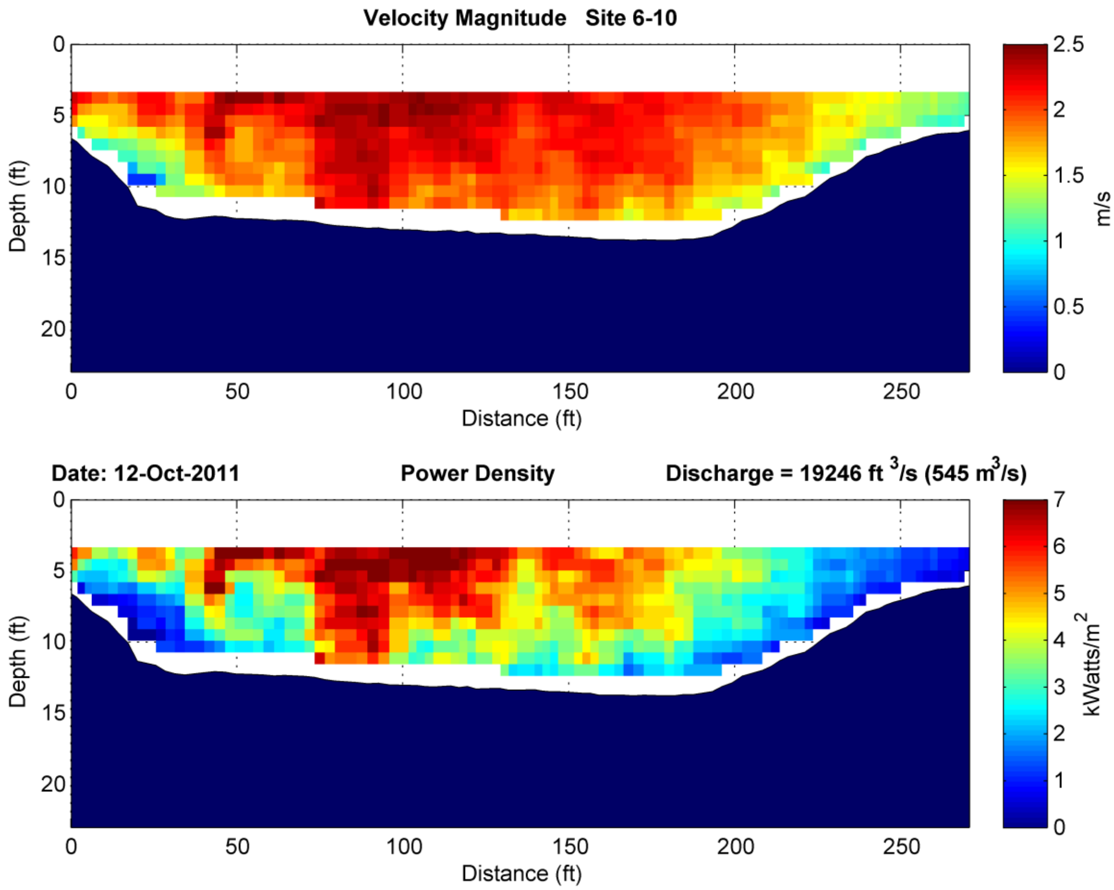

Figure 36 – ADCP transect Site 6-10.

The left side of the channel continues to fill at site 6-11. The channel is developing a profile that has a gradual slope from the left to a low point about 75 m from the left bank. Then there is a steep slope up to the left bank. A more clearly defined thalweg is starting to form on the right side. The elevated energy density zone is in the center of the channel. It appears to be less dense than it was in the upstream profiles, Figure 37.

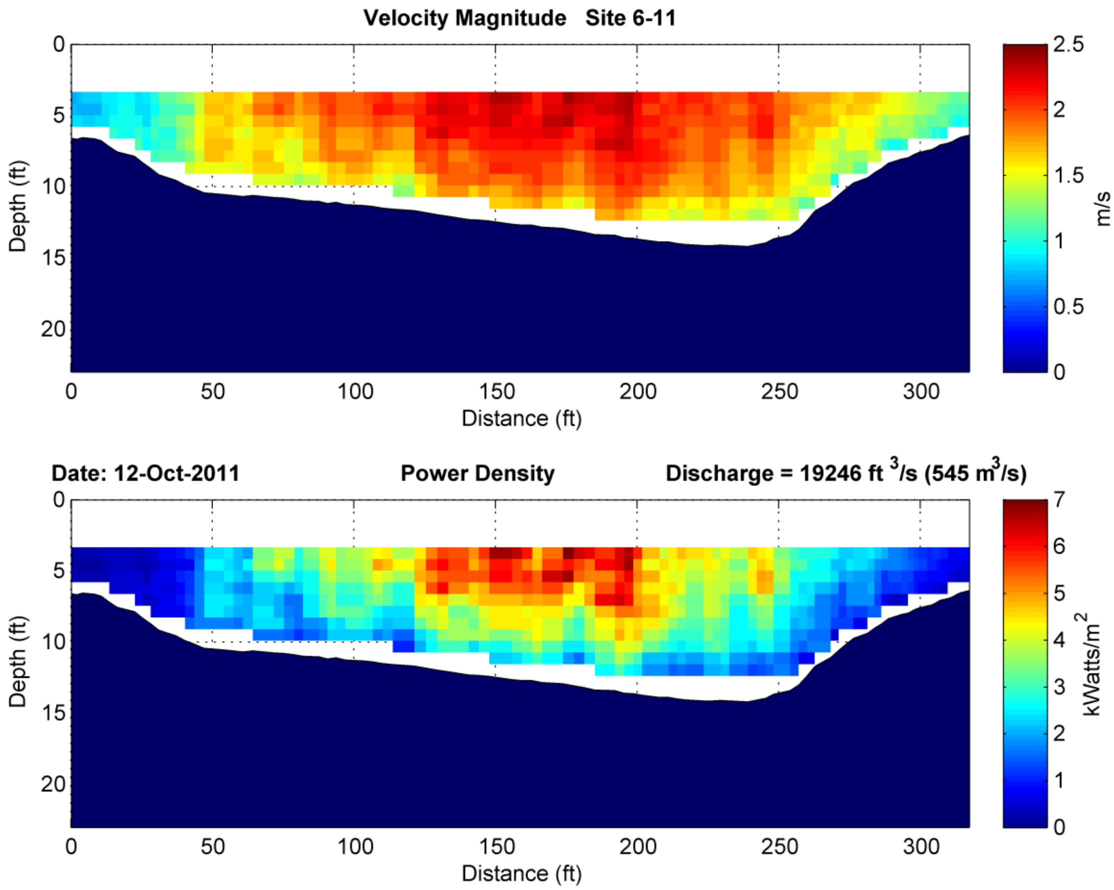

Figure 37 – ADCP transect Site 6-11.

At Site 6-11 the left side starts to fill. This is a harbinger to the inverted profile that emerges in Site 9.

Overall Site 6 offers a stable zone of elevated energy density. The channel is primarily broad and deep. It is close to the current power generation facility and the Fish and Game Boat landing. All three of these features make it a prime candidate site for an electric turbine.

10.2.3.2 Station 9

Station 9 exhibits a stable zone of high energy density that is located in the center of the channel. Even at the lower discharge rate the energy density is between 5 and 7 kW/m^2. The average flow velocities for Station 9 are 1.9, 1.4, 2.0 m/s for each of the successive expeditions, Figures 38, 39, 40.

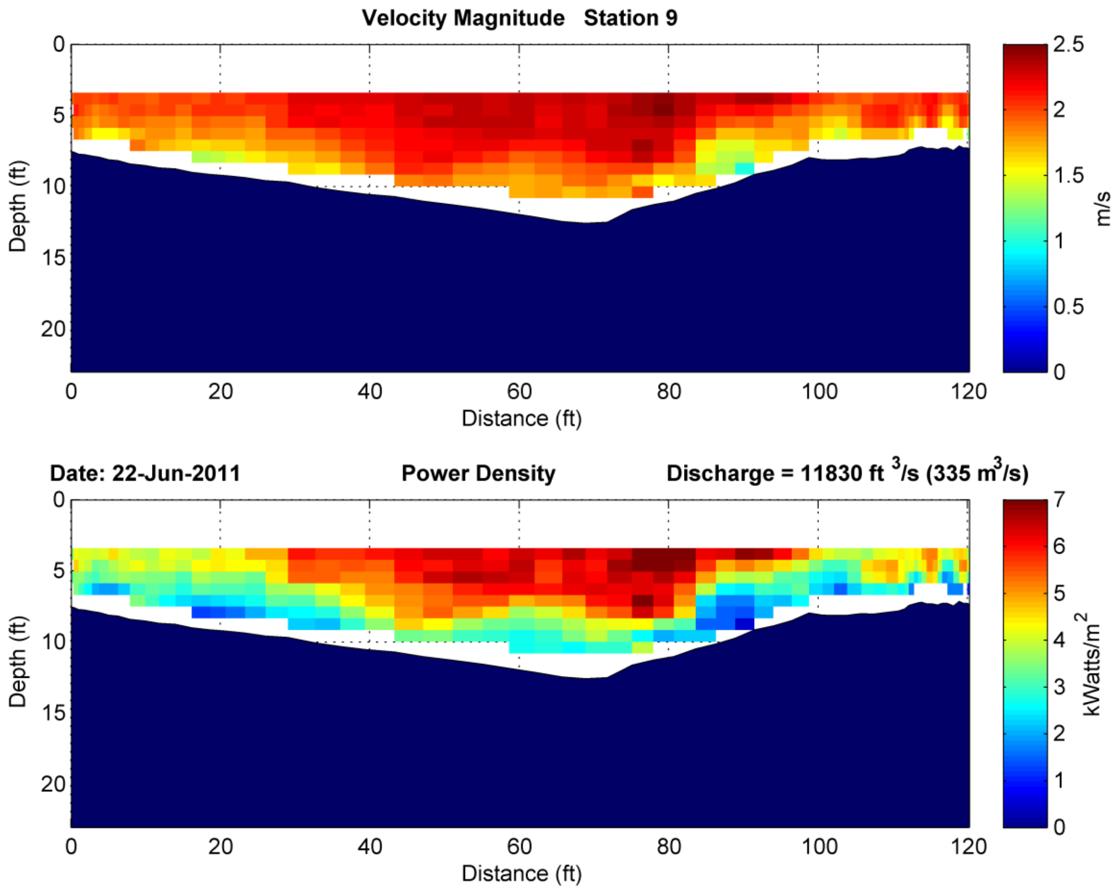

Figure 38 – ADCP transect Station 9 Expedition II.

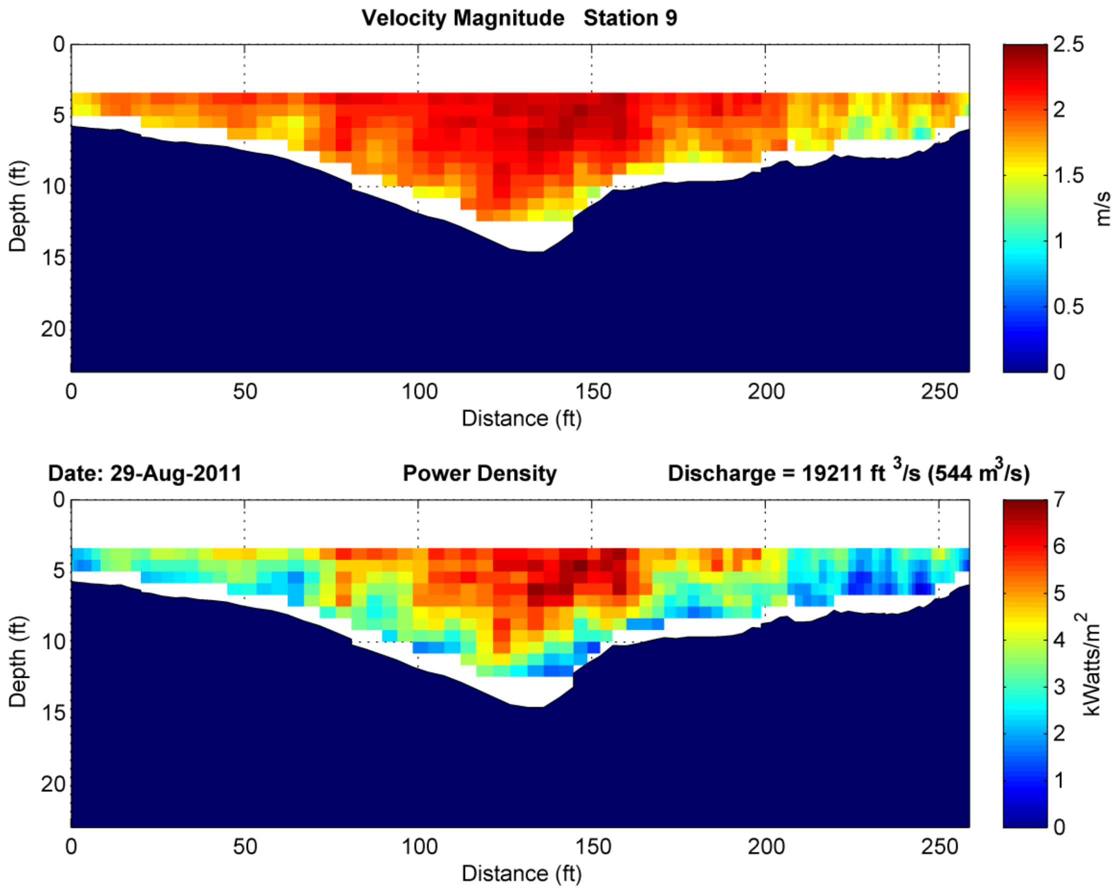

Figure 39 – Station 9 Expedition III.

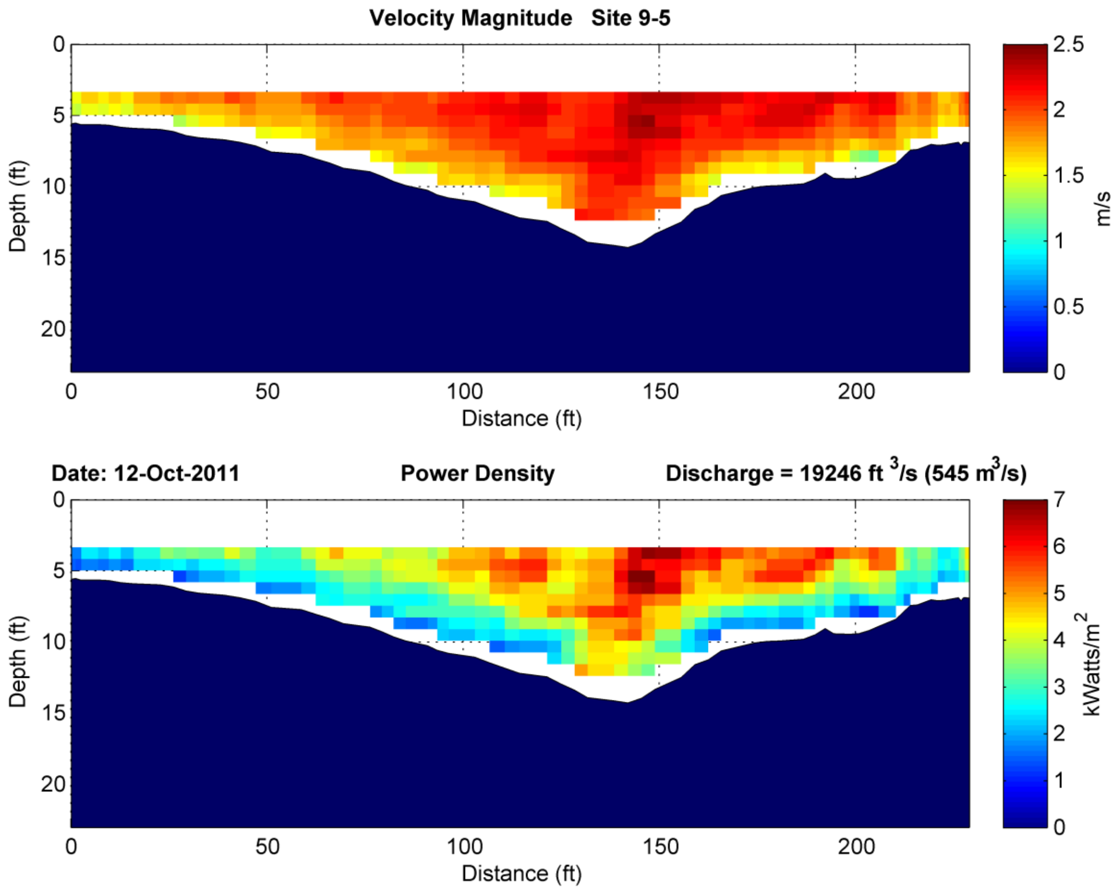

Figure 40 – ADCP Transect Station 9 Expedition IV.

10.2.3.3 Site 9

The reach in the vicinity of Station 9 exhibited a very high energy density at its downstream end. Therefore it was also selected for more detailed ADCP profiling on Expedition IV.

At the upstream end of the reach the thalweg is well defined and roughly centered in the channel. The overall profile of the channel is an inverted triangle, Figures 41, 42, 43. At site 9-1 there is a small elevation of energy density slightly to the right of the thalweg. The channel is progressively excavated on both sides as it goes down stream.

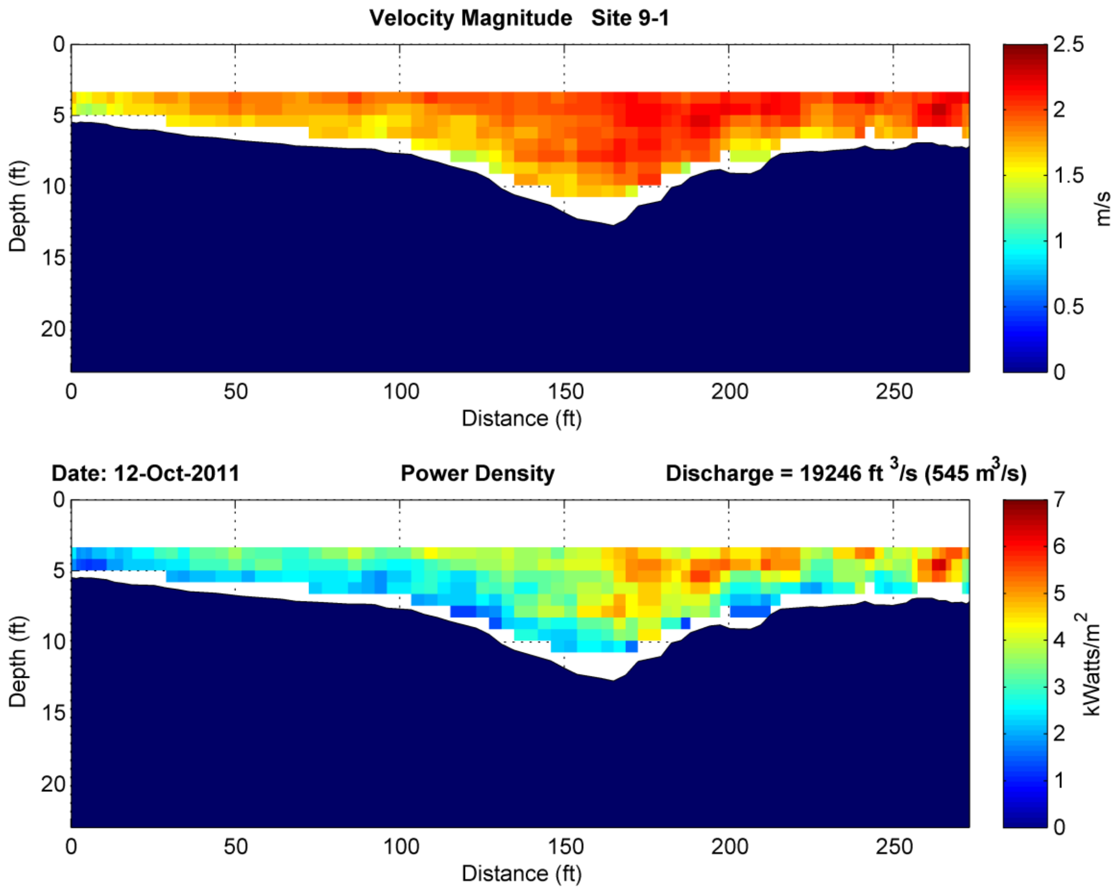

Figure 41 – ADCP transect Site 9-1.

The inverted triangular profile with a central well defined thalweg continues for the first portion of Site 9.

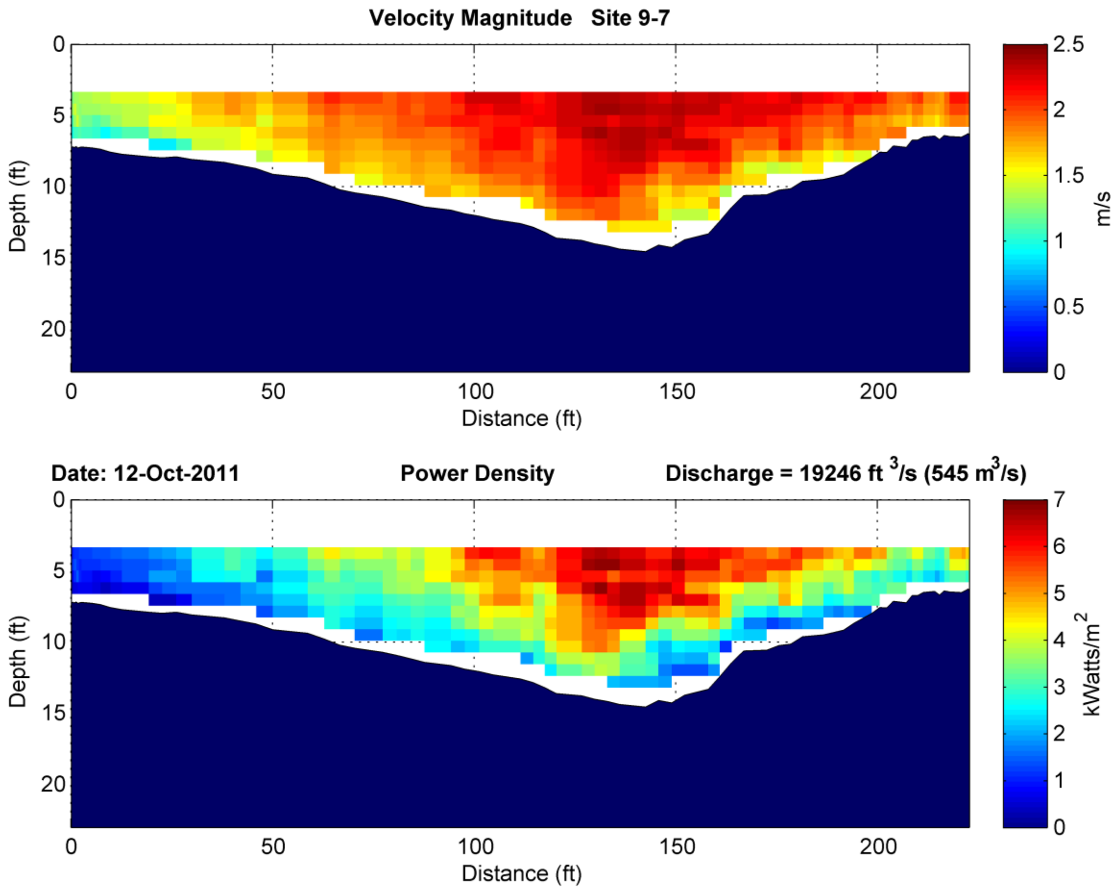

Figure 42 – ADCP transect Site 9-7.

At Site 9-7 the channel begins to open up and move toward a trapezoidal profile.

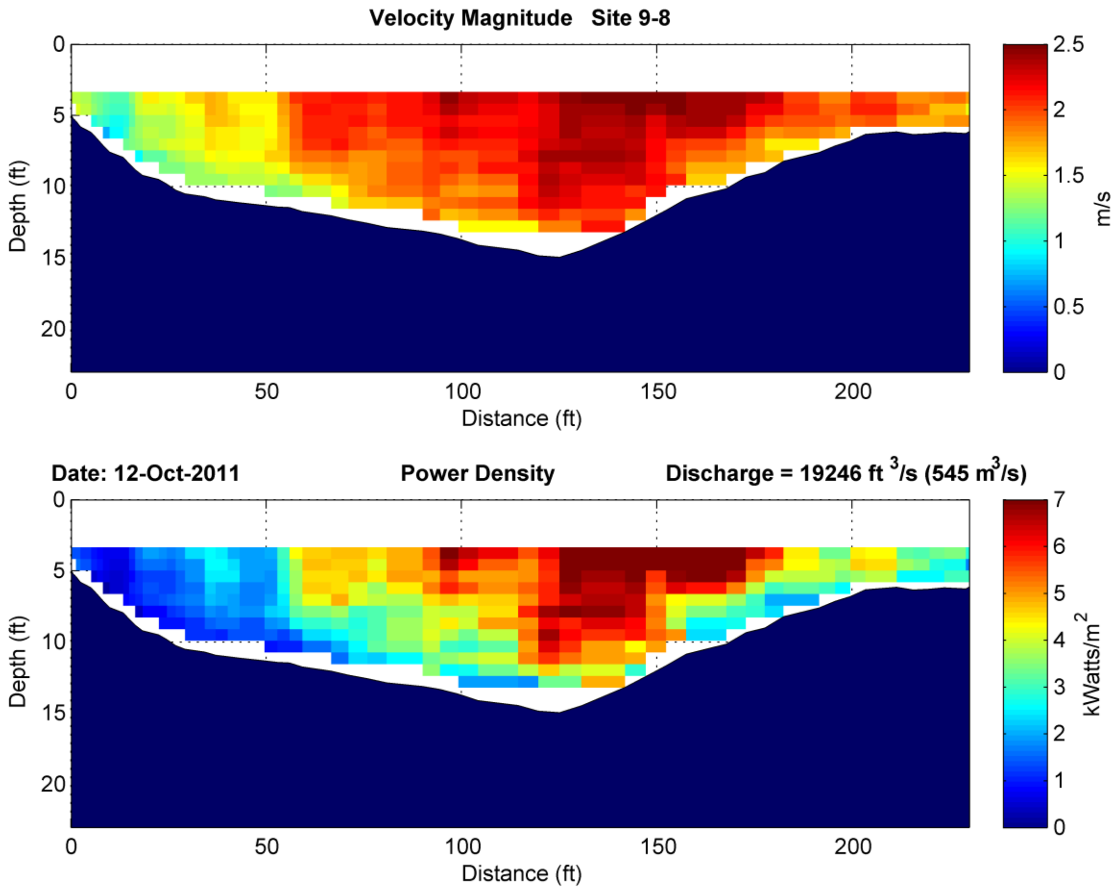

Figure 43 – ADCP transect Site 9-8.

By Site 9-8 the well defined central thalweg starts to give way to a broad flat bottom that rises with steep slopes to the left and right banks, Figure 43. With further progress downstream this zone tends to align with the thalweg and the energy density rises. As the thalweg becomes wider the high energy density zone expands and becomes more intense, Figure 44. By Site 9-10 the high energy zone dominates the right side of the channel. The energy density in the zone is between 5.5 kW/m^2 to 7 kW/m^2, Figure 44.

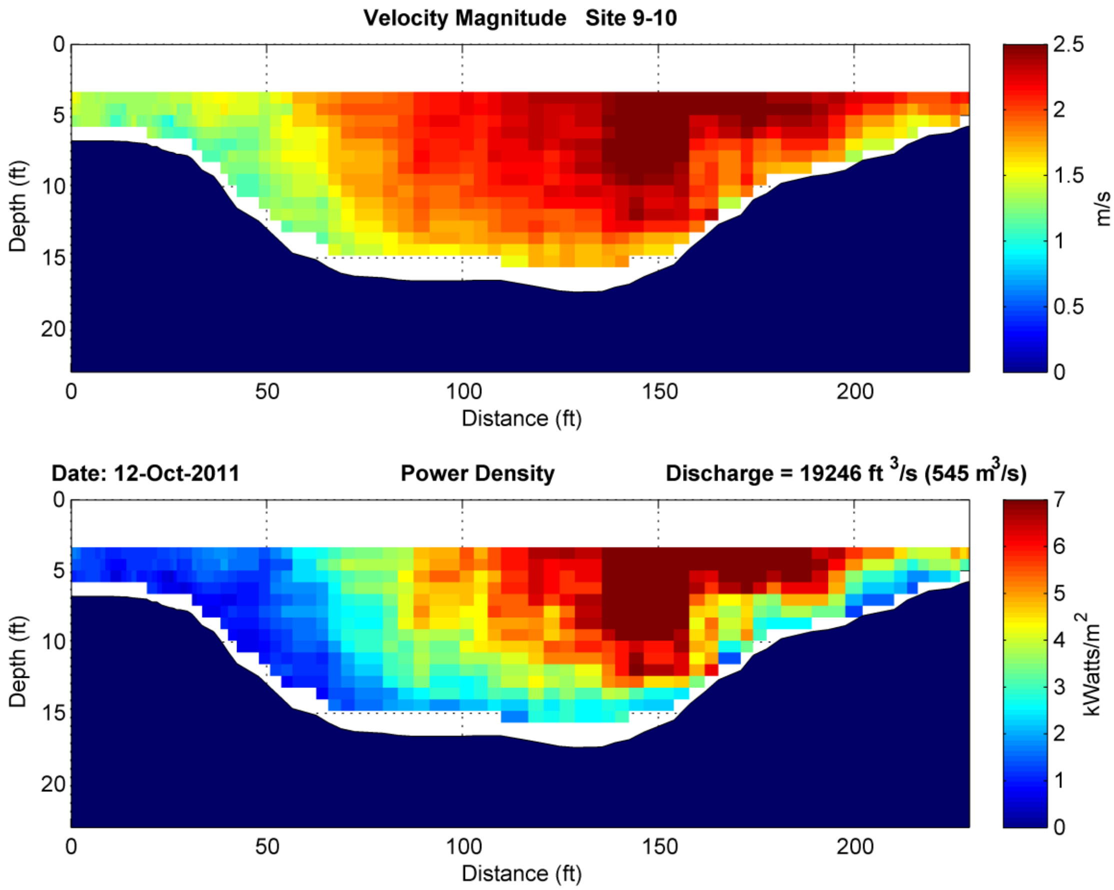

Figure 44 – ADCP transect Site 9-10.

The downstream end of Site nine presents a well-defined zone of high energy density. This zone favors the right bank. The channel is moderately broad. However, it is not as spacious as Site 6.

10.2.3.4 Sites 10 and 11

Site 10 is immediately downstream of Site 9. The first transect of Site 10 is 20 meters downstream of the last transect for Site 9. The transect spacing at Site 10 is 30 meters. There are 11 transects at this site. There is only one transect at Site 11. The characteristics of this transect are not very different from the last transects of Site 10. Indeed it appears to be an additional increment of a trend that started at the end of Site 9 and continues through Site 10.

The morphodynamic and hydrokinetic trends that started at the end of Site 9 continue at Site 10. The channel becomes progressively wider and develops a more open parabolic form. Likewise the zone of high energy density remains in the center and continues to increase, Figures 45, 46. The central zone of high energy density appears to peak between Site 10-3 and 10-5, Figure 46, 47 At Site 10-7 the channel begins to change shape. For the rest of the reach it starts to form a trapezoidal profile.

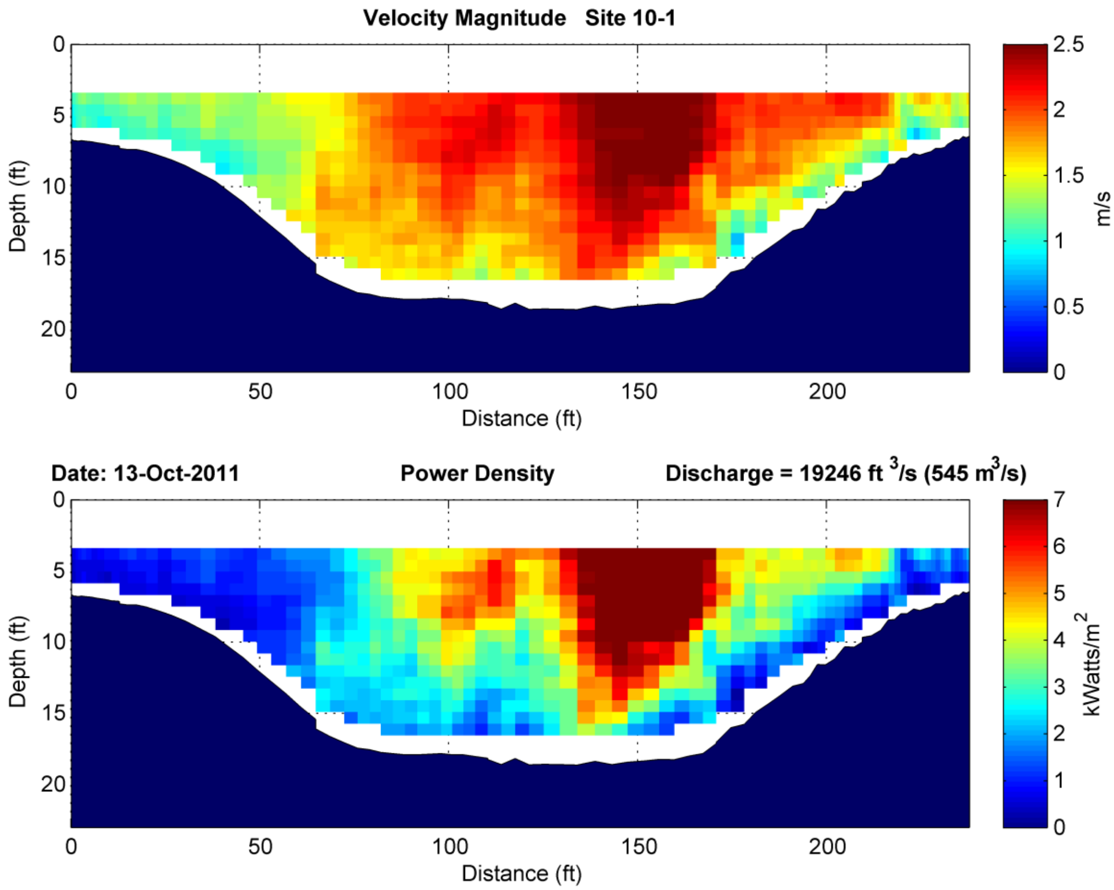

Figure 45 – ADCP transect Site 10-1.

At Site 10-1 the trapezoidal profile is frank.

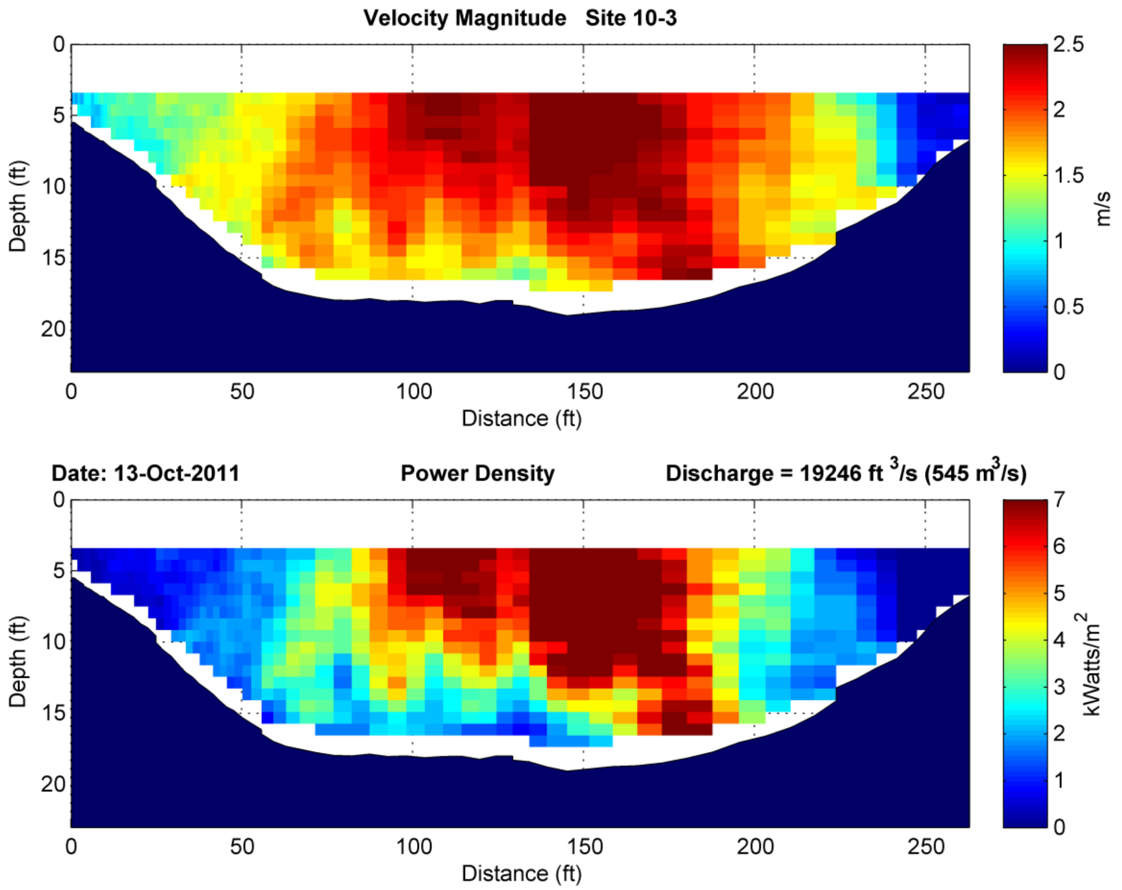

Figure 46 – ADCP transect Site 10-3.

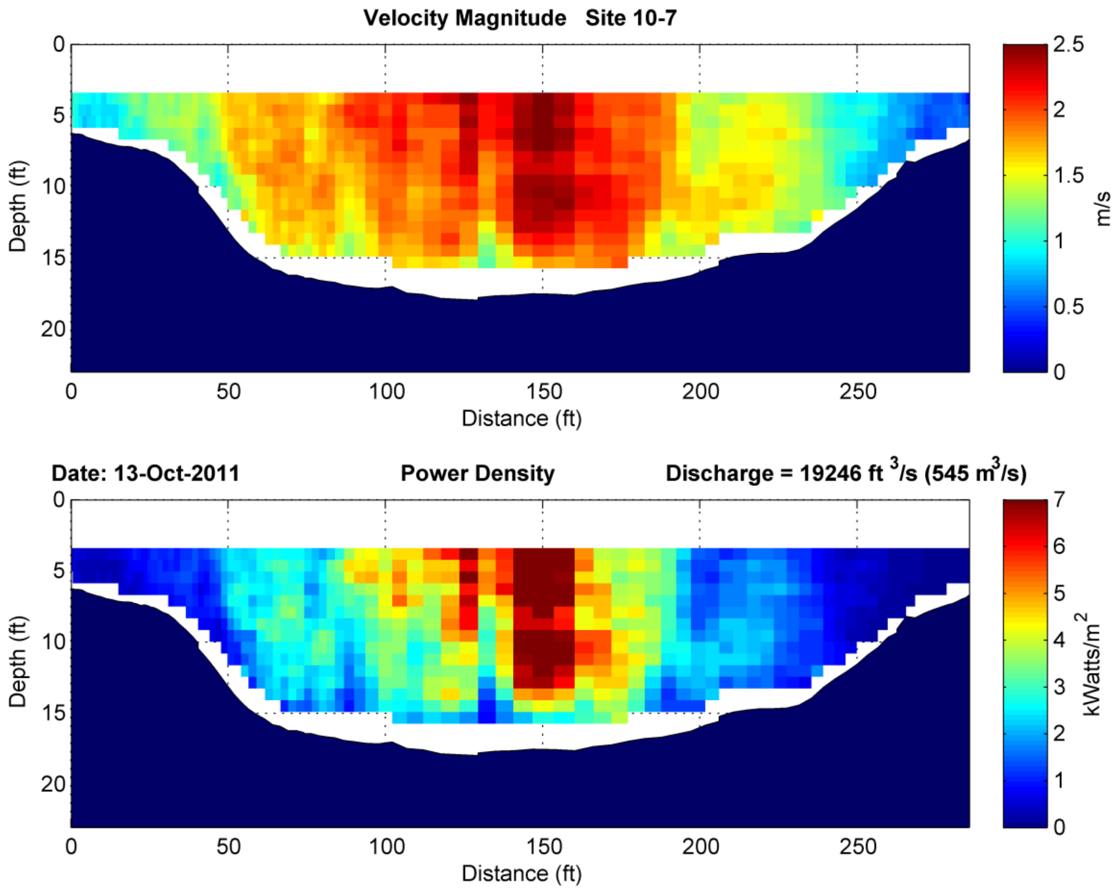

Figure 47 – ADCP transect Site 10-7.

From Site 10-7 to 11-1 there is a gradual filling of the channel coupled with a flattening of the center. At Site 10-8 a trapezoidal profile begins to emerge, Figure 48. By Site 10-10 the channel is a well formed trapezoid, Figure 49. This profile remains to Site 11-1 figure 50. Along this extent of the river the zone of elevated energy density remains in the center of the channel. However, it is diminished.

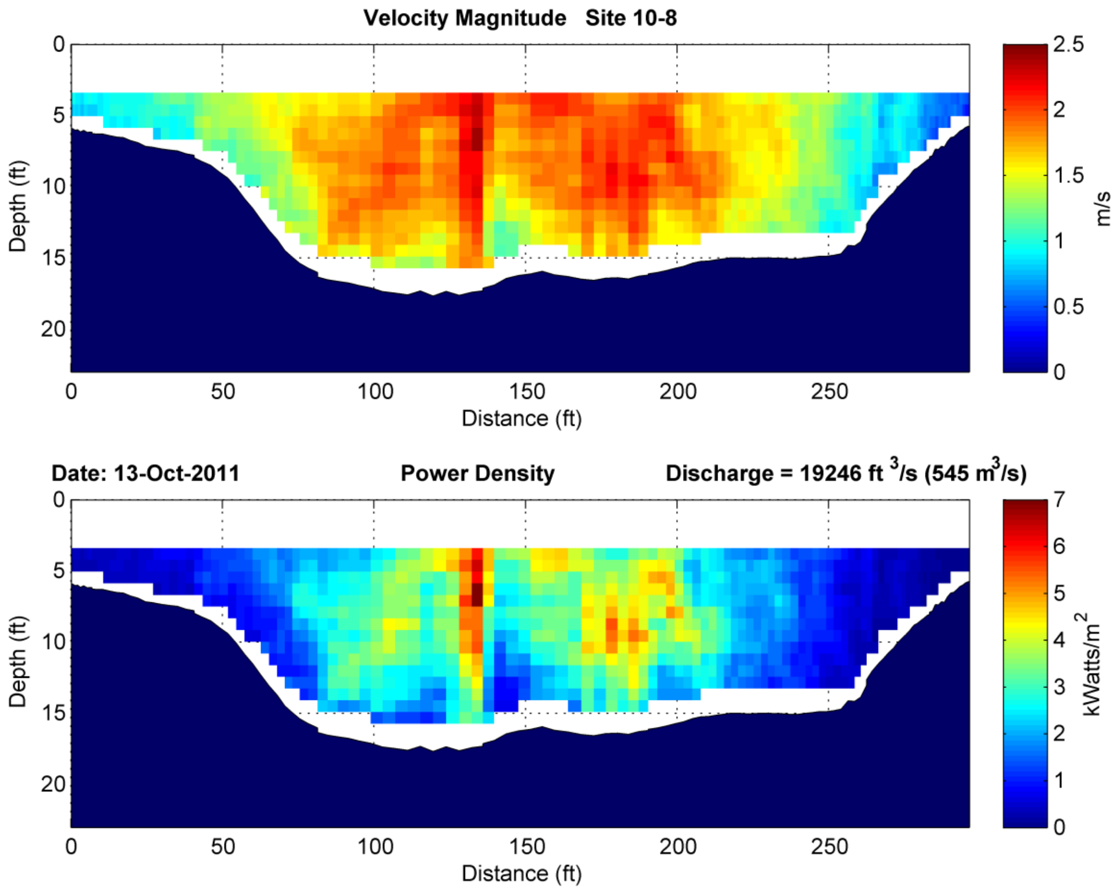

Figure 48 – ADCP transect Site 10-8.

At Site 10-8 the trapezoidal profile remains, however the zone of high energy density is waning.

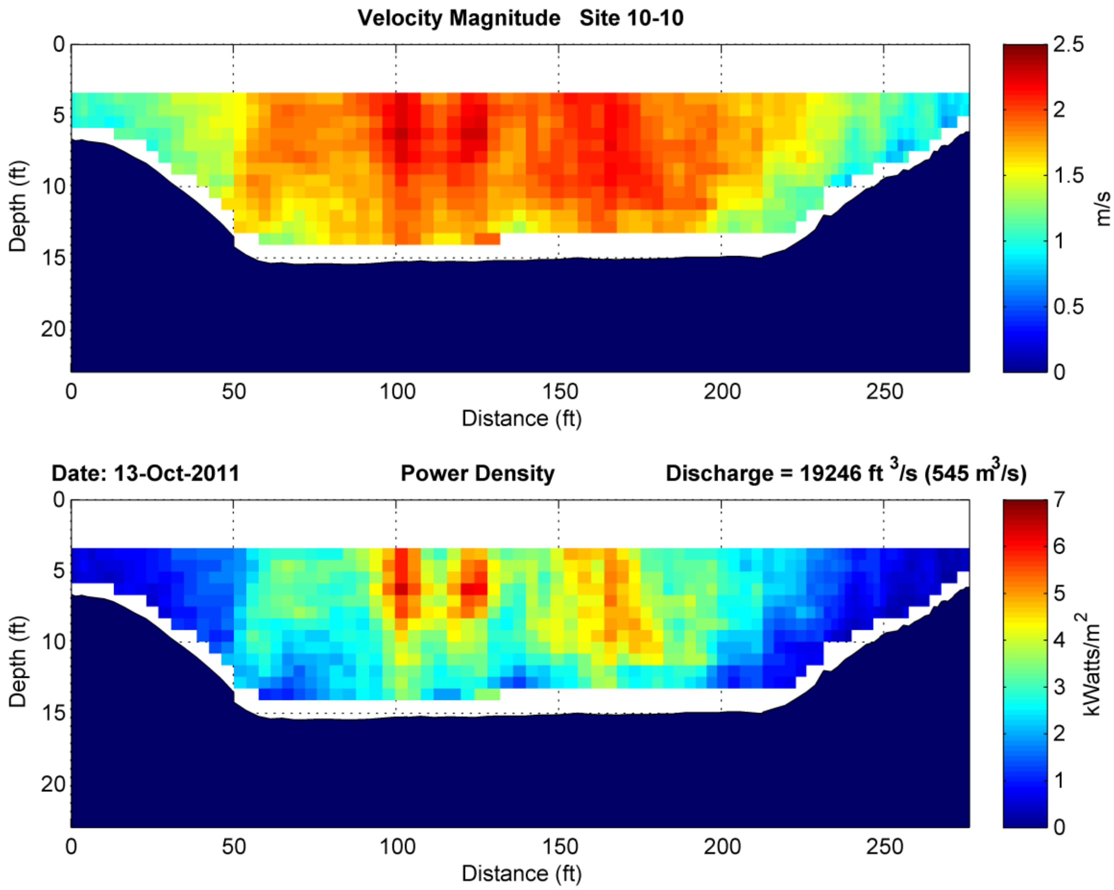

Figure 49 – ADCP transect Site 10-10.

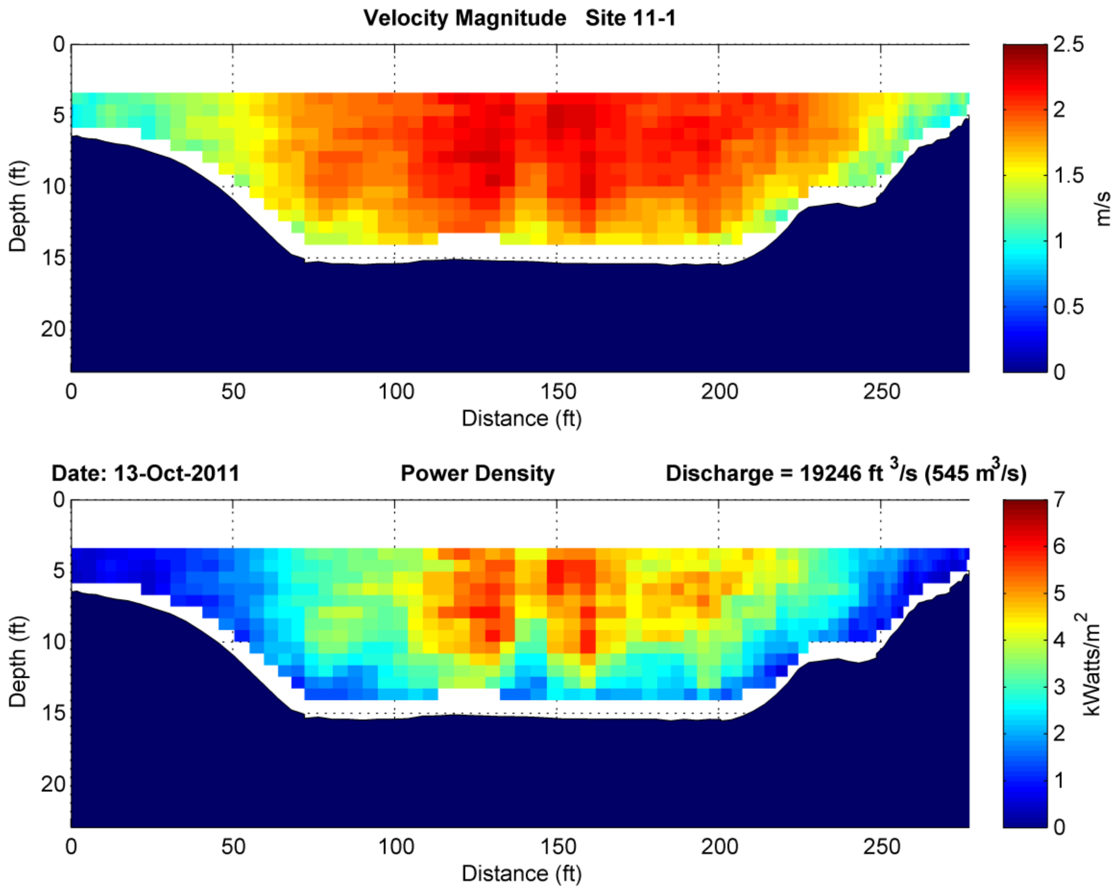

Figure 50 – ADCP transect Site 11-1.

10.2.3.5 Top Section Flow Velocity

The first ADCP measurement bin starts at 75 cm below the surface. This leaves a gap to the surface from the first bin where no velocity data is collected. TRDI's WinRiver II software uses an extrapolation algorithm to estimate the velocity in this area for the purpose of measuring discharger. However, it does not report an estimated flow velocity.

Therefore it was decided to make some measurement of flow velocity in this area with a Marsh-McBirney Flowmate 2000 flow meter. The flow meter was pole mounted on the port side of the boat. The sensor head was placed 61 cm below the water. The boat was navigated across the ADCP transects and held at select positions across the river. Four to five measurements were taken at even spacing across the channel.

The measurements taken during expedition IV are depicted on the map sheets in Appendix 1. The surface velocities were typical for this type of river. Near the banks the velocities tended to be slower than in the middle channel. The values that were reported are roughly the same as those observed in the top bins of the ADCP profile. On some of the transects at Site 10 there is a back eddy by the right bank. At these locations the river flow is reversed. These velocities are reported on the map sheets as (-) values.

10.3 River Bed Findings

An R2Sonic 2024 MBES was used to do a bathymetric survey from about 0.12 km above the mouth to a downstream extend of about 2.7 km. This survey was used to identify dangers to navigation, hazards for construction, and give a detailed picture of the shape of the river bed. The surveyed has been depicted on the included map sheets in Appendix 1

Immediately before the mouth of the river there is a small field of sand waves that tend toward the left bank. On the right a shoal extends from shore into the lake and then continues along the right bank downstream to the vicinity of the Fish and Game Boat Landing. The thalweg develops quickly at the mouth and descends to a depth of about 14 feet. About 1000 feet downstream there is an abrupt rise to 8 feet which is followed a quick drop to 12 feet. The bed slowly rises again to 5 feet in the vicinity of Station 5. Then the river starts a bend to the right and the bed drops once more near Station 6. This time it forms a 10 foot deep thalweg on the right side and there is a shoal that forms on the left by the Fish and Game Boat Landing. The shoal remains on the left and extends into the channel on the left side of the first island. On the right side the bed rises again to 2 feet and starts to curve left. At the approach to Site 9 the river narrows and a sharp central thalweg forms. In the downstream half of Site 9 there is rapid drop to 18 feet. This feature has come to be called "*The Chute.*" *The Chute* opens into Site 10. Here the channel fills and takes on a trapezoidal profile. It continues downstream with the same profile as the bed slowly rises to 10 feet just beyond Site 11.

Numerous dangers to navigation, (DtoN) and hazards for construction, (HforC) have been identified in the bathymetric surface. In this report a DtoN is defined as any object with a volume greater than 1 m^3 that rises to within 4 feet, (1.22 m) of the water surface. The DtoN's in the Kvichak River include numerous boulders and the various shoals. The DtoN's are depicted on the accompanying map sheet in Appendix 1. The map sheet also has a table of coordinates for all of the DtoN's. The HforC's are presented on the accompanying map sheets. There is also a table of coordinates for the HforC's. In this report a HforC is defined as any bottom object that is greater than 1 m^3, and extends more than 3.3 feet, (1 m) feet above the bed.

The bed materials of the Kvichak River appear to be quite stable with respect to the short term. No moving bed was detected with the ADCP. The collected bed samples consisted primarily of larger forms that were predominantly in the range of gravel and cobbles. Nonetheless this does not obviate the fact that the river is very energetic. It also has a constant source of material in the lake and along the banks. Further, ice enters the river from the lake each year. This ice could dislodge bed material and create strong localized areas of scour. Therefore, while the river bed may appear more stable than many other rivers, it is still important to keep all manners of sediment transport in mind when considering construction designs for the banks and the river bed.

The river morphology of the Kvichak was well characterized by the 2011 bathymetric survey. The upper Kvichak River along the Village of Igiugig has a significant bend (approximating a 90º bend) in the river with a non-uniform alveus for most of the range along the project area. Statements from village residents and evaluation of historical maps and aerial photographs indicate that the Kvichak River has experienced significant change within recent recorded history. Of particular note, the zone constituting the bend in the river across from the Fish and Game Boat Landing has changed dominant flow regimes several times within the last 70 years. The cross-sectional peak flow within the river may also shift significantly throughout this portion of the river. TerraSond interprets that the thalweg is not stable, particularly distinct, nor well confined geomorphologic body within this river structure. Persistent geologic formations are not constraining this river, and it is believed that the Kvichak River can be expected to demonstrate change over time. Several areas of the river appear to be more static and persistent than the bend noted above. In particular, the opening to Lake Iliamna and the stretch after the bend appear to demonstrate more persistent behavior.

10.4 Tie of Current Survey Data to USGS Gage

The field crew could not locate any of the USGS gaging station RM’s or associated equipment. Given the field search, and consultation with the USGS and the local community it is highly probable that all of these items have been lost. Therefore, it is not possible to make a sound physical tie to the original USGS gaging station. Nonetheless a coarse relationship has been established using current ADCP discharge measurements, RTK GPS water level observations, and the USGS rating curves. The USGS data is several decades old. However, it is the best data record available for this site. The river dimensions and climatology have changed. The relationships that are developed in the following sections are at best tenuous extrapolations. These relationships are not intended to replace a current and complete hydrologic study. They are an attempt to use past data as a means to gain insight into the hydrologic characteristics of the river. Great care should be exercised if this data is used for any design development and analysis.

The USGS Gaging Site 15300500 was established at Igiugig on the Kvichak River on 15 June 1967. It was operational until 1987. The methods used at the time were published in Techniques of Water-Resources Investigations of the United States Geological Survey, Chapter A8, *Discharge Measurements at Gaging Stations*, Book 3, Applications of Hydraulics, 1969. During this time they did 39 discharge measurements. The USGS used these measurements to establish a set of rating curves for the site. There were two sets of RM’s used for the river gage height. Both sets of RM’s originated from an assumed arbitrary value. By coincidence the values selected for both references were close. The first set was used for measurements 1 to 16. Measurements 17 to 39 were completed using the second set of RM’s. The exact date that the USGS switched RM’s is not certain. It was most likely sometime between discharge measurement 16 and 17. These measurements took place on 28 September 1970, and 24 March 1971. There was no mention in the USGS station records of a level loop being done to tie the two sets of RM’s together. Nonetheless the USGS appears to have adjusted the gage heights for discharge measurements 8 to 16 and carried them forward to the later rating curves, Figure 51.

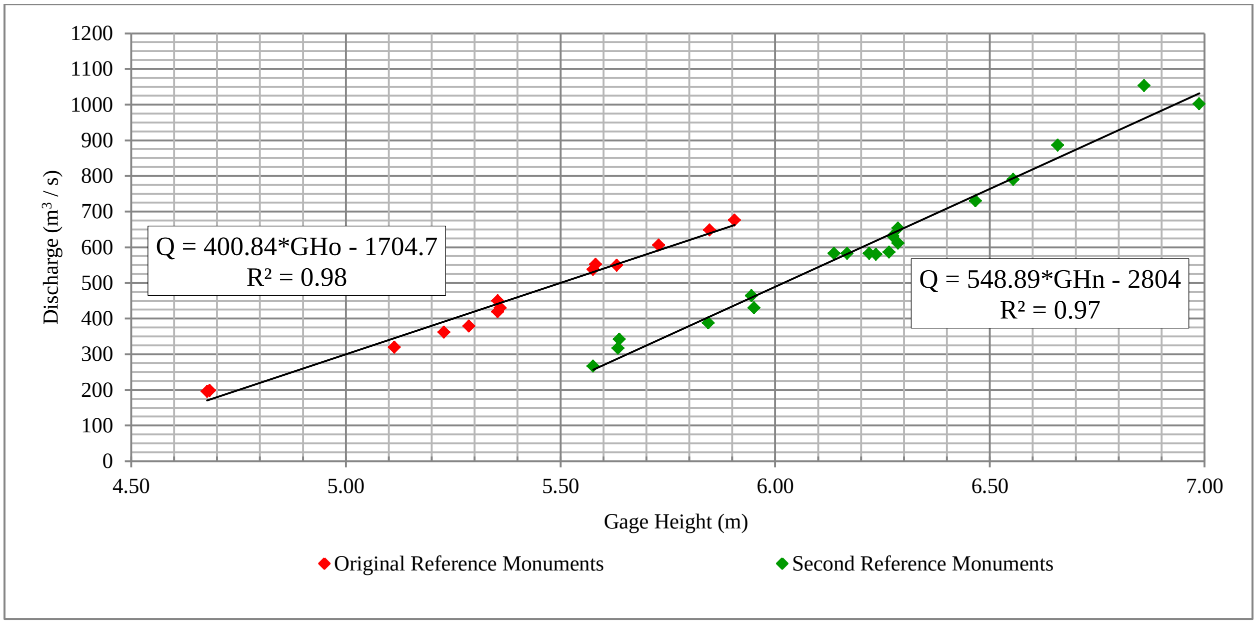

Figure 51 – USGS discharge versus gage height with respective regressions.

A relationship between the KRIGIPVD11 datum and the original USGS rating curve was established using two current river levels and ADCP discharge measurements. Three ADCP discharge measurements were completed for this project. RTK GPS observations were made in close temporal proximity to the ADCP discharge measurements. The timing of these measurements was sufficiently close to allow a reasonable assumption to be made that the river level was not significantly changed from the level at the exact time of the ADCP discharge measurements. The first ADCP discharge that was used for establishing the relationship to the USGS rating curve was done on 21 June 2011, and the second was done on 12 October 2011. The measured discharge on 21 June was 335 m^3/s and the observed ellipsoid height of the water surface was 25.90 m. On 12 October the measured discharge was 545 m^3/s, and the ellipsoid height of the water surface was 26.44 m. These discharges were plotted on the original USGS rating curve to determine the corresponding USGS gage heights. The USGS gage heights for the two discharge values were 16.95 feet, (5.17 m), and 18.50 feet, (5.64 m). The offsets between the report USGS stages and the ellipsoid height of the water were 20.73 meters, and 20.78 meters, respectively. The average of these two values was taken to be a standard offset between a given ellipsoid height and the USGS gage height for the original set of RM's. This value was 20.76 meters. Thus the corresponding current ellipsoid height for any given USGS gage height value on the original curve was estimated by adding 20.76 meters to the gage height. This sum was compared to 25.00 meters to determine where the particular stage was with respect to the KRIGIPVD11 datum. For example, an original USGS gage height of 6.00 m would correspond to a water surface ellipsoid height of 26.76 m. The water surface level would be 1.76 m above the KRIGIPVD11 datum.

Discharge measurements 1 to 16 tended to cover the lower discharge values. The higher discharges were covered by the later measurements that used the second set of RM's. Slightly less than 1/5 of the USGS measured discharges overlapped. These values were clustered around the overall average measured discharge, Figure 51. Therefore, if the analysis of stage and discharge required for this report was going to be based on a complete range of reported discharges a means of referencing the two sets of measurements had to be developed. This was done by applying a conformal transformation to map gage heights from the domain used for the second set of measurements to the domain used for the original set of measurements.

Six of the USGS discharge measurements were omitted from the calculations to reference the two sets of measurements. Measurement two was removed because the USGS did not use it for the development of their original rating curve. This measurement appeared to be an erroneous outlier. Measurement three was also an apparent outlier. Measurements 23, 24, 35, and 39 did not have complete information in the USGS field notes. The remaining measurements were used as reported by the USGS.

The second set of gage heights were transformed to correspond with the first set. This was done by first determining a linear regression model for each set of values. Then the two regression models were set equal to each other, Figure 51, equations 10.1a, b, c.

EQN 10.1a $Qo = Mo\ GHo + Io$

EQN 10.1b $Qn = Mn\ GHn + In$

EQN 10.1c $Mo * GHo + Io = Mn * GHn + In$

Where: Qo and Qn = respective river discharges in m^3/s.

Mo and Mn = the slope of the regression line for the original gage and the second gage heights.

GHo and GHn = the original and second reported gage heights in meters.

Io and In = the intercept values for the original and second gage heights.

Equation 10.1c was manipulated to derive an expression that transposed the second set of gage heights to the regression of the original gage heights, equation 10.1d.

EQN 10.1d $\Delta GHi = \frac{Mn * GHn - Io + In}{Mo} - GHn$

Where: ΔGHi = the i^{th} gage height shift from the second set of gage heights to the gage heights with respect to the regression equation for the original set of gage heights.

The slopes of the two regression lines are not parallel. It was desirable to retain the full character of the second set of discharge measurements after they were transformed. Simply applying Equation 10.1d would not have accomplished this. It would have only expressed the transformed gage heights as dictated by the regression equation of the original discharge data. In order to preserve the full character of the second set of discharge measurements the mean of all values given by Equation 10.1d was computed. This mean shift was applied to the gage heights reported for the second set of discharge measurements. Thus the gage heights were transformed conformally. This is confirmed by demonstrating that the slope of the regression for the transformed discharge data is parallel to the first regression, Figure 52.

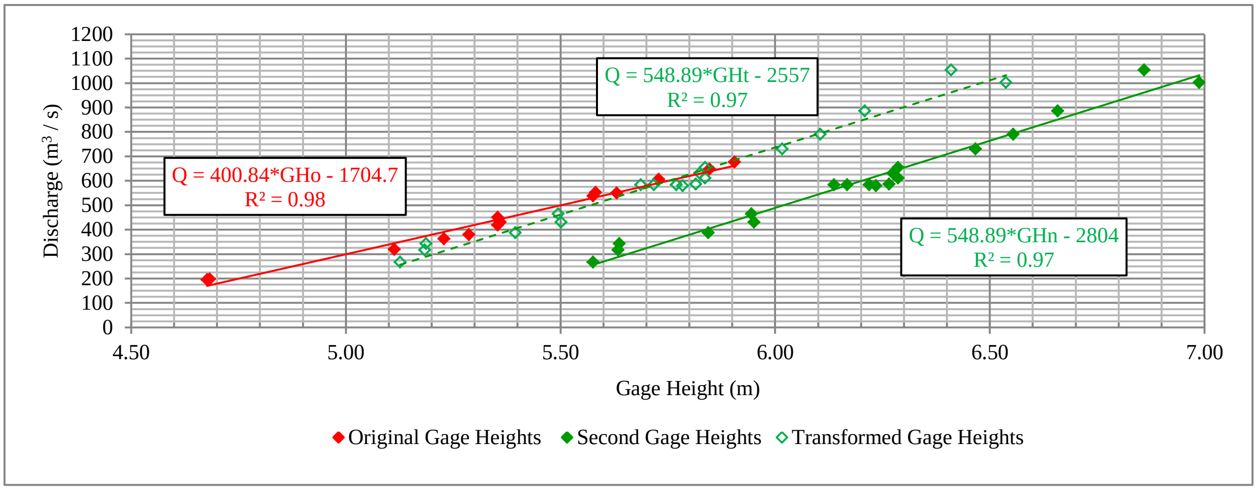

Figure 52 – Regression of USGS discharge measurements.

The USGS gage heights of the first discharge measurements and transformed gage heights were unioned to form a single set. This set was then regressed with respect to the gage heights, Figures 52, 53.

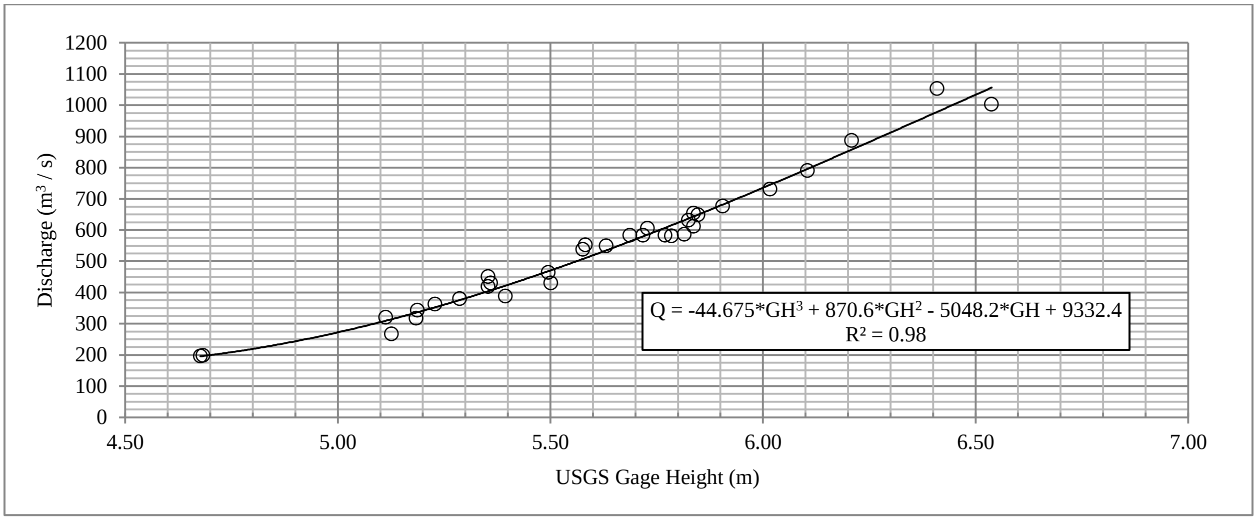

Figure 53 – Regression of combined and transformed USGS discharge measurements.

The combined data was regressed to several forms. The best fit was achieved with a third order polynomial, Equation 10.2.

EQN 10.2 $Q = -44.675*GH^3 + 870.6*GH^2 - 5048.2*GH + 9332.4.$

The relationship between the USGS gage height and the KRIGIPVD11 datum was derived from the comparison of discharge measurements and the USGS original rating curve. This was applied to the combined gage height data set to develop a regression of discharge as a function of height above the KRIGIPVD11 datum, Figure 54.

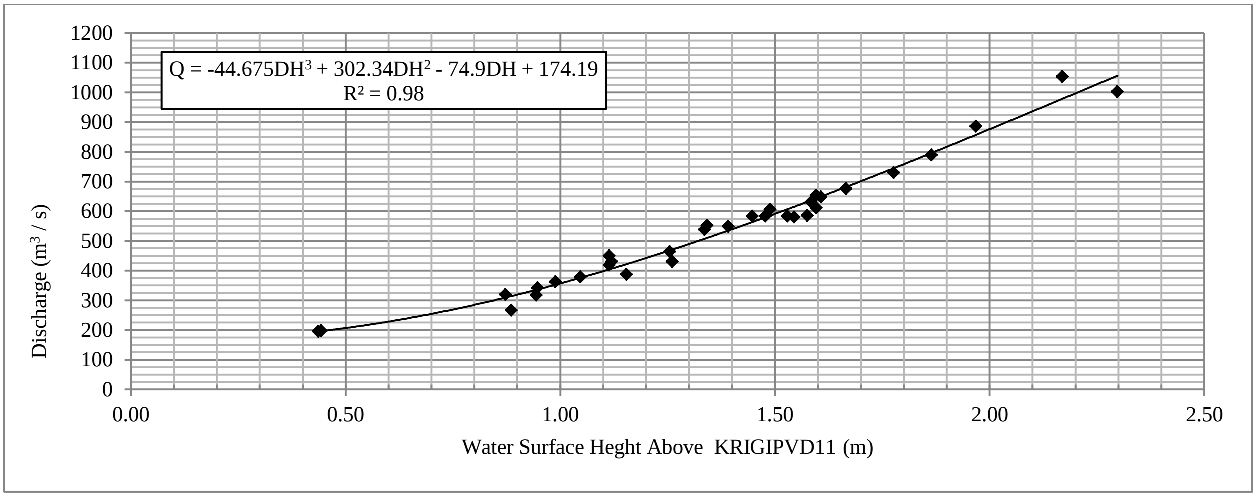

Figure 54 – Regression of discharge with respect to water surface height above the KRIGIPVD11 datum.

This regression gave the following polynomial equation.

EQN10.3 $Q = -44.675*DH^3 + 302.34*DH^2 - 74.9*DH + 174.19$

Where: DH = water surface height above the KRIGIPVD11 datum

The USGS estimated the average flow velocity for the channel cross section as part of their discharge measurements. This data was regressed to an exponential form that expressed discharge as a function of velocity, Figure 55 Equation 10.4.

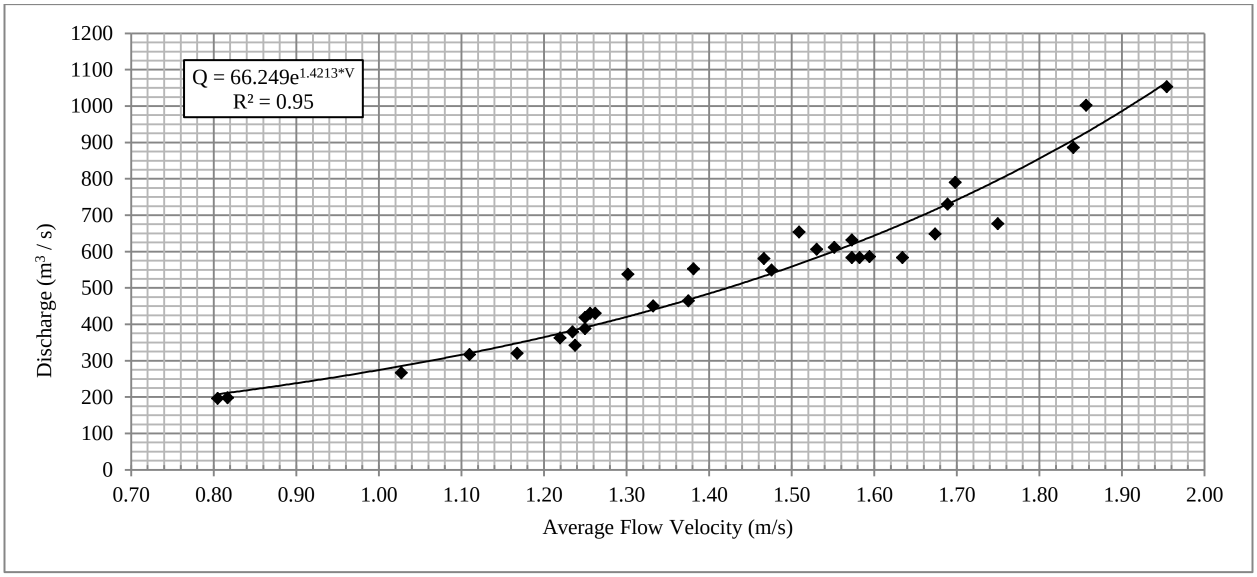

Figure 55 – Regression USGS discharge with respect to average cross section flow velocity.

EQN 10.4 $Q = 66.249 * e^{1.4213*V}$

Where: e = base of the natural logarithm
V = average cross sectional flow velocity in m/s

The relationship between height above the KRIGIPVD11 datum and discharge was used for a regression to a power law equation to express average flow velocity as a function of height above the datum, Figure 56, Equation 10.5.

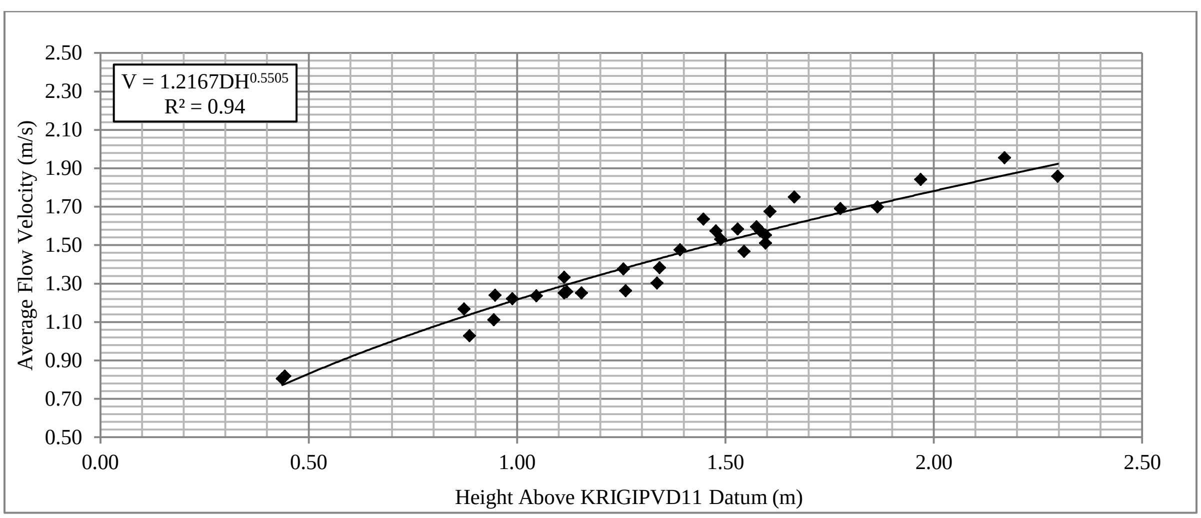

Figure 56 – Regression of flow velocity with respect to height above the KRIGIPVD11 datum.

EQN 10.5 $V = 1.216*DH^{0.5505}$

The USGS used their rating curve and gage height to produce daily estimates of discharge. They issued values for everyday from 1 January 1968 to 1 January 1987. The above regression equations were applied to this data to produce plots of discharge versus flow velocity, and height above the KRIGIPVD11 datum, Figures 57, 58.

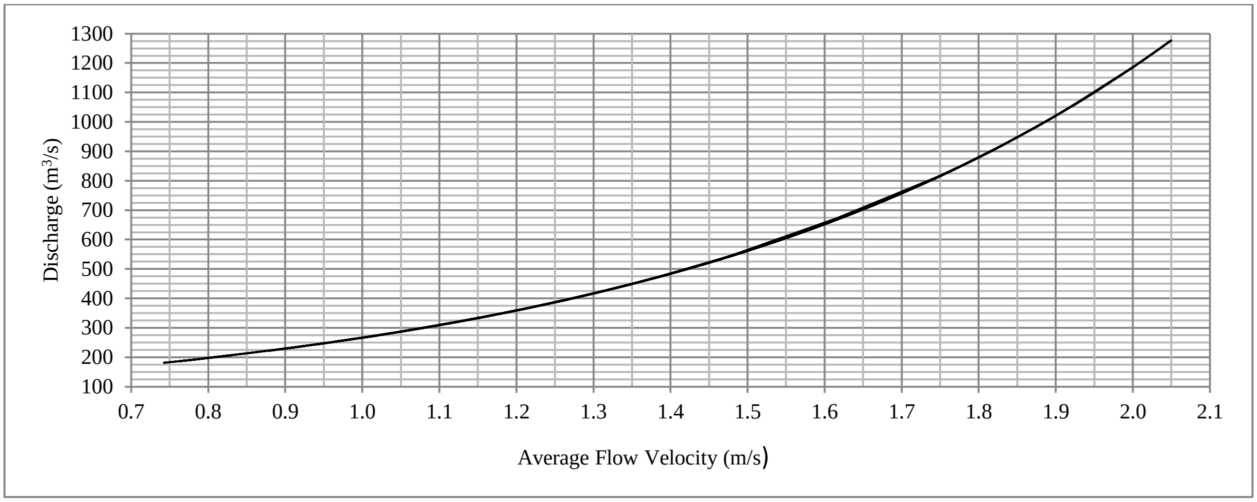

Figure 57 – Full record plot of USGS discharge as a function of mean flow velocity.

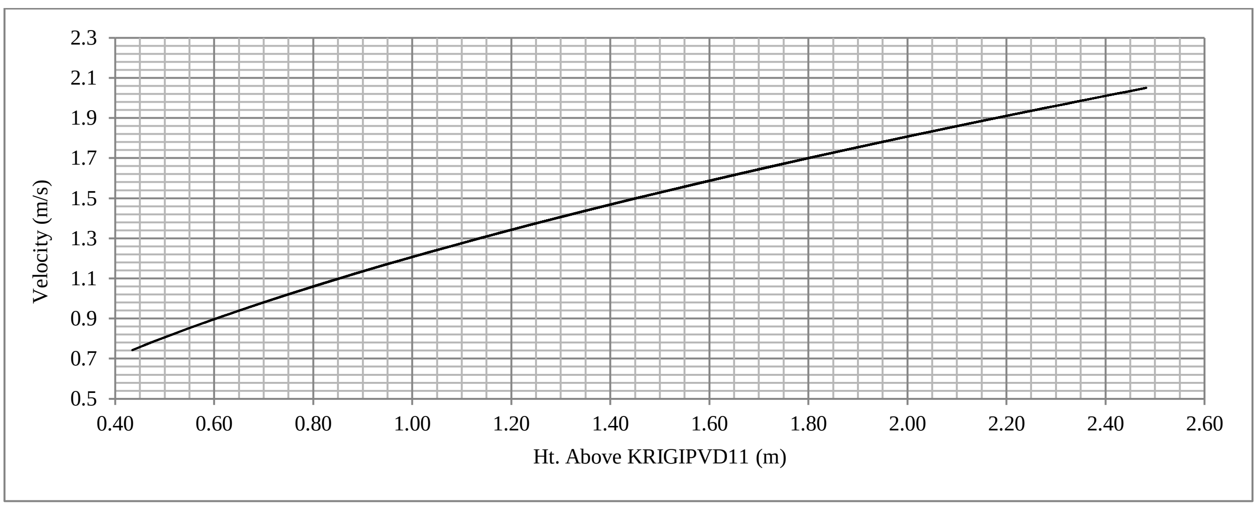

Figure 58 – Full record plot of USGS flow velocity and a function of height above the KRIGIPVD11 datum.

The published USGS discharge data was used to complete a return period analysis using the Log-Pearson Type III distribution as outlined in *Guidelines For Determining Flood Flow Frequency*, Bulletin #17B of the Hydrology Subcommittee, Interagency Advisory Committee on Water Data, USGS, 1982. Once the discharge return events were determined the relationships between discharge, and flow velocity and height above the KRIGIPVD11 datum developed for this report were used to create an expression for the corresponding return periods with respect to these parameters, Figure59, Equations 10.6a, 10.6b.

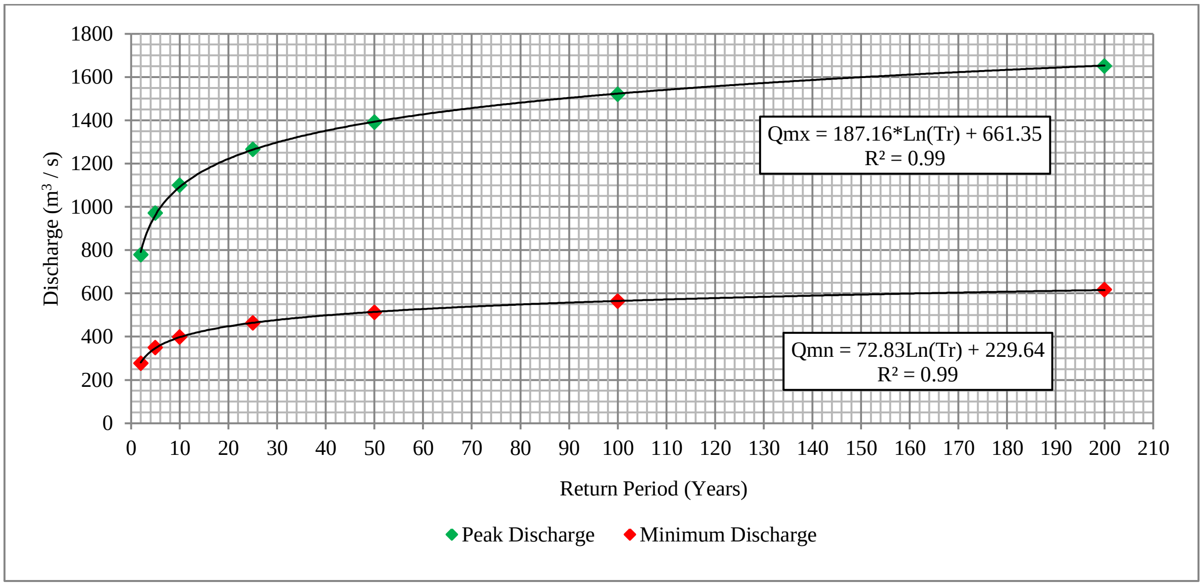

Figure 59 – Plot of discharge return period for the Kvichak River at Igiugig.

Equation 10.6a and 10.6b give an empirical expression for the discharge as a function of return period.

EQN 10.6a Return period for annual maximum discharge

Qmx = 187.16*Ln(Tr) + 661.35

EQN10.6b Return period for annual minimum discharge

Qmn = 72.83Ln(Tr) + 229.64

Where: Qmx = annual maximum discharge for a given return period

Qmn = annual minimum discharge for a given return period

Tr = return period in years

A return frequency analysis was developed for height above the KRIGIPVD11datum and average flow velocity. These were computed by applying the previously developed relationships to the discharge return analysis, Figures 60, 61.

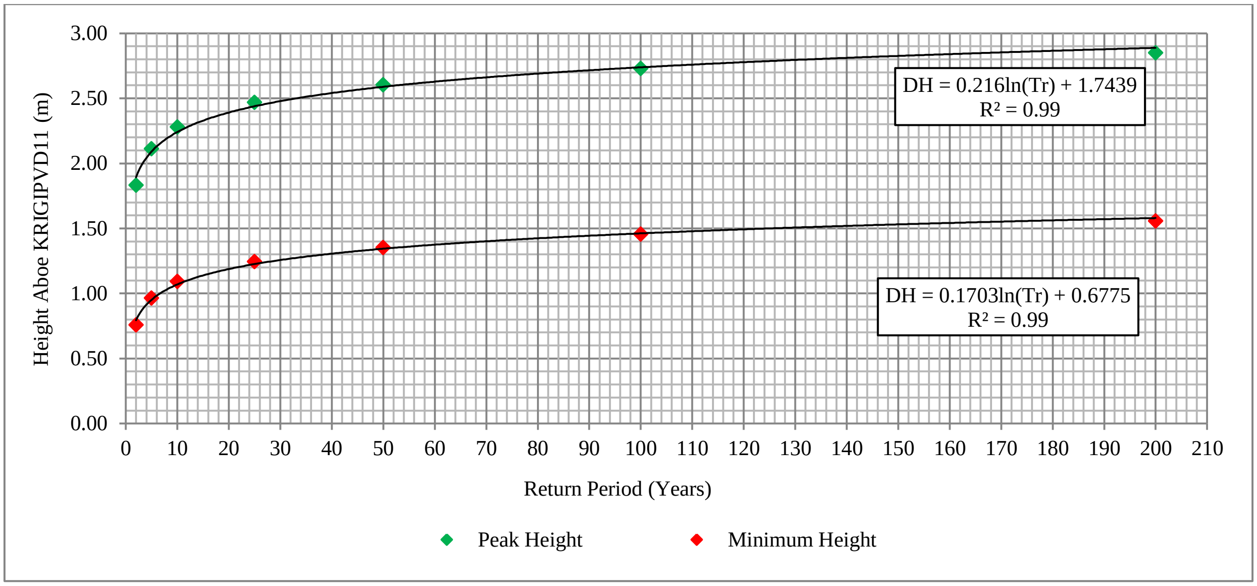

Figure 60 – Plot of return period for height above the KRIGIPVD11 datum the Kvichak River at Igiugig.

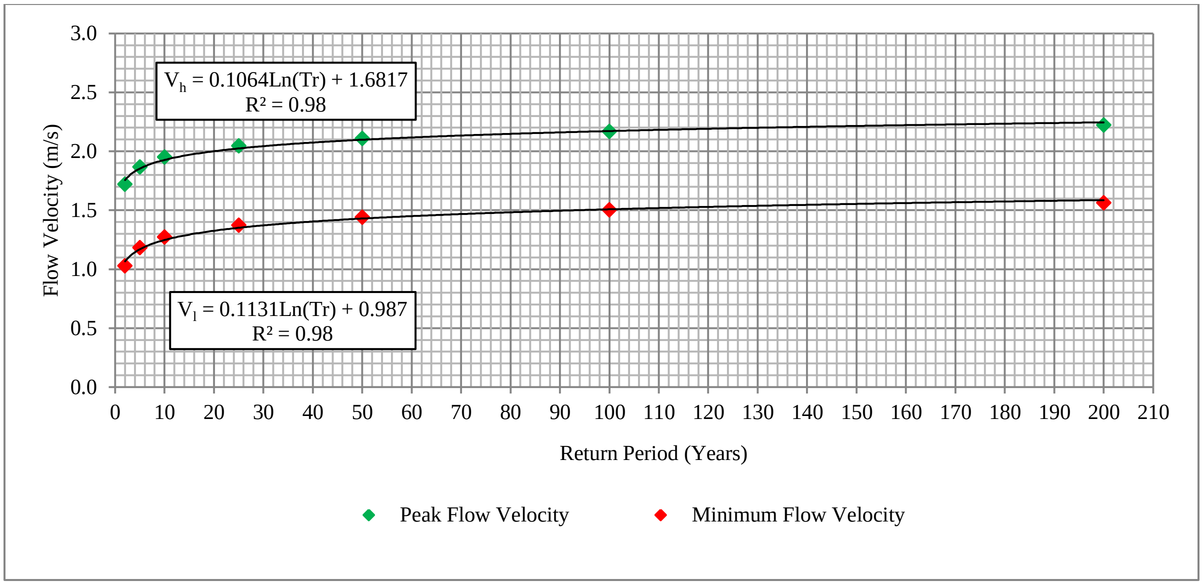

Figure 61 – Plot of the return period for mean flow velocity for the Kvichak River at Igiugig.

The following regression equations give an expression height above the KRIGIPVD11 datum and flow velocities for a given return period.

EQN 10.7a $DH_h = 0.216*Ln(Tr) + 1.7439$

EQN 10.7b $DH_l = 0.1703*Ln(Tr) + 0.6775$

EQN 10.7c $V_h = 0.1064*Ln(Tr) + 1.6817$

EQN 10.7d $V_l = 0.1131*Ln(Tr) + 0.987$

Where: The subscripts h and l refer to the respective high or low of the given parameter.

Figures 62 and 63 depict the flow velocities and height above datum as determined by applications of the respective regressions to the full record of USGS daily discharge values.

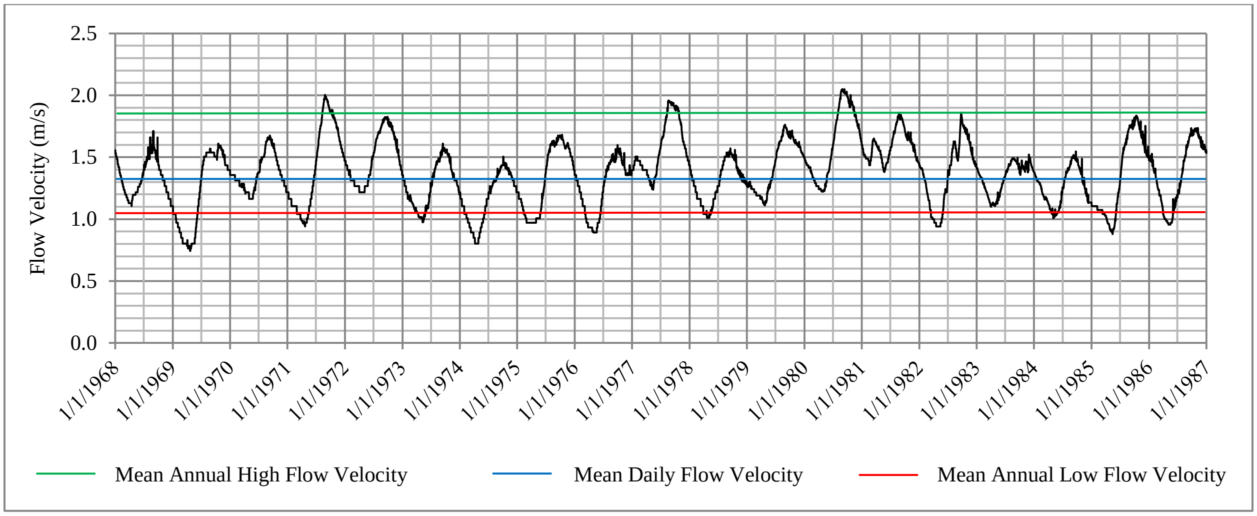

Figure 62 – Daily flow velocities.

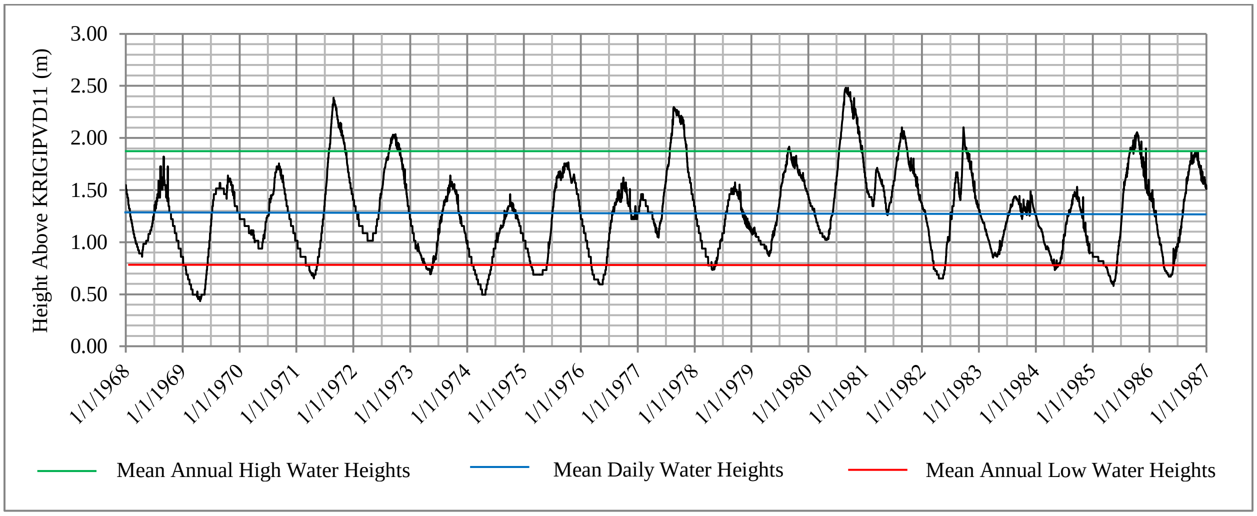

Figure 63 – Average Daily height above KRIGIPVD11 Datum.

Some key parameters that were determined from the preceding regressions are summarized in the following tables.

Year	Date	Q (m^3/s)	V (m/s)	Ht. (m)	Rank	Exceedance Probability
1981	2/21/1981	510	1.43	1.35	1	0.05
1977	4/26/1977	399	1.27	1.09	2	0.10
1980	4/19/1980	371	1.22	1.02	3	0.15
1972	4/21/1972	368	1.22	1.01	4	0.20
1970	5/27/1970	362	1.21	1.00	5	0.25
1979	4/23/1979	314	1.11	0.87	6	0.30
1968	4/14/1968	311	1.11	0.86	7	0.35
1983	4/2/1983	309	1.10	0.85	8	0.40
1984	5/4/1984	271	1.01	0.74	9	0.45
1978	4/25/1978	269	1.01	0.73	10	0.50
1973	5/9/1973	256	0.97	0.69	11	0.55
1975	4/9/1975	255	0.97	0.69	12	0.60
1986	5/17/1986	249	0.96	0.67	13	0.65
1971	4/22/1971	244	0.94	0.65	14	0.70
1982	5/15/1982	244	0.94	0.65	15	0.75
1976	5/1/1976	227	0.89	0.59	16	0.80
1985	5/14/1985	222	0.88	0.58	17	0.85
1974	4/27/1974	198	0.80	0.50	18	0.90
1969	4/21/1969	181	0.74	0.43	19	0.95
	Mean	293	1.04	0.79		
	Std Dev 1σ	81	0.17	0.23		
	Median	269	1.01	0.73		

Table 8 – Summary of annual minimum discharge.

Summary of USGS annual minimum discharge and computed flow velocity, Water level height above KRIGIPVD11, and exceedance probabilities. Q = discharge, V = mean flow velocity, Ht = height above KRIGIPVD11 datum.

Return Period (Years)	Q (m^3 / s)	V (m/s)	Ht (m)
2	278	1.03	0.76
5	350	1.18	0.97
10	399	1.27	1.09
25	463	1.37	1.24
50	513	1.44	1.35
100	564	1.50	1.46
200	617	1.56	1.56

Table 9 – Summary of minimum discharge return periods.

Summary of return periods for annual minimums for Kvichak River at Igiugig. Q = discharge, V = mean flow velocity, Ht = height above KRIGIPVD11 datum.

Year	Date	Q (m^3/s)	V (m/s)	Ht (m)	Rank	Exceedence Probability
1980	9/12/1980	1277	2.05	2.48	1	0.05
1971	8/27/1971	1192	2.00	2.39	2	0.10
1977	8/27/1977	1104	1.95	2.28	3	0.15
1981	8/24/1981	963	1.86	2.10	4	0.20
1982	9/24/1982	963	1.86	2.10	5	0.25
1985	10/12/1985	929	1.84	2.06	6	0.30
1972	9/23/1972	912	1.82	2.03	7	0.35
1979	8/31/1979	833	1.76	1.92	8	0.40
1986	11/8/1986	799	1.74	1.87	9	0.45
1968	8/29/1968	770	1.71	1.82	10	0.50
1975	9/17/1975	731	1.68	1.76	11	0.55
1970	9/15/1970	714	1.66	1.73	12	0.60
1969	10/17/1969	663	1.61	1.64	13	0.65
1973	9/14/1973	663	1.61	1.64	14	0.70
1976	9/30/1976	651	1.60	1.62	15	0.75
1978	9/17/1978	626	1.57	1.57	16	0.80
1984	9/7/1984	578	1.52	1.48	17	0.85
1974	10/4/1974	566	1.51	1.46	18	0.90
1983	8/24/1983	555	1.49	1.44	19	0.95
	Mean	815	1.73	1.86		
	Std Dev 1σ	213	0.17	0.31		
	Median	770	1.71	1.82		

Table 10 – Summary of annual maximum discharge.

Summary of USGS annual maximum discharge and computed flow velocity, Water level height above KRIGIPVD11, and exceedance probabilities. Q = discharge, V = mean flow velocity, Ht = height above KRIGIPVD11 datum.

Return Period (Years)	Q (m^3/s)	V (m/s)	Ht (m)
2	778	1.72	1.83
5	971	1.87	2.11
10	1101	1.95	2.28
25	1266	2.04	2.47
50	1392	2.11	2.60
100	1520	2.17	2.73
200	1651	2.22	2.85

Table 11 – Summary of maximum discharge return periods.

Summary of return periods for annual maximums for Kvichak River at Igiugig. Q = discharge, V = mean flow velocity, Ht = height above KRIGIPVD11 datum.

11.0 RECOMMENDATIONS

11.1 Turbine Site Recommendations

TerraSond has analyzed the collected data during the four Expeditions in 2011. These recommendations are based on interpretation of the alveus, bathymetry, the power density magnitude, the power density stability, and knowledge of the vessel traffic requirements. Specific bathymetry requirements were unavailable during this site selection due to still undetermined project plans. The candidate site recommendation were based on criteria provided by AEA, AE&E. and turbine designs which were under consideration for this project at the time of this report.

No specific turbine design and installation method have been selected this time. Therefore it is important to recognize that all recommended candidate sites presented here may not be appropriate for all turbine configurations and design methodologies. However, all candidate sites presented within this report are appropriate for at least one construction methodology or turbine configuration.

This study has identified several locations that may be well suited for power conversion. Three candidate site areas are recommended for perspective RISEC development. The sites are designated as Site 6, Site 9, and Site 10. These designations are based on the proximity to the original ADCP transect station determined during Expeditions II and III. The exact turbine location is not recommended in this report. These site recommendations are only intended to provide guidance for the direction of future studies of a more detailed nature.

11.1.2 RISEC Site Six

The area of Site 6 is recommended as the best suited for power production using shallow water power conversion systems. This is the closest site to the village power generation facility. It presents the lowest cost and effort for connection to the existing grid. The peak power density is most frequently located outside the thalweg. Thus the site is well suited to simultaneous use for power generation and vessel navigation. It has not been determined if this site offers a longer power production season or a larger diesel offset, however, the potential for less operational maintenance effort from offline turbine moves is a possibility for this site, Figure 46.

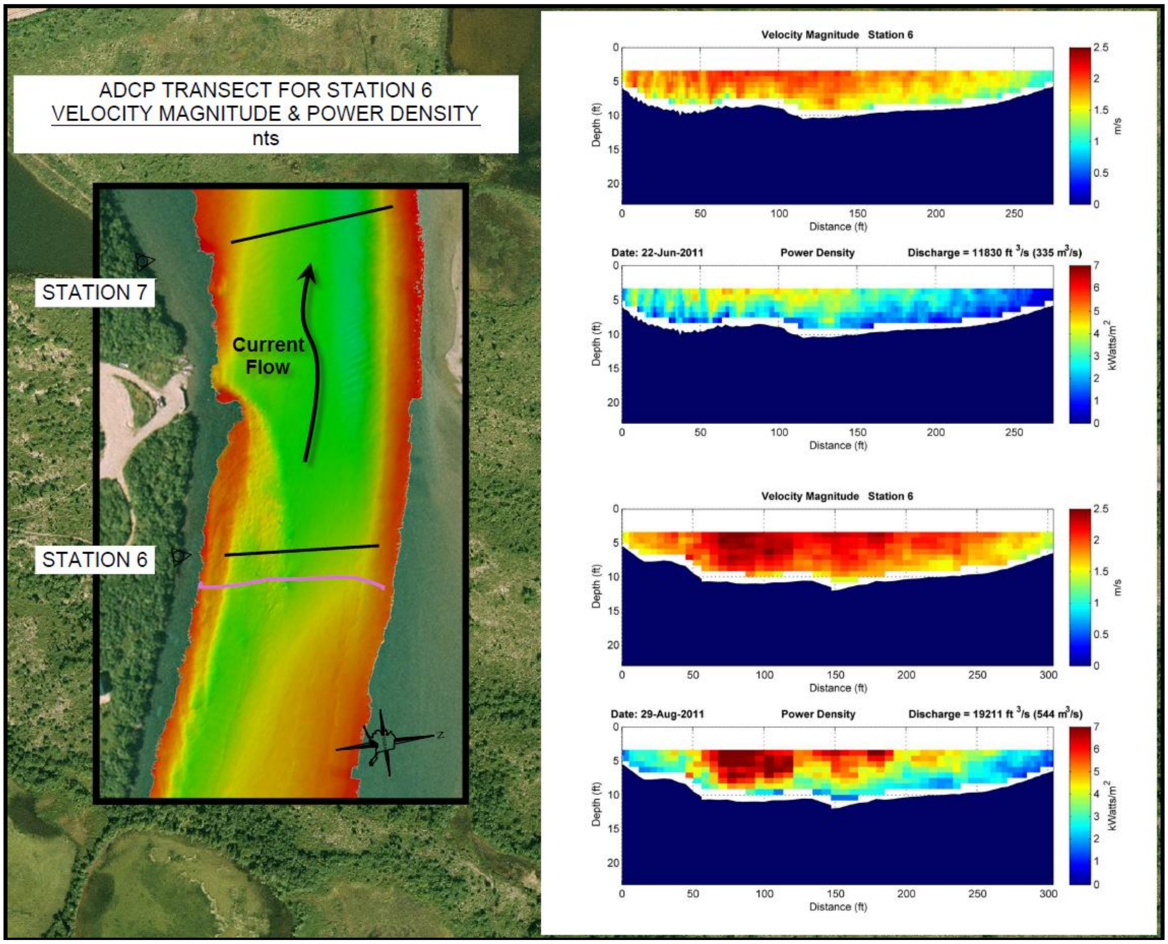

Figure 64 – Site 6 candidate site.

Several items must be considered prior to construction of an in water turbine system at this site.

1. Is the power cross sectional regime stable enough during peak discharge periods?

2. This area is likely to offer little opportunity for debris shedding. The river may guide debris directly into the turbine and create an accumulation point between the turbine and the left bank. Debris will need to be directed into the thalweg by engineering efforts.

3. The bathymetry for this site is shallower than other sites recommended within this study. Also, there is a naturally occurring sandbar directly below this site. Future operations will need to monitor the development of this accretion zone to insure that it does not interfere with turbine performance or significantly alter river flow.

11.1.3 RISEC Site Nine

Site 9 is also well suited for in water turbine construction Figure 65. It exhibits a peak power regime that should be more stable through the season that the one at Site 6. The alveus appears to be constant with slow cycles for change. This portion of the river appears to contain the most significant gradient along the thalweg. The flow is predictable and consistent through the *Chute*. The power density reaches deep into the water column and offers the ability to product power at deeper levels within the river than at Site 6. This site may offer the ability for surface and subsurface power production.

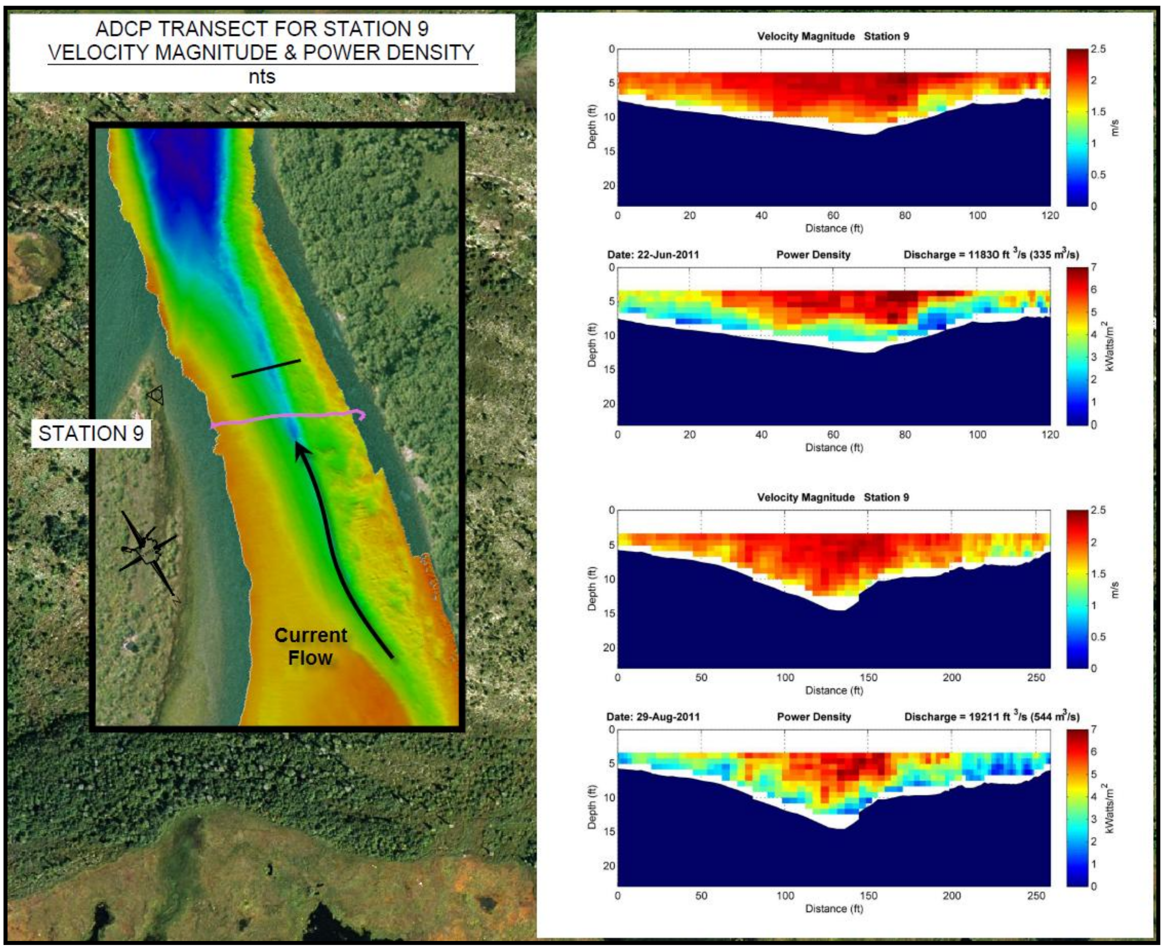

Figure 65 – Candidate Site 9.

Site 9 is a narrow channel. Navigability needs to be carefully considered at this site. The river, particularly at lower river stages, will experience significant spatial constraint. It is not known at this time if any turbine design modifications will be required to satisfy the navigational constraints it this site. Comments from the community and discussions with AE&E indicate that vessel traffic may not require many shutdown periods during a season. Although currently uncalculated, this site may require the highest transmission infrastructure cost.

Significant considerations still remain prior to construction at Site 9.

1. Cost for connection to the grid is potentially very expensive compared to Site 6.

2. Sediment transport issues may exist for this site based upon alveus morphology and should be monitored through time. Property issues will need to be sorted out for this site prior to construction.

3. A Vessel traffic plan will need to be established for total operation and maintenance costs to be well understood.

4. Debris and hazard evaluations will be required prior to project construction. This area is likely to offer little opportunity for debris shedding during low river stages due to the horizontal constraint of the channel. The river is likely to direct debris into the vicinity of the turbine. Detailed understanding of debris episodes, debris momentum, and the general path of debris through this channel will be needed to develop mitigation options.

11.1.4 RISEC Site Ten

The third potential location is Site 10 This site offers the best location for deployment of multiple turbines. This site is attractive as an adaptable and expansive project site that offers opportunity to produce a substantial portion of the power for the Igiugig. This site has the deepest bathymetry of the candidate sites. This stretch of river could accommodate an array of turbines to be placed on the bed or floating. The high energy density zone is long and stable.

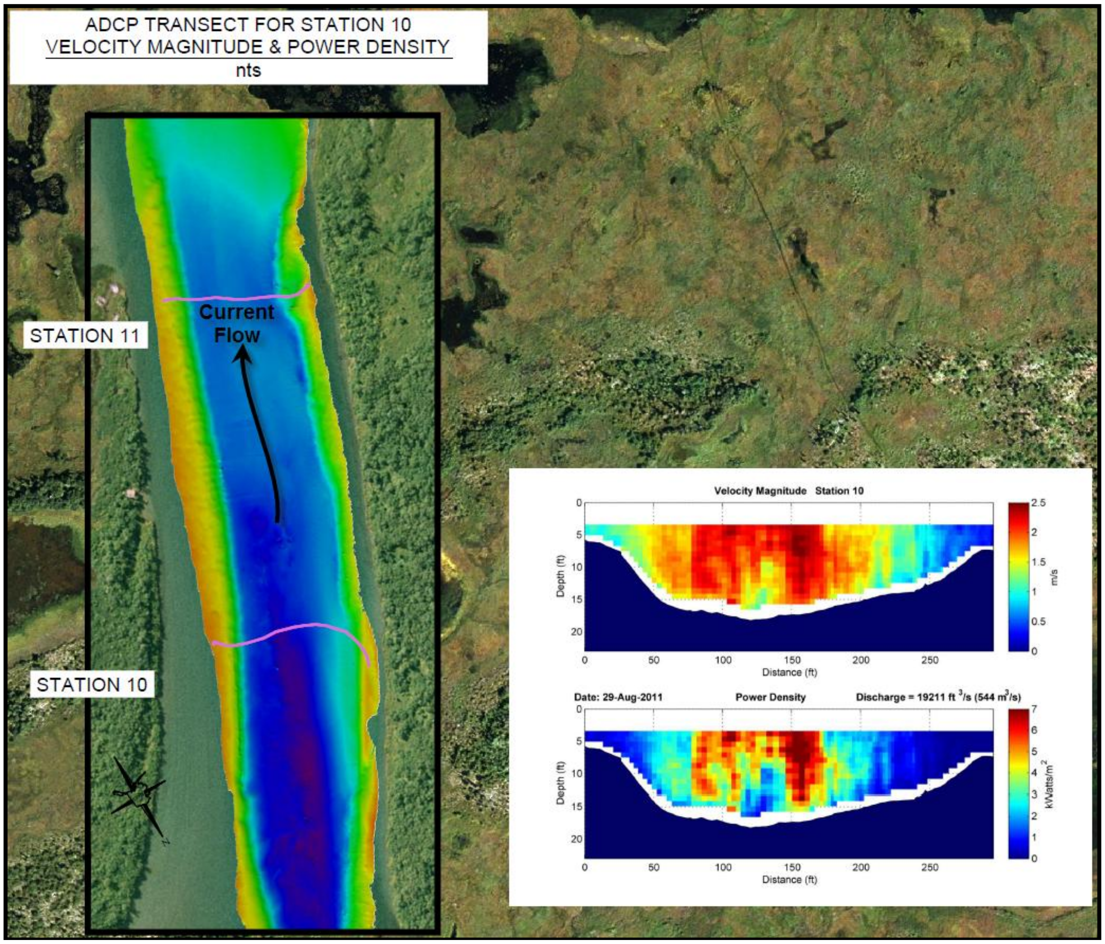

Figure 66 – RISEC Site 10.

RISEC Site 10 has a channel that is broad and deep. This gives the site 10 the best potential for power generation while minimizing interference with navigation. However, the distance from the generation facility and the left bank increases the cost and effort required to connect to the power grid.

Significant considerations still remain prior to construction at Site 10.

1. Can the cost for transmission infrastructure to Site 10 be offset by increased power production from multiple turbines?

2. The length of river appropriate for construction will require additional measurements which have not been accomplished in this study. If bottom mounted turbine configurations are considered, detailed bethymetry will be required to identify suitable bed locations. The extent of the area presented in this report has not been identified at this time and it should not be assumed that the entire length of river presented in the figure is appropriate for turbine installation.

3. A Vessel traffic plan will need to be established for proper estimation of operation and maintenance cost.

4. This site demonstrates significant power low in the water column which appears to result from the significant drop in elevation from RISEC Site 9. This could indicate that an area of increased turbulence may exist throughout RISEC Site 10 and may affect the range for potential construction.

5. Debris and hazard evaluations will be required prior to construction. The river is likely to bring debris into the turbine. Debris will need to be directed away from the turbines.

11.2 Future Studies

The results reported in this document represent the first field investigation for the design and construction of an in water turbine facility in the Kvichak River at Igiugig. The prior assessments presented have relied on historical data. The bulk of the site characterization was based on USGS gage data from Site 15300500. This data was 24 years old. Even a cursory inspection of USGS topographic maps, Community Development Maps, and aerial photography revealed that the river has experienced significant changes over the past three decades.

The MBES survey completed this year is thought to be the only one of its kind done in this area of the river. It has given a tremendous view of the current river bed condition. However, it is only a baseline study. Future MBES surveys should be done at locations considered favorable for a turbine site. These surveys should be scheduled for a high flow river state. This would offer an opportunity to maximize bottom coverage. Detailed MBES surveys should be done at any turbine location before and after placement. These studied should be planned with consideration for detection of changes in bed morphology.

The ADCP data collected to date gives a good initial description of the flow velocities and energy density in the river. However, they only represent three limited views in time. True high and low flow conditions have not been captured. Further, the stability of flow could not be adequately assessed with the three data sets. There is a need for long term current monitoring at the potential turbine sites. This is the best way to determine the nature of the flow regime. In particular it is important to assess the level of turbulence in the river and determine the long term stability of the thalweg and the zones of high energy density. The most suitable means of doing this would be an ADCP moored on the bottom of the river for up to one year.

In spite of the fact that it was over 24 years old the USGS gage data was still of some use for the present work. However, in the decades since this gage was operational there have been changes in the river climatology and morphology. Further there are no features remaining from the original USGS installation that may be used to establish a physical tie to their data set. Any relationships between current observations and the USGS record presented in this report are tenuous and should be used with caution. Long term automated monitoring of the river’s water level is important for the future success of any turbine project. Even though the results of this year’s efforts are considered successful, they would have been better if a gaging station had been placed at the start of the work. This station would have provided a continuous record of water level. It would have made it easier to estimate the right time to do discharge measurements for peak flows. And the initial data for the creation of a new rating curve could have been obtained. The gage could have been left in place for the foreseeable future. Thus there would be a dependable record of river stage leading up to the placement of a pilot project. With regard to the hydrologic aspects of this project a solid record of river stage is of paramount importance. Every effort should be made to establish a new gaging station at Igiugig and develop a current rating curve. A good record of river stage and discharge will be invaluable for the monitoring and assessment of turbine operation and performance.

The stability of the river bed is only given light consideration if this report. Prior to any turbine placement the prospective site should receive a detailed assessment. This assessment should include determination of sub bottom conditions, and proper sieve analysis of bed material. Near bottom flow velocities should be measured and used to determine the threshold for insipient movement of the bed materials. ADCP profiles and channel profiles should be used to optimize Manning's equation for the select section of river.

There is no detailed knowledge of ice conditions on the river. Numerous accounts of ice conditions have been received from the USGS and the community. However, there is no solid quantitative data on ice dimension, composition, disposition and seasonality. Such information is crucial to the construction and operation of a turbine in this river. The collection of a solid data record for the river ice should be started as soon as possible. An excellent first step would be to start a local observer program that involves the local school. This could be augmented with the installation of game cameras to capture regular images of river ice. These first steps are simple and inexpensive. With respect to data quality they offer an excellent value.

TerraSond looks forward to assisting with these studies and remains available to AEA, AE&E, and the Village of Igiugig as they develop the industry capability, instrumentation, methodologies, and future techniques needed by the emerging in - stream hydrokinetic industry.