TERRASOND

TERRESTRIAL AND SEA FLOOR MAPPING

Hydrokinetic Power Conversion Project
Pre-deployment Hazard Clearance Survey

Yukon River at Eagle, Alaska

March 5, 2010
Ver. 1

Prepared for
Alaska Power and Telephone

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PROJECT SUMMARY

On July 21, 2009, TerraSond Ltd. (TerraSond) mobilized under contract for Alaska Power and Telephone (AP&T) to Eagle, Alaska. The project specified the recording, processing, analysis, and interpretation of remotely sensed data for the purpose of measuring the physical character of the Eagle In-stream Hydrokinetic Power site. The survey area included a 255,404 m^2 area of the Yukon River adjacent to the Town of Eagle, AK.

The vessel used for all operations was the custom built 19 ft aluminum survey vessel *MV Ducer.* The geophysical instrumentation deployed during this project included a pole mounted multibeam echosounder (MBES), a pole mounted side scan sonar (SSS), a vessel mounted scanning laser, and various global positioning system kits (GPS).

The primary objective of this effort was to assess if significant change had occurred to the project site after the catastrophic Breakup Flood, Spring 2009 which may inhibit proposed development. In the period after the flood, AP&T questioned the integrity of the local geodetic monumentation, possible man-made or natural debris in the sub-river surface, and the possible disturbance in the foundation of the riverbed. Additional goals include gathering data that better characterized the geomorphology with the high density data for precise distance estimation, baseline surface for sediment transport analysis, and future power conversion modeling.

In 2007, TerraSond measured a sparse DEM of the Yukon River and the left shore embankment acquired with a single beam echosounder (SBES) and fixed height RTK GPS system. This data can be referenced in TerraSond report “Reconnaissance Survey for Hydroelectric Turbine Sites Yukon River, Eagle, Alaska, Project ID 2007-057”. The project goals described above required a dense dataset in order to visualize and measure obstructions within the project area. TerraSond referenced the 2007 work to expand upon the products for this report and to help correlate the two efforts for increased usefulness to AP&T.

TerraSond acquired, processed, analyzed, and interpreted data from each instrument and successfully produced meaningful deliverables that have increased the understanding for the project site. The physical and digital deliverables include this comprehensive report, a 3D comprehensive Caris Presentation, a 2009 Digital Elevation Model (DEM), an Acoustic Intensity Image Mosaic of the riverbed, a Surface Comparison Evaluation between the 2007 and the 2009 DEMs, a Danger to Navigation (DtoN) Interpretation, a Hazard for Construction (HforC) Interpretation, a Post-Flood Orthorectified Image of Eagle vicinity, 2009 Bathymetric Chart, an Acoustic Image Chart, an Obstructions and Zones of Caution Chart, and a reproduction of 2007 Bathymetric Chart.

The final products have been generated to maximize the usefulness with information published by United States Geological Survey (USGS) and other governmental agencies. All final products are relative to Alaska State Plane, Zone 2, US Survey Feet (usft), as positioned in reference to

the North American Datum (NAD83). All final products are relative to the vertical datum of USGS Stream Gage Station ID 15356000, located in the vicinity of Eagle Alaska as published prior to the 2009. The distance between WGS84 ellipsoid and the local USGS Stream Gage datum is 865.2 ft.

This report contains descriptions of the sensor acquisition methodology, processing path, and quality assurance techniques as exercised by TerraSond. It will also generalize specific information regarding data analysis, interpretation, and product dependencies for each dataset mentioned above during the finalized product development.

A primary objective of this survey was to evaluate the migration or destruction of historic geodetic monumentation present in the vicinity of Eagle, Alaska. The effort accomplished in 2007 provided a unique opportunity for this evaluation and significantly increased the confidence of this evaluation. The flood event and the questions raised by AP&T about the reliability of this geodetic infrastructure prompted a fundamental change in spatial reference for the products and deliverables of the 2009 report. This change is described in more detail within Section 1.1 of this report. TerraSond has abandoned the published NGS values which had previously defined our space for charting efforts. For the purposes of this report, TerraSond has referenced the geodetic network space ("CORS space" for the purposes of this report) determined from holding CORS stations CENA (4210863.480 NORTH, 1233861.983 EAST, 929.802 usft), FAI 1 (3992465.014 NORTH, 730064.282 EAST, 489.051 usft), and FAIR (4049001.036 NORTH, 789501.792 EAST, 1045.549 usft) fixed in horizontal ASP z2, usft. The distance shift ("Δ (delta) shift" for the purposes of this report) from the original NGS space used in the 2007 project and the 2009 project is northing = -2.66 usft, easting = +4.05 usft, vertical = 1.00 usft down.

TerraSond was able to recover all three of the historic monuments used in the 2007 reconnaissance survey (*PINK 1990, RAMP, and HYDRO1*). TerraSond also recovered an additional existing monument (EAA A) which had historic published NGS values. An additional monument was established (HYDRO2).These monuments were used to strengthen the final positioning of the 2009 geodetic network.

The three original monuments were evaluated for position migration. The primary monument for this analysis was *PINK 1990* which had published values by NGS and OPUS solutions from 2007 and 2009. The method for determination included the submission of both 2007 and 2009 static data to OPUS holding three similar CORS stations as reference, the reevaluation of the 2007 geodetic network as established in NGS space, the reevaluation of the 2007 geodetic network as established in CORS space, and the 2009 geodetic network in both NGS and CORS space. The difference in position was found to be trivial and within the error of the evaluation methodology. TerraSond interprets no significant migration for PINK 1990, RAMP, or HYDRO 1 monuments caused by the flood event of 2009. The additional monuments were used in the evaluation of the final 2009 Geodetic Network.

The bathymetry within the project site was found to be advantageous for hydrokinetic development per the turbine placement requirements described by AP&T. The depth range covered by the Multibeam survey was 25.6 usft as referenced to project vertical datum (reference Section 1.3). TerraSond interprets very little topographic change beyond the geomorphology of the thalweg. Large areas of peak flow remain compliant with the design requirements as understood by TerraSond at the time of this report.

TerraSond's interpretation of the riverbed identified very few obstructions within the survey area. Obstructions have been interpreted to be boulder size and the origin for the obstructions is determinable. TerraSond has produced a regular grid DEM with node distance of 0.5 m. Obstructions of ≥1 m^3 are observable within this dataset. TerraSond has provided a list of obstructions within the body of this report and estimated the volume for each obstruction from the sonar data. Two Dangers to Navigation (DtoN) and one Hazard for Construction (HforC) were identified. Three Warning Zones are discussed in this report. Obstructions interpretations can be found within the Section 1.3.4 of this report.

The river bed analysis indicates some disturbance in the form of Ice Gouge and Ice Scour. This may have occurred during the flood event as grounding of large ice blocks. The 2007 bathymetric dataset is not dense enough support or refute the disturbance occurring within this time widow. However, the 2009 Breakup Flood does fit as a likely candidate for disturbance of this magnitude.

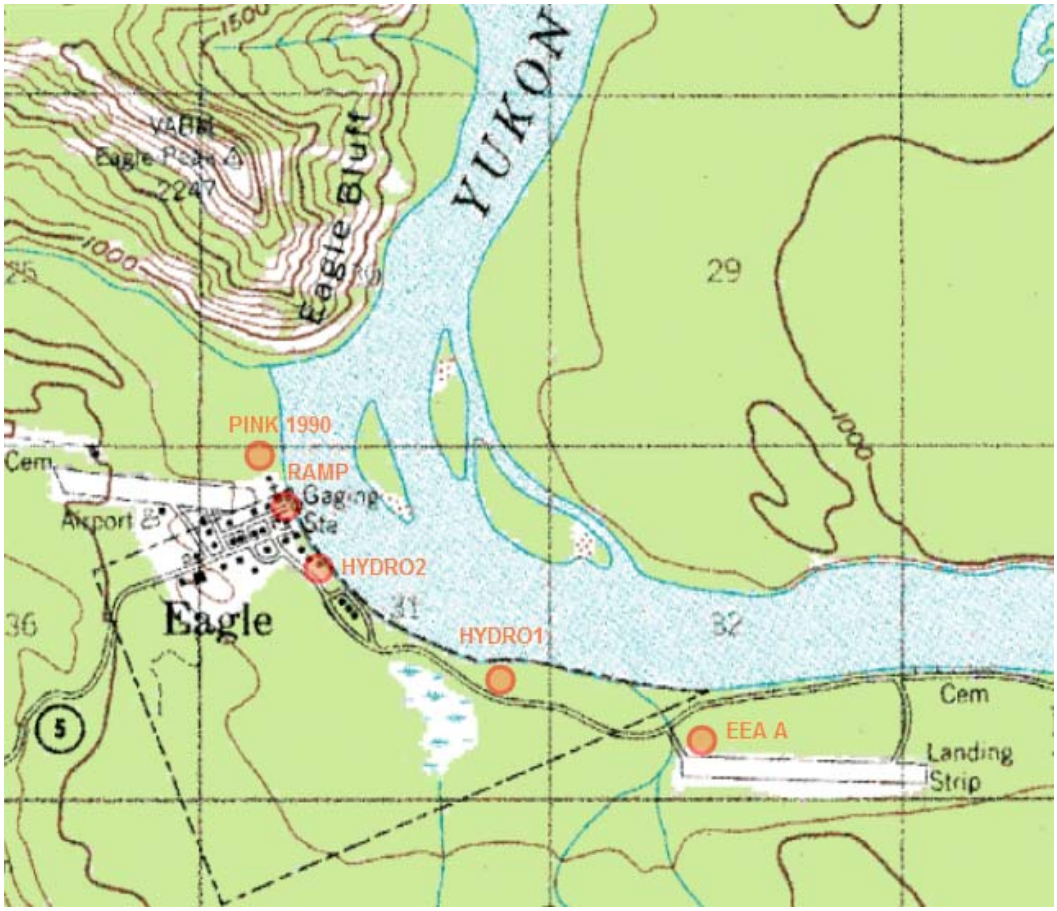
TerraSond computed a surface comparison in the form of a regular gridded surface from the 2007 and 2009 bathymetric data. Significant differences were identified on the 10 ft^2 scale, however, no major change in the depth of the river was computed for the river as a whole. No sign of channel migration or change in geomorphology was identified from the surface comparison. The surface comparison computed change in the depth range from +XX ft to -XX ft. This change has been identified with clearly distinguishable features in the bathymetry that may have been present prior to the 2007 survey. A cable route evaluation was beyond the scope of this project, however, TerraSond did evaluate the integrity of the left river bank and its toe at four locations along the river project area with a consideration for anchors, cable connection, turbine deployment, and turbine landing. This evaluation is discussed in Section 1.3.4 of this report.

The Side Scan Sonar record visualizes a riverbed of similar geologic composition and is largely acoustically homogeneous. The riverbed geology of the prospect is highly worked resilient sediments indicative of high energy zones. Acoustic records demonstrated a highly reflective riverbed with minimal transference into the substructure. The variation between the cobble, boulder, and sands is almost indistinguishable in this acoustic record. Unique zones within the mosaic indicate acoustically absorptive sediments which TerraSond interprets to be mud and/or other unconsolidated fines. A geologic interpretation was beyond the scope of this project, some level of geology classification is required in order to isolate features from the background signal.

Obstruction/contact recognition revealed important features that collaborate well with the MBES data.

TerraSond finds no significant man-made infrastructure, geographic, or geologic obstruction which would preclude this site from future development for hydrokinetic power conversion activity. Although obstructions and warning zones exist within the project boundaries, it is the opinion of TerraSond that no obstacles were identified that cannot be avoided, remediated, or otherwise overcome through skillful engineering.

1.0 GEODESY & NAVIGATION



Graphic A - Local Geodetic Strategy for the vicinity of Eagle, Alaska

TerraSond was contracted to evaluate the integrity of the existing geodetic network for the town of Eagle, AK.

In 2007, TerraSond measured and computed a local geodetic network in Eagle, Alaska necessary for river measurements and survey control intended to facilitate the deployment of in-stream hydrokinetic power generation equipment. The results from this work can be referenced in TerraSond report "Reconnaissance Survey for Hydroelectric Turbine Sites Yukon River, Eagle, Alaska, Project ID 2007-057". The position of three monuments (PINK 1990, RAMP, HYDRO1) along the river was precisely known and the relationship between these monuments and features regarding the river, waterline, USGS Stream Gage were well described. This survey was reported relative to published NGS space with PINK 1990 held as N64° 47 25.08054, W141° 12 06.65996, 18.646 m (local USGS Stream Gage Datum).

PINK 1990 (in 2007)									
Published Position				Published Elevation	Raw Measured Position				Measured Elevation
NAD 83 (2007)		SPC AK Zone 2 (m)			NAD 83 (2007)		SPC AK Zone 2 (m)		
Latitude	Longitude	North	East	NAVD 88 (m)	Latitude	Longitude	North	East	local USGS datum (m)
N64 47 25.08054	W141 12 06.65996	1202162.349	537943.494	273	N64 47 25.10185	W141 12 06.73172	1202162.997	537942.538	18.646
Described by Alaska Department of Transportation in 1990: This station is located at Eagle Alaska. Station is 64ft east of the most easterly corner of the U. S. Department of the Interior Yukon-Charley Rivers National Preserve Headquaters 2 ft southeast of a wooden guardrail around the headquarters 46ft west of the top of the left 30ft high bank of the Yukon River and is northeast of the east end of a grass airstrip.									

Table One ***NGS Monument "PINK 1990" as published in 2007***

During the project planning period after the catastrophic Breakup Flood, Spring 2009, AP&T questioned the integrity of the local geodetic monumentation which comprised the geodetic network computed in 2007. The focus of all geodesy effort on this expedition was to recover the historic network and, if still in existence, to evaluate the monument stability.

If monuments were not recoverable, TerraSond was directed to establish new monumentation. If the monuments were recoverable, then TerraSond was directed to evaluate if position had changed from the 2007 location. Even if visual inspection looked as if the monuments were still in place and unaffected by the flood event, possible changes in monument position could be attributed to the migration of surrounding geology through slumping or subsidence under force of river flow, water mass, and liquefaction of sediments. The determination for movement was beyond the scope of this project, the primary objective was to evaluate the existing monumentation and to ensure that reliable survey monumentation was useful for future measurements, construction operations, and studies.

TerraSond referenced the same monumentation when planning for the control network integrity evaluation of 2009. In addition, TerraSond established one new monument, and included an additional monument with a published NGS position. The process for evaluating the location of monuments and the change in geodetic reference space is discussed with more detail in Section 1.1.

TerraSond utilized Global Positioning System (GPS) receivers during the positioning and navigation for all survey activities. All survey navigation, both hydrographic and terrestrial, were accomplished with RTK position corrected GPS (RTK GPS) which greatly increased the precision of our measurements. The navigation information is discussed with more detail in section 1.2. All survey information was acquired in geodetic space and translated into Alaska State Plane, NAD83, Zone 2, in U.S. Survey Feet (usft). Vertical datum was maintained from the 2007 survey to be USGS Stream Gage Station ID 15356000 datum in feet.

1.1 Geodetic Control Verification

On July 21, 2009 TerraSond recovered and measured three monuments identified from the 2007 survey literature. Each monument was recoverable and upon preliminary inspection did not appear to have significant disturbance.

Graphic B - Images of RAMP infrastructure in 2007

RAMP (in 2007)

Published Position				Published Elevation	Raw Measured Position				Measured Elevation
NAD 83 (2007)		SPC AK Zone 2 (m)			NAD 83 (2007)		SPC AK Zone 2 (m)		
Latitude	Longitude	North	East	NAVD 88 (m)	Latitude	Longitude	North	East	local USGS datum (m)
N/A	N/A	N/A	N/A	N/A	N64 47 18.60660	W141 12 00.14289	1201962.974	538032.083	11.95

Described by TerraSond in 2007: The monument is an unstamped aluminum plate imbedded in concrete near the top of the pedestrian ramp at the east railing concrete foot block.

Table Two Monument RAMP Information in 2007

Graphic C - Image of Monument RAMP infrastructure in 2009

Although the infrastructure in the vicinity of RAMP had experienced significant damage, the survey crew did not identify direct disturbance to the monument or to the immediate area which encased the monument during visual inspection. An RTK base station was established above the monument RAMP following the methodology from the 2007 survey. The monument RAMP was held as N64° 47 18.60660, W141° 12 00.14289, 11.95 m. Static measurements were recorded for this location over extended periods of time, which would be post-processed for integrity evaluation, OPUS submission, and geodetic network computations. The GPS receiver at RAMP served a dual function as it was used for both a static record over a known monument and as a base station for the distribution of GPS corrections broadcast as radio transmissions used during all terrestrial and vessel navigation during data acquisition. The RTK broadcast range exceeded the project boundary and this base station was operational during all survey activity reported for this project.

Monument designation	Latitude (WGS84)	Longitude (WGS84)	Elevation (Local, usft)
PINK 1990	N64 47 25.08054	W141 12 06.65996	61.21
RAMP	N64 47 18.60660	W141 12 00.14289	39.21
HYDRO 1	N64 46 57.04054	W141 10 54.15474	30.19

Table Three Historic survey monument position as reported in the 2007 survey.

All survey operations were accomplished with RTK precision. TerraSond recovered the remaining monuments PINK1990 and HYDRO1. Both appeared to be unaffected by the flood activity upon visual inspection of the monuments. GPS receivers were established above each monument and co-located simultaneous measurements were recorded. No less than two monuments were occupied for any data that was used to confirm network integrity.

In order to strengthen the geodetic network, TerraSond established one new monument along the river and within the historic network of monuments. The new monument was named HYDRO2 and was located in the vicinity of the termination of power pole infrastructure adjacent to the riverbank at 64° 47 09.13117, 141° 11 44.99221, 918.7 usft (WGS84 Ellipsoid).

Prior to the expedition, TerraSond had determined that NGS posted monumentation at the southern end of the geodetic network would significantly strengthen the computation and evaluation of network integrity. TerraSond identified a monument at the airport that provided this expansion. EAA A was introduced into the network in order to both strengthen the network through spatial extension and by allowing for the more complete NGS to CORS space translation.

On July 30, 2009, the raw data was received by the TerraSond Survey Processing department. The data was processed for a short term result, and then again after precise ephemeris was accessible, the data was finalized and the each monument position was established.

The first step in the evaluation of the integrity of the control network was to establish wither a horizontal migration or vertical migration was identifiable. Three reference values were available

for the monument PINK 1990; the NGS location (used for the 2007 products), an average of OPUS solutions from 2007 measurements, and an average of the OPUS solutions from 2009 measurements. Monuments RAMP and Hydro 1 had average OPUS solutions for the 2007 and for the 2009 measurements.

TerraSond used the same CORS stations for each OPUS computation as we recalculated the 2007 information. These were used again as we submitted the 2009 data. The submission of 2007 and the 2009 data resulted in an average horizontal difference of 0.025 usft.

This disagreement could be attributed to exist within the error of the measurements and processing algorithms. TerraSond recomputed the network using the mean average of the monument positions and determined no significant change to the position of PINK 1990, RAMP, or HYDRO1. TerraSond does not believe that large scale slump or subsidence has occurred along the bank of Eagle and that the monumentation is valid for reference to historic planning and use for future project efforts.

During the planning of the geodetic network evaluation, TerraSond became alert to the fact that large scale catastrophes as experienced during the Breakup Flood, Spring 2009 highlighted vulnerabilities to the recovery of a network that did not include monumentation external to the immediate project area. TerraSond included Continuously Operating Reference Stations (CORS) into the 2009 geodetic network in order to ensure that future operations would not include this weakness.

Geodetic positions were processed by using the following CORS stations:

- CENTRAL ALASKA CORS ARP (CENA)
- FAIRBANKS WAAS CORS ARP (FAI1)
- GILMORE CREEK OBS CORS ARP (FAIR)

Horizontal control was established using a constrained network using the three CORS stations listed above as the fixed control. Precise ephemeris was downloaded from the CORS website allowing for higher accuracy and precision in static vector processing. This method was selected in order to negate the effects of artificially held control migrating moving over time. This geodetic control methodology allows for more repeatable surveys and specifically places the survey in the most modern and dynamic GPS space for future survey efforts.

Static GPS data was quality checked in the field and the final processing was executed by the TerraSond Survey Department in Palmer, AK. Analyses of each baseline solution and baseline loop closure were performed using Trimble Geomatics Office (TGO) version 1.63. A minimally constrained least squares horizontal network was performed and resulted in a self diagnostic which tested the quality of the observations relative to themselves. The fully constrained network utilized the least squares adjustment method which adjusts the network with respect to the held control (CORS stations).

Vertical control was calculated by holding OPUS solution ellipsoid heights (referencing CORS stations) for control monuments PINK1990 and EAA A as part of the constrained network adjustment. This was done to provide the most consistent repeatable values in the future for the vertical component of the survey. The reported height for PINK is based on an averaged OPUS ellipsoid height.

USGS stream gauge heights as referenced to RAMP (and there for the geodetic network) were determined in 2007 and applied to the 2009 data. This effort was completed using 2007 level notes and applying deltas to the adjusted ellipsoid elevations of control points.

Monument locations per 2009 CORS referenced Geodetic Network

Monument	Geodetic		Alaska State Plane (usft)		Vertical Datum	
I.D.	Latitude	Longtitude	Northing	Easting	Ellipsoid	USGS Vert. Datum
PINK 1990	64° 47 25.07485	141° 12 06.63904	3944093.74	1764903.86	926.41	62.194
RAMP	64° 47 18.57991	141° 12 00.05049	3943437.53	1765197.63	904.42	40.204
HYDRO1	64° 46 57.37882	141° 10 54.06257	3941320.28	1768084.43	895.35	895.35
HYDRO2	64° 47 09.13117	141° 11 44.99221	3942485.91	1765862.23	918.70	54.484
EAA A	64° 46 43.13382	141° 09 36.25038	3939917.31	1771475.61	929.03	929.03

1.2 Terrestrial Survey

The Terrestrial-survey utilized two Trimble SPS880 R8 L1/L2 GPS antenna units, with RTK correctors. One unit was positioned on shore over the *RAMP Monument* as a stable base station transceiver. The second unit was established as a roving receiver and fixed to a variable-height staff. The positions were recorded with Trimble SC2 and evaluated with Trimble Geo Office software. A third Trimble unit was established at another monument for simultaneous collocated static measurements used for the control processing.

1.3 Navigation

RTK corrections were used for vessel navigation and recorded as the positioning for all sensors utilized during this survey. This can be a more precise system of measurement than uncorrected GPS and is expected to significantly increase accuracy. This system utilizes the additional information of the carrier signal, and, when properly processed, will include the Carrier-Phase Enhancement in the final position.

RTK uses the GPS satellite's carrier as its signal, not the messages contained within. The improvement possible using this signal is over a thousand times as fast as a typical GPS receiver. This corresponds to a 1% accuracy of 19 cm using the L1 signal, and 24 cm using the lower frequency L2 signal. When the two signals are correctly aligned, the generally accepted error estimation is 20 cm. RTK corrections were transmitted to the vessel navigation and recorded by the acquisition software during all survey activity.

By establishing the RTK GPS base station at a known monument which has been tied to the USGS River Height Staff (near sheet pile stairway access) and correcting the survey to that datum; TerraSond was able to ensure that the RTK survey measurements are in agreement with the USGS Stream Gage vertical space and therefore this survey is consistent with USGS published river information.

All navigation was received in geodetic coordinates and presented to the navigator and vessel pilot in Alaska State Plane, Zone 2, NAD83, usft. The vertical space was already shifted to the local USGS Datum by establishing the historic values from the 2007 survey at RAMP as the base station.

Due to the geodetic methodology described above and additional error attributed to the general unknowns associated with sensors and acoustic spreading, TerraSond prioritized the information gathered by the MBES Survey above other geophysical instrumentation for this survey. The positions recorded in the multibeam and the terrestrial surveys are considered to be correct and precise. Positions for the side scan sonar and the scanning laser are secondary sensors and may have been shifted reasonable distances spatially during the processing and interpretation phase to support multi-sensor interpretation.

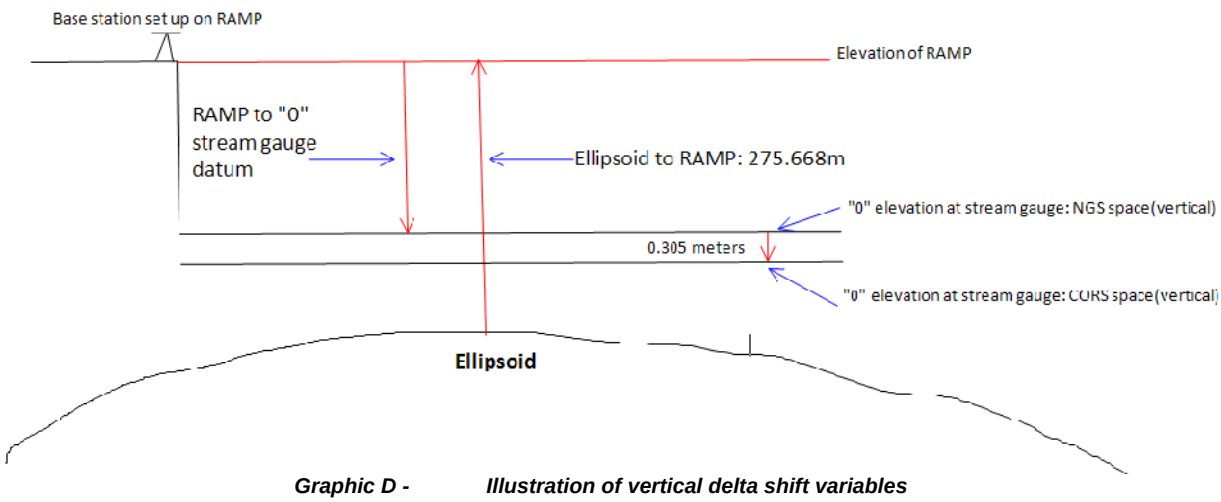
1.4 Transition to CORS Space

Although TerraSond did not measure a significant movement in the monument positions between the 2007 and the 2009 measurements, please recognize that TerraSond is reporting new locations for all monuments and that the entire survey has been shifted in space to reference this global space shift.

The result of introducing CORS stations into our network did result in a spatial shift. One that TerraSond believes to be more correct and more repeatable for future survey activity. For the purposes of this report TerraSond distinguishes the two reference spaces as NGS space and CORS space. The 2007 was processed in NGS space as we held PINK 1990 to published NGS values. The 2009 survey held three CORS stations constant in the reevaluated network.

TerraSond does acknowledge that the CORS stations are a longer distance from the project site then is typically desirable, however, such is the situation when dealing with the sparse infrastructure of Alaska. It is also important to note that the distances that we are describing are relatively small (on the scale of a single meter), the reason for this shift was not to compensate for historic error, but to place our most recent information in a more consistent and repeatable space for future efforts which require precise measurements.

We recommend that future surveys reference these publicly published stations when controlling their measurements from these or new monumentation in order to maintain consistency.



Graphic D - Illustration of vertical delta shift variables

Ellipsoid to RAMP = 275.668m

Ramp to Stream Gauge Datum = 11.950m

Ellipsoid to Stream gauge Datum = 275.668-11.950 = 263.718m

Stream Gauge Datum to CORS space = 263.718-0.305 = 263.413m

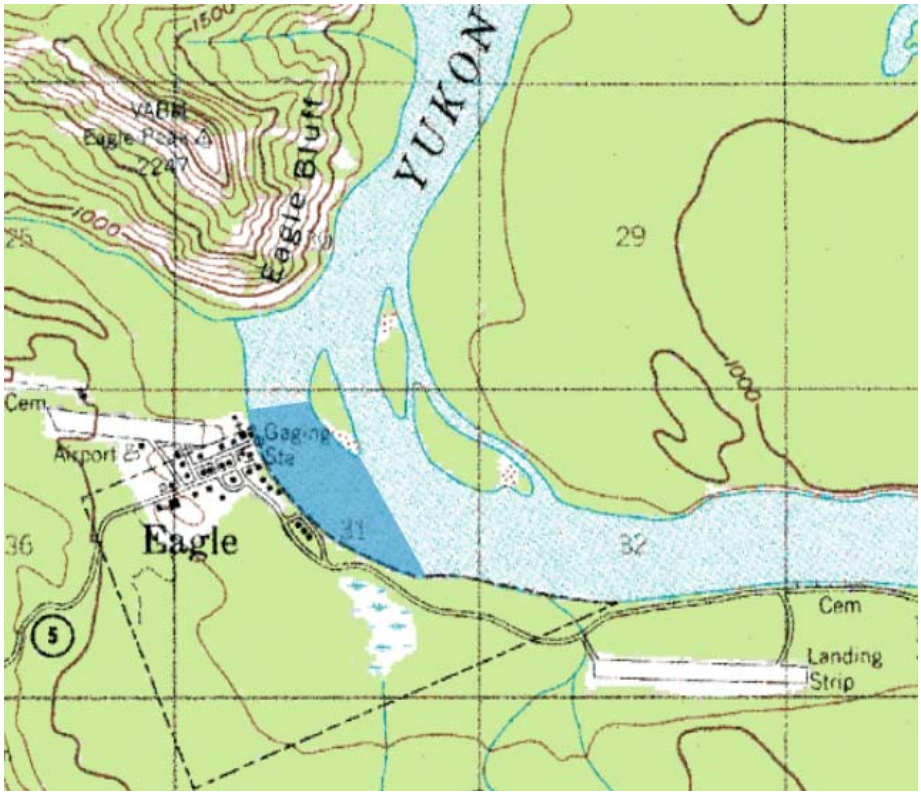
Subtract 263.413 m from ellipsoid heights to arrive at zero stream gauge datum in CORS space.

Every point measured with terrestrial survey, every monument position, every point in the processed multibeam surface, each Side Scan Mosaic image, every point in the scanning laser has been manually or bulk shifted to CORS space in order to maintain the standard described above.

The global delta shift for this translation from NGS space to CORS space is:
X: 1.233 m
Y: -0.812 m
Z: 0.305 m

X: 4.1 ft
Y: -2.7 ft
Z: 1.0 ft

2.0 HYDROGRAPHY



Graphic E - Image of survey area of interest

On July 19, 2009, TerraSond mobilized *M/V Ducer*, a custom 19 ft aluminum survey vessel based out of Palmer, Alaska. The mobilization crew consisted of the project Lead Hydrographer and four Survey Technicians. The vessel mobilization took place at TerraSond's shop and was completed prior to expedition departure for Eagle, Alaska.

Graphic F - Mobilization of MV Ducer for river MBES, SSS and Scanning Laser surveys

The recovery period during the summer of 2009 after the spring flood event left few opportunities for lodging in the town of Eagle, AK. For this reason, TerraSond rented a motor home for the expedition.

Graphic G - Transit to project site with both lodging and survey vessel

The goal for the hydrographic effort was to establish a dense data set which would be acceptable for the interpretation of sub-river hazards which may exist prior to or due to the spring flood event. The Hydrographic data set includes both the Multibeam and the SSS products. The mapping effort of the MBES establishes the precision and accurate foundation for which the Side Scan mosaic can be draped. Both surveys were controlled with through the use of with RTK corrected GPS as described in Section 1.2, however, it is important to note that the precision of the MBES which utilizes the ray tracing methodology is far superior across track then the SSS which only controls the horizontal position of ping transmission. For this reason, the SSS which is represents a continuous analog record of the acoustic magnitude may have some error in the position of identified objects.

The high density data that made up the DEM produced from the MBES survey provided an interpretable geomorphological surface to a horizontal precision of 0.5 m. DtoN and HforC contacts of 1 m^3 are resolvable. The shoal depth precision of for all contacts identified in the regular gridded DEM can be expected to have sub meter accuracy.

2.1 Acquisition of Hydrographic data

Graphic H - Reson SeaBat 8124 Multibeam Echosounder Sonar

2.1.1 *Acquisition of Multibeam data*

The MBES calibration acquisition of Multibeam Echosounder (MBES) data occurred on July 22, 25, and 26 2009. TerraSond acquired bathymetric point data with Reson 8124 Multibeam Echosounder sonar and recorded that information using Hypack Integrated Acquisition Software. An ASL acoustic velocimeter was used to measure the near field speed of sound at the sonar face. An additional Odom Digibar Pro acoustic velocimeter was used to measure the speed of sound throughout the water column by manual casts performed intermittently throughout the survey effort.

The MBES Calibration test accounts and corrects for electronic timing errors, roll, pitch, and yaw bias. TerraSond accomplished the MBES calibration acquisition according to the industry standards.

Multibeam Echosounder SPECIFICATIONS	
Sonar Type	SeaBat 8124
Sonar Operation Frequency	200Khz
Beam Width, Across Track	1.5 degrees
Beam Width, Along Track	1.75 degrees
Number of Beams	80
Swath Coverage	120 degrees
Max Ping Rate	20 pings per second

Table Four Technical information for the Reson 8124 MBES

TerraSond performed a calibration of the MBES using radio corrections broadcast from the RAMP RTK base station over a river bed feature and an area of significant slope near the position N 64° 47 44.891, W 141° 11 32.306.

The 200 kHz acoustic data was acquired as along the topography of the thalweg lines throughout the main scheme survey area with irregular line spacing resulting in 99 main scheme survey lines. An additional 4 cross lines were recorded as part of the TerraSond Quality Control Plan. This bathymetric project resulted in a full ensonification of the river bed significant swath overlap allowing for a confident interpretation of the sea floor. Sound velocity measurements were accomplished by manual cast and measured the entire water column during MBES operations.

Non-systematic line acquisition was exercised in the shallow portions of the river in an attempt to achieve full coverage and reduce holidays as the swath area geometry decreased.

All vessel position and attitude were calculated with a Coda Octopus F-185 Integrated Navigation System (F185). The F185 consists of two GPS antenna and an inertial motion unit (IMU). The GPS antennas have a primary (L1/L2) antenna and an additional secondary antenna (L1) co-located no less than 1 m apart creating a fine baseline. The F-185 IMU was located on the *M/V Ducer* near to the Central Reference Point (CRP) of the vessel. The trajectory of the vessel was computed by the F-185 and recorded by the acquisition software.

The RTK corrected GPS navigation was recorded and displayed in Hypack during vessel operations. The offsets and lever arms associated with the primary GPS phase center and the IMU were computed within the F-185 and referenced to the CRP of *M/V Ducer*.

Offsets from CRP to Sonar Acoustic Center of the MBES were computed in Hypack and a real-time acoustic coverage was computed and displayed for the survey crew.

Graphic I - MV Ducer during hydrographic acquisition operations on the Yukon River at Eagle, AK

The hydrographic survey crew and the terrestrial survey crew were in communication to ensure safe river operations as the hydrographic crew approached shore.

2.1.2 *Acquisition of Side Scan Sonar*

Graphic J - Image of Imagenix Side Scan Sonar Fish body

On July 26, 2009, the *M/V Ducer* was mobilized for side-scan sonar operations. An Imagenix Yellowfin model 372 was hard-mounted to the starboard side of the vessel. SSS acquisition accomplished at 330 kHz nominal, 50 m range, resulting in an across-track resolution of 5 cm (2 in). Navigation was to real-time kinematic (RTK) precision using a combination of a Coda F185 L1/L2 combination GPS receiver and heave sensor, and a Trimble TrimMark III which relayed the RTK correctors from the land-based network of Trimble SPS880 transceivers to the Coda unit. Data was acquired using Hypack 2008 software.

Imagenix Yellowfin Side-Scan Sonar S P E C I F I C A T I O N S	
Frequency (dual simultaneous)	Choice of either 260 kHz / 330 kHz / 770 kHz nominal
Horizontal Beam Width (HDM)	260 kHz: 2.2° x 75°, 330 kHz: 1.8° x 60°, 770 kHz: 0.7° x 30°
Range Resolution	Range Scale/1000
Interface	Analog Telemetry
Towing Speed (max safe)	3 knots
Towfish Material Aluminum	Aluminum
Maximum Operating Depth	300 m
Tow Cable Type	Coaxial
* Does not meet NOAA Shallow Water Survey Specification- Min 3 pings on a 1-meter target at 100 meters range.	

The SSS data was acquired parallel to the river channel geomorphology resulting in 300% coverage. Twenty two main scheme lines were acquired. Cross lines were not possible due to the maneuverability of the vessel under the influence of the flow of the river and the orientation of the SSS.

2.2 Hydrographic Processing

TerraSond exercises a systematic methodology regarding data transfer from the field, processing, editing, and the development of hydrographic products. This rigorous protocol ensures product integrity throughout the processing path.

Prior to processing, the entire field project was uploaded to our server system and included in the regular twice/day backup and daily replication scheme. The data was distributed and organized by the Processing Department prior to further development.

2.2.1 *Application of Control Information*

On July, 30 2009, the TerraSond Survey Department in Palmer, AK received the raw Terrestrial Survey data. The Base station established on RAMP utilized a fixed NGS position during the broadcast of GPS corrections. For this reason all raw data acquired under RTK conditions was inaccurate as recorded by the acquisition software once the CORS reference space was established. This methodology is a commonly practiced technique and resulted in no loss of final processed data precision. The associated navigational error was consistent, systematic, and recoverable.

All survey records required the assumed position error to be compensated for through a global position shift for all points measured. The temporary horizontal (WGS84) and vertical (local USGS) position was shifted from the temporary NGS space measurement to the processed network position computed by TerraSond. The data for each survey was then migrated as a consistent delta shift by an equivalent factor (reference Section 1.4 for more detail).

The 3-dimensional shift was applied to the terrestrial survey in Trimble Geomatics Office suite. The vertical position for each point in the Bathymetric DEM surface was adjusted in Caris HIPS. The Horizontal shift for each point in the Bathymetric DEM surface was accomplished in Trimble Terramodel. The vertical position for each point in the terrestrial laser point cloud was adjusted in Caris HIPS. The Horizontal shift for each point in the terrestrial laser point cloud was accomplished in Trimble Terramodel. The Acoustic Intensity Mosaic image was shifted using Chesapeake Technologies SonarWiz.

2.2.2 *Multibeam Echosounder Processing*

The MBES calibration (commonly called a “Patch Test”) acquired from July 22, 2009 was processed for the identification of temporal latency and MBES orientation errors. This effort was accomplished using the Caris HIPS and SIPS calibration Tool and the correction values were entered into vessel configuration file for CARIS Hydrographic Information Processing System (HIPS) version 6.1.

On July, 30 2009, the TerraSond Processing Department in Palmer, AK received the raw MBES data and associated acquisition records for final processing. HIPS version 6.1 was used for all data processing and adjustments necessary to produce final bathymetric products. The Caris HIPS workflow is designed to ensure that all edits and corrections made to the raw data, and all computations performed with the data followed a specific order and were saved separately from the raw data to maintain the integrity of the raw acquisition data. TerraSond uses well defined procedures during HIPS processing; all actions are tracked to ensure that no steps are omitted or performed out of sequence.

2.2.3 *Vessel Editor*

The first component of the HIPS processing workflow requires establishment of a framework in which recorded navigation, vessel motion, raw (unprocessed) depths and vessel draft are referenced to a common position. The HIPS Vessel Editor is an application used for viewing and editing the position and calibration of sensors installed on the vessel. This information is stored in the HIPS Vessel File (HVF). The HVF is divided into a number of distinct sections, each describing one type of sensor. The sections are time-tagged and multiple entries can be defined for different time periods. The HVF is based on a three-dimensional coordinate system which locates equipment within an X-Y-Z axis using a reference point on the vessel as the point of origin. The reference point for this survey is co-located with the motion sensor which is installed at the vessel's approximate center of gravity; the point at which the least amount of motion is experienced. The position of the multibeam echosounder transducer as well as the static draft (waterline) of the vessel is recorded in the HVF with respect to the reference point. Static draft values were measured on a daily basis for entry in the HVF to track changes in vessel draft caused by loading and fuel consumption. During data acquisition, RTK GPS positioning was referenced from the X-Y-Z coordinate of the GPS antenna phase center to the motion sensor within the vessel coordinate system. All recorded navigation data is referenced to the RP. Therefore, the X-Y-Z coordinates of the GPS antenna phase center need not be entered in the HVF.

2.2.4 *Raw Data Conversion*

CARIS HIPS was used to create a folder structure organized by the project, vessel, and Julian day to store data. Raw MBES data was converted from its native Hypack format, *.hsx files, into CARIS HIPS using the CARIS conversion wizard module. The wizard was used to create a directory for each line separating the *.hsx files into sub-files which contain individual sensor information. All data entries were referenced using the time associated with the *.hsx file to relate the navigation, azimuth, heave, pitch, roll, and slant range sensor files.

2.2.5 *Navigation Editor*

Navigation data was reviewed using the CARIS Navigation Editor. The review consists of a visual inspection of plotted fixes noting any navigation gaps in the data. Additionally, vessel speed, distance between navigation fixes and course made good are examined for anomalies. If any anomalies are detected, the processor may choose to reject or interpolate the affected areas. The data in this project displayed no anomalies with respect to navigation.

2.2.6 *Attitude Editor*

Attitude data was reviewed using the HIPS Attitude Editor. The review consists of a visual inspection of the heave, pitch, roll and GPS (ellipsoidal) height which are displayed simultaneously in a graphical representation using a common x-axis scaled by time. The Attitude Editor, like the Navigation Editor, is used to identify anomalies and has the ability to

interpolate or reject the affected areas. The data in this project displayed no anomalies with respect to attitude.

2.2.7 *Sound Velocity Editor*

Each sound velocity profile, or cast, was examined using the HIPS Sound Velocity Editor for potential outliers prior to its application in HIPS. Erroneous sound velocity changes will cause a concave or convex artifact within the sea floor depth position. This artifact is caused by the sound velocity correction required for the outer beam forming computation. The data in this project displayed no anomalies with respect to sound velocity.

The sound speed adjustment in HIPS uses slant range data, applies motion correctors to determine launch angles, and adjusts for range and ray-bending resulting in a sound speed-corrected observed-depths file. It is recommended that sound velocity correction be executed before cleaning the data.

2.2.8 *GPS Tide Computation and Merge*

Upon review of navigation, attitude, and sound velocity, the vessel positioning was converted from of local datum heights to water level and subsequently to the final CORS space datum. In our case, the tide and GPS tide was the variation of the vessel vertical motion from the position of the base station offset. These processes are referred to as the computation of GPS Tide and Merge. The full formula for GPS Tide is shown below.

GPS Tide = GPS (ellipsoidal) Height - Datum Height - Heave - Waterline Offset

Where:

- **GPS height =** RTK ellipsoidal heights referenced to the vessel RP
- **Heave** = time-tagged measurements of the vessel's vertical motion recorded by the motion sensor and referenced to the vessel RP
- **Waterline offset =** time-tagged waterline levels referenced to the vessel RP and measured daily by the Hydrographer
- **Datum Height:** The distance from the ellipsoid to project datum (USGS Stream Gage Datum).

Once post-processing of the static GPS network was completed (as described in Section 1.1), a value of 0.305 meters was used to shift the datum of the dataset from NGS to CORS space during the HIPS computation of GPS Tide. Finally, the HIPS Merge process was conducted on the dataset. Merge is the process of calculating final positions and depths for soundings, based on all relevant inputs such as observed depths, navigation information, vessel dynamics such as gyro, heave, pitch and roll, and tide.

2.2.9 *Subset Editor*

Following final processing and quality assurance of draft and GPS tide applications, several area-based editing processes in CARIS HIPS Subset Editor were performed during the office review of survey soundings. During subset editing, the processor was presented with two and three-dimensional views of the soundings and a moveable bounding box to restrict the number of soundings being reviewed. Using the two-dimensional window, soundings were viewed from the south (looking north), from the west (looking east) and in plan view (looking down). These perspectives, as well as controlling the size and position of the bounding box, allowed the operator to compare lines, view features from different angles, measure features, query soundings and change sounding status flags. Soundings were also examined in the three-dimensional window that could be rotated on any plane. Vertical exaggeration was increased as required to amplify trends or features. While HIPS does not allow for the deletion of any sounding, spurious soundings (noise) were flagged as rejected during subset editing. Soundings flagged as rejected are excluded from any final bathymetric product.

2.2.10 *Caris BASE Surfaces*

The CARIS HIPS Bathymetry Associated with Statistical Error (BASE) Surface is a 3D, georeferenced image of a multi-attributed, digital terrain model. To build a BASE surface, HIPS assigns a set of gridded nodes at user-defined spacing and bounding coordinates. Each grid node is assigned a depth value based on nearby sounding values. All BASE Surfaces use range weighting to determine how a sounding is applied to a node. Range weighting is based on distance; soundings close to a node are given greater weight than soundings further away. Additionally, all BASE surfaces created for this project use a weighting scheme based on a beam's intersection with the seafloor; soundings formed by the outer beams are weighted less in the algorithm than more reliable nadir beams. BASE surfaces can be used to identify areas requiring further cleaning as well as comprise the final bathymetric product.

Once the sounding dataset was cleaned and all corrections were applied, a 0.5 meter resolution BASE surface was created for use in development of bathymetric products. Points identified to be the shoal point of an object above the ambient sea floor interpreted to be rocks or other anomalous features were designated, exported, and appended to the gridded DEM surface in order to minimize the height attenuation of obstructions common to surface generation.

2.2.11 *Processing of Side Scan Sonar*

All main scheme lines were processed and evaluated for DtoN and HforC obstructions. Select lines were used during mosaic production. The software used to process this data was Chesapeake Technologies SonarWiz Map 4.04.0052 (SonarWiz).

SonarWiz.MAP software was used to create a folder structure organized by Julian day to store data. Side scan raw data (.hsx) files were imported into SonarWiz.MAP using the SonarWiz.MAP Import Side Scan Files function, which converted the sonar files into

SonarWiz.MAP compatible .csf format. SonarWiz.MAP does not permit raw data manipulation during processing. All raw data is maintained in the original, unmodified, format to ensure data integrity.

TerraSond uses well defined procedures during side scan data processing and all actions are tracked to ensure that no steps are omitted or performed out of sequence. After conversion, vessel navigation data was visually evaluated for inconsistent, erratic, or unrealistic changes in speed, distance, and course made good. The side scan lines were opened in the SonarWiz.MAP Bottom Track Editor where towfish altitude was manually digitized; this is the process of digitizing the floor or removing the water column from the record. The final process applied to the side scan sonar data was the application of XY offsets to represent the tow point with respect to the central reference point (CRP) of the vessel to correctly position the data geographically, the offsets are as follows:

The side scan record was carefully examined for significant obstructions and classified as contacts in the slant-range corrected record. Significant contacts included, but were not limited to, contacts with a shadow length indicating a contact height of 1.0 m or greater. Contacts were digitized using the contact tool in SonarWiz.MAP Side Scan Digitizer View. Each contact was automatically assigned a unique identifier based on the date, time, and channel (port or starboard). Once identified, the contact's length and width were measured with the Measure Length and Measure Width tools and the contact shadow length was measured using the Measure Shadow tool. SonarWiz.MAP automatically calculates contact height once the shadow length is measured. Additionally all contacts were assigned a S-57 classification attribute and feature name. SonarWiz.MAP generated an image of each digitized target and included a corresponding text file containing all recorded information specific to the contact and placed the contact in the project folder.

Contacts were then exported as targets to an ESRI shape file. This information was then spatially referenced with MBES data for evaluation and reporting. The product of target classification was obstacle detection, identification, and positioning in the form of an Obstruction List.

Select lines with the best representation of river bed coverage and meaningful albedo were selected to contribute to the acoustic intensity mosaic image.

2.3 Hydrographic Products

While the HIPS workflow allows for application of vertical changes in order to perform datum transformations and adjustments, the software does not allow for horizontal migration.

The 0.5 m resolution BASE surface was exported to X-Y-Z ASCII format, imported into Trimble Terramodel Software, and horizontally shifted by the values described in Section 1.4. Terramodel is a drafting and analysis tool used for analyzing three dimensional terrestrial data. The horizontal projection of the dataset is Alaska State Plane, NAD83, Zone 2 and all soundings

are vertically referenced to Local USGS Gage Station ID 15356000. All units are expressed in usft.

The horizontal shift of the mosaic and the bathymetric MBES surface (DEM) by the CORS space correction was the final processing step in the processing flow.

2.3.1 *Bathymetric DEM gridded dataset and imagery*

The regular gridded Digital Elevation Model surface is a critical product. This surface is the foundation for all charting, positioning, and it is the reference surface for the obstruction list and the SSS deliverables. This surface was considered in each interpretation and during the generation of all location positions.

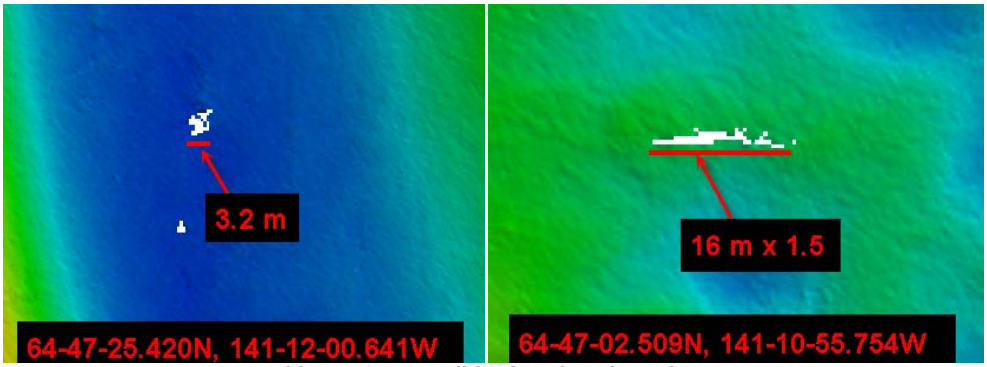
The sole origin for this digital DEM is the MBES point file. The high density data from the MBES is often too large to manage by most software suites. TerraSond reduces the data through the process of surface generation in Caris HIPS software.

The number of points in the original post processed and post edited surface that was used to generate the DEM was 51,447,127 points. The number of points in the final DEM product distributed with this report is 1,020,931 points.

There is a small loss of detail that develops as we reduce the data that makes up the surface of the DEM product. This loss is directly related to the node spacing established in the final surface. The exact location of loss is not known nor controlled. During regular gridding, TerraSond will not have control of the data that is reduced. We will not be able to confirm that the most shoal depth of an obstruction is the exported grid point nor if it is properly represented in the DEM. For this reason all values for shoal height are conservative and were exported as a shoal biased grid. For the reasons stated above, we cannot verify more vertical precision in the DEM obstructions depths finer than sub meter precision. The horizontal precision is accurate to 0.5 m and obstruction identification resolution is 1 m^3.

The DEM surface was generated from referencing a maximum footprint size 5x5 grid cells with a minimum of 6 nearest neighbors. The DEM product grid spacing was 0.5 meter distance.

This surface was interpolated in order to maintain the high level of detail necessary for obstruction detection and interpretation, however, several holidays were present in the final surface. TerraSond filled the holidays present in the 0.5 m surface grid with information by applying an interpolation function contained in the Caris processing software which allowed for the generation of a contiguous image. Most holidays between swath lines were insignificant and no obstruction could be present without notice, however, two locations did have gapes in the data that could hide a significant obstruction.

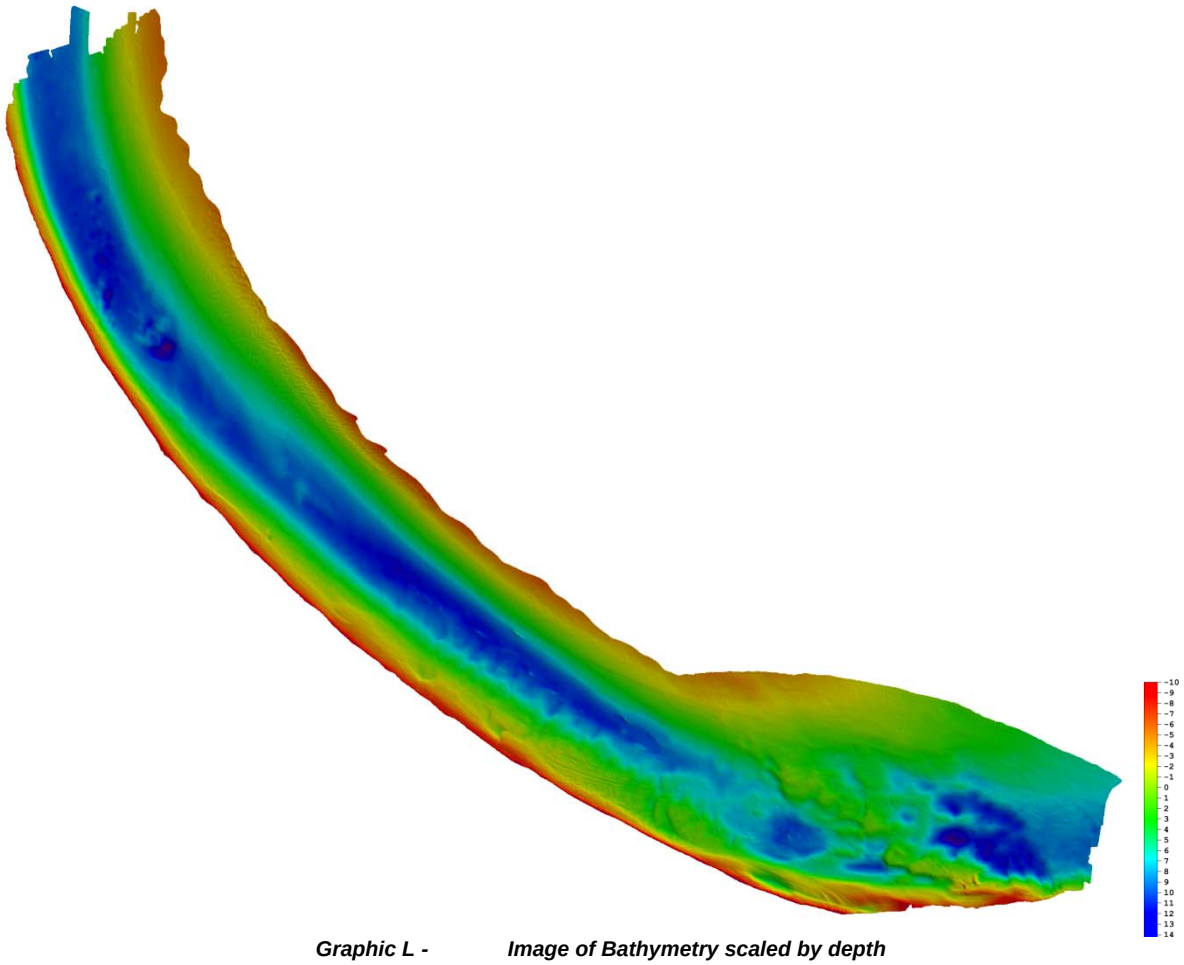


Graphic K - Holiday locations in Bathymetry

The geodetics for the output file are Alaska State Plane zone 2 projected as NAD83 and the units are usft for the horizontal dimension. The vertical dimension (positive axis up) is also in units of feet and is based upon the datum of USGS Stream Gage (Station ID 15356000 at the monument position of RAMP (CORS space).

This surface was included in the Caris Easy View file bundle and distributed on both the TerraSond FTP site and included in the DVD data distribution which accompanies this report.

Two images with different color scales have been generated from this DEM. Both are the same except for the inclusion of the color purple in the spectrum. All images which do not include the purple in the color scale spectrum are suitable visualization with common 3D glasses for a enhanced visualization and interpretation by the viewer. The files that included purple in the color scale spectrum are intended for finer differentiation of depth and digital distributions, but do not visualize well through 3D glasses.



Graphic L - Image of Bathymetry scaled by depth

2.3.2 *Acoustic Intensity Mosaic*

The Acoustic Intensity Mosaic is a compilation of selected SSS lines which best visualize the riverbed spatially and through albedo spectrum. The lines are assembled as a stack of linear image files processed with Automatic Gain Control algorithm. The compilation was digitally compiled in SonarWiz.MAP and the seams were digitally muted through the *cover-up* software option.

There are lineations in the mosaic which can be attributed to the image boundaries and should be recognized as artifacts of the images when viewing this mosaic. Two sources of lineation artifacts are present in the mosaic; image boundaries and nadir stitching.

Graphic M - Acoustic Intensity Mosaic Image

2.3.3 *Obstructions Target List*

The Obstruction Target List is a composite table from both the MBES and the SSS surveys and the interpretation of obstructions from those data. The terminology of the obstructions list is not consistent with the terminology found in NOS Hydrographic Surveys Specifications and Deliverables, NOAA, Dept. of Commerce, 2009. The criteria were modified by the Project Hydrographer to a more stringent project specific standard.

One criterion stated in the NOS Hydrographic Surveys Specifications and Deliverables regarding Danger to Navigation is stated as:

"Depths from the present survey which are found to be significantly shoaler then the charted depths or features, and are navigationally significant (typically depths of 11 fathoms (fms) (66ft) or less)."

A typical standard for obstruction interpretation for navigation charting is:

"1.0 m proud of the seafloor in depths < 11 fms or 10% of depth in depths > 11 fms"

TerraSond recognizes that this project will required the vessels to land on shore and will require considerations beyond the definition established for commercial vessels transiting navigable waters. The standard implemented for this project considered the grounding of vessels on the river bank for the transfer of personnel and equipment. We considered the power cable route and the possibility of interference with structural or anchor cable siting. The methodology implemented considered the construction work that is envisioned upon the river bed.

The contributing surveys to the Obstruction List are:

- Left River Bank Visual Inspection and Terrestrial Survey
- Multibeam Echosounder Sonar Survey
- Side Scan Sonar Survey

The Shoreline Danger to Navigation surveyor was not given direction to identify only objects that have 0.5 m or greater relief. The criteria for that survey were based upon a judgment from the field acquisition surveyor for any object that was fixed to the riverbed matrix and would not "give" if struck by a vessel. A large flat rock on the seafloor is an example of an obstruction classified as a DtoN by the criteria used during this phase of the evaluation that would not be classified as a DtoN under the NOS standard. No significant obstructions were identified on the river bank worthy of note.

The criteria for the Obstruction List during the cable route to shore included the Shoreline DtoN survey data, the MBES survey data, and the Side Scan survey data. The criteria for the obstructions identified for the river bank (near shore) portion of the cable route are consistent

with the criteria listed in the paragraph above. The criteria for the obstruction interpretation are depth/relief dependent. TerraSond determined the depth boundary of 5 ft for the depth transition for obstruction classification.

This project used the standard for Danger to Navigation as:

DtoN = “0.5 m proud of the river bed in depths < 5 ft (Local Datum)”

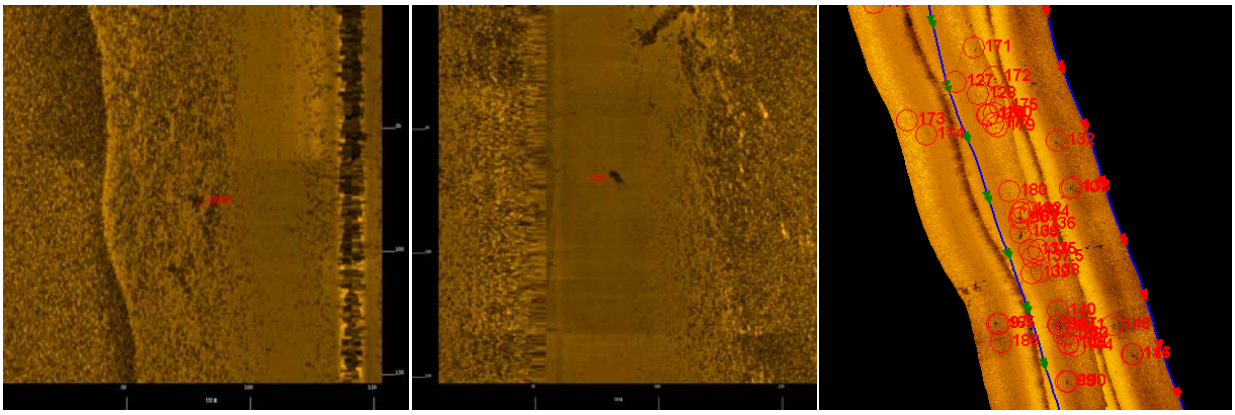
The methodology used for the classification was based upon the maximum estimated keel depth of any vessel traveling the river at very low water stage of 0 ft USGS datum.

Danger to navigation was not the only obstruction criteria for this project. The criteria required consideration for hazards for construction as well. TerraSond addressed this issue by classifying all obstructions ≥ 0.5 m in depths < 5 ft as DtoN. TerraSond classified all obstructions ≥ 0.5 m in depths > 5 ft as HforC. By this definition, all DtoN should be considered potential HforC. However, all HforC should be deeper than potential interaction with vessel traffic and will theoretically not be DtoN.

This project used the standard for Hazards for Construction as:

HforC = “0.5 m proud of the river bed in depths > 5 ft (Local Datum)”

Contacts identified in the Side Scan sonar were interpreted by sonar processors. Contacts were considered during geologic and obstruction interpretations and the contact list from this effort is extensive (reference Table Five). Of the contacts identified in the SSS a subset was evaluated for DtoN and HforC. Shadow height and other measurement tools were utilized during this interpretation, however, all dimensions for DtoN and HforC were ultimately measured from the MBES data. The SSS contact processing was accomplished using Chesapeake Technologies SonarWiz Map 4 v. 4.04.0052.

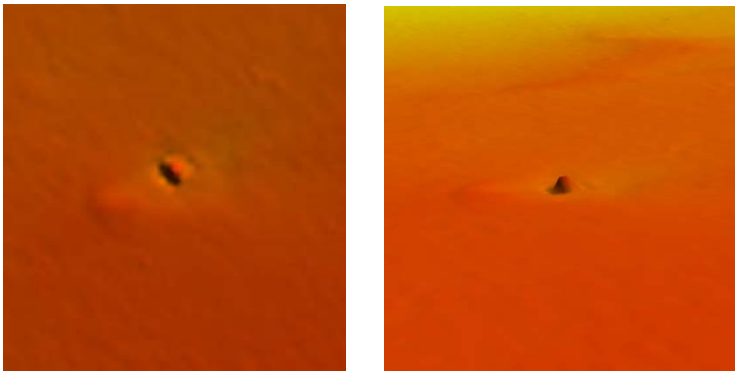


Graphic N - Example of contact from preliminary processing of SSS

There is consistent acoustic interference from an environmental source on the starboard channel near the nadir which is visible in most lines (width varies with depth but typically ~35’;

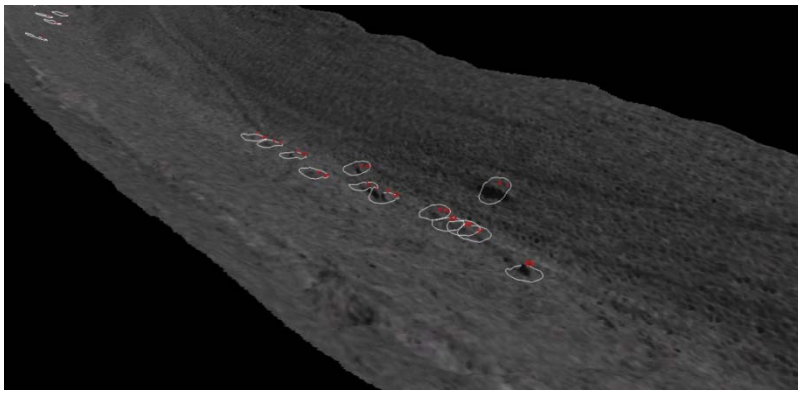
Figure 5). Attempts with gain and filters were not effective in restoring resolution to the area. In regions with strong river bottom relief, such as the patch of bed forms (Figure 6), a signal is in fact visible throughout the side scan image. Only in those areas where backscatter is more even does the dropout become obvious. Since the artifact could not be wholly repaired, only the port channel of lines has been used where possible, and the starboard channel is visible only where it fills in edges and gaps between the port channel records.

Contacts in the bathymetric data were initially evaluated during the processing of the MBES. The contacts identified from the MBES were much more reliable then the data from the SSS. Preference for position, depth, and often general shape were determined from the MBES data.



Graphic O - Example of MBES contact demonstrates geo character of the obstruction

The MBES contact can often be interpreted for characteristics which can indicate persistence such as the images above demonstrate recognizable scour properties. Although no definitive information can be determined, geo characteristics such as these were considered during obstruction interpretation and hazard for construction evaluations. Final interpretation of the MBES obstruction heights used Caris Easy Viewer 2.0. Obstruction positions identified in MBES were ultimately evaluated against SSS mosaic imagery overlaid upon the DEM surface for positional agreement. This effort was accomplished using Fledermaus Professional software (version 7.0D).



Graphic P - Series of HforC Side Scan mosaic draped over MBES DEM during contact verification

The mosaic was draped over the DEM for 3D comparison during the DtoN and HforC analysis. Reference Graphic P for an image of the mosaic draped over the DEM presented with Obstruction List in Caris Easy View.

Obstruction List

Target Designation		ASPNAD83z2 Position		Geodetic Position		Shoal Depth	Volume
Contact ID	SSS Name	Easting ft	Northing ft	Latitude	Longitude	ft	ft^3
DtoN 01	Target0001	1768531.156000	3941554.296000	64.783229	-141.178802	1.6	91.3
HforC 01	Target0003	1767078.312000	3942071.615000	64.784695	-141.188070	8.1	1234.8
HforC 02	Target0005	1767079.938000	3942115.584000	64.784815	-141.188056	7.2	4214.8
HforC 03	Target0007	1766932.203000	3942129.975000	64.784859	-141.189002	9.1	192.5
HforC 04	Target0006	1767007.584000	3942139.974000	64.784884	-141.188518	8.9	98.4
HforC 05	Not Seen in SSS	1766760.791000	3942261.595000	64.785225	-141.190090	8.0	854.7
HforC 06	Not Seen in SSS	1766707.058000	3942328.727000	64.785411	-141.190429	10.0	26.9
HforC 07	Not Seen in SSS	1766695.116000	3942337.754000	64.785436	-141.190505	9.9	41.9
HforC 08	Not Seen in SSS	1766678.563000	3942343.871000	64.785453	-141.190610	8.9	97.5
HforC 09	Target0009	1766659.759000	3942369.513000	64.785524	-141.190729	10.3	87.9
HforC 10	Target0011	1766597.543000	3942396.131000	64.785599	-141.191125	9.1	2628.9
HforC 11	Target0010	1766718.376000	3942397.822000	64.785599	-141.190351	6.1	2224.1
HforC 12	Target0013	1766567.086000	3942421.457000	64.785669	-141.191319	10.9	165.5
HforC 13	Target0012	1766506.447000	3942424.036000	64.785678	-141.191707	8.7	486.4
HforC 14	Not Seen in SSS	1766544.897000	3942468.622000	64.785799	-141.191457	10.2	529.5
HforC 15	Target0014	1766458.954000	3942479.449000	64.785831	-141.192007	9.1	791.2
HforC 16	Target0015	1766413.747000	3942514.019000	64.785927	-141.192294	9.5	253.8
HforC 17	Target0016	1766382.272000	3942533.087000	64.785981	-141.192494	9.1	245.7
DtoN 02	Target0018	1765848.866000	3942796.253000	64.786719	-141.195892	-0.6	200.6
DtoN 03	Target0021	1765679.799000	3943048.867000	64.787415	-141.196955	4.8	72.1
DtoN 04	Target0023	1765622.497000	3943095.253000	64.787544	-141.197318	4.5	38.0
DtoN 05	Target0024	1765513.557000	3943179.212000	64.787777	-141.198010	3.3	63.8
HforC 18	Target0025	1765594.674000	3943180.449000	64.787778	-141.197490	6.5	84.8
DtoN 06	Target0026	1765488.502000	3943225.881000	64.787906	-141.198167	3.3	39.0
HforC 19	Target0030	1765336.959000	3943530.174000	64.788743	-141.199113	12.0	50.6
HforC 20	Target0032	1765223.317000	3943753.443000	64.789357	-141.199824	8.7	45.8
DtoN 07	Target0033	1765066.403000	3943944.963000	64.789886	-141.200814	-5.3	112.4
HforC 21	Target0034	1765102.978000	3944319.243000	64.790908	-141.200549	7.6	52.4

Table Five Table of Obstruction List

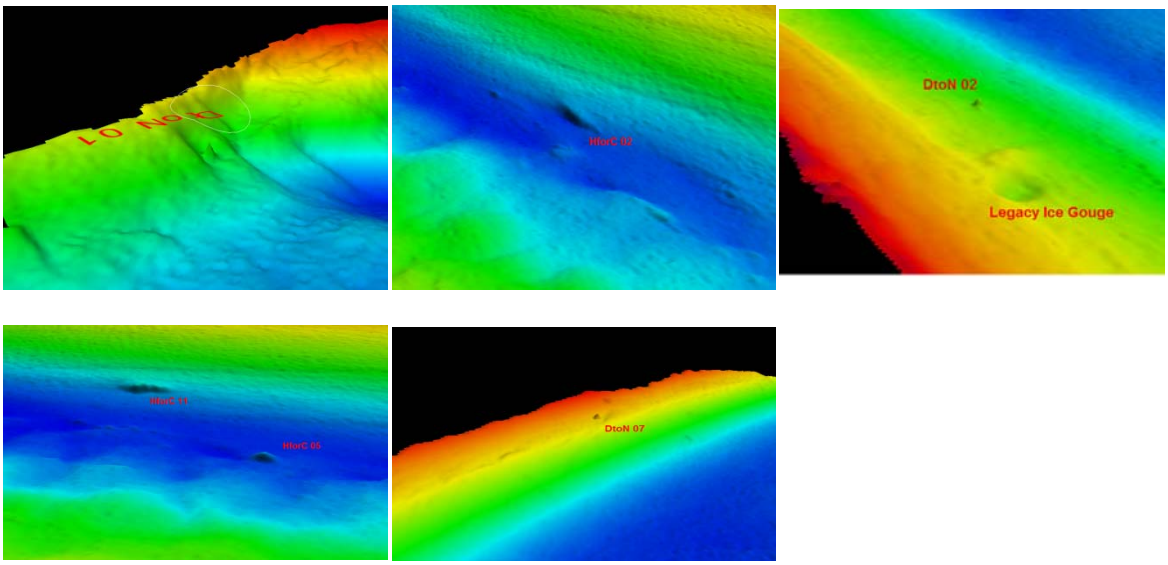
Each of the Dangers to Navigation and the Hazards for Construction meet the criteria discussed above and should be avoided if possible. However, the interpretation of the geo characteristics indicate that most of the shoal features noted above appear consistent with unconsolidated sediments which are shaped by current flow. If this is the case, many of the Hazards for Construction noted above may not be problematic or persistent. They may be sediment depositional bodies in some process of migration which at the time of survey where measured to have a shoal height fit with the criteria for Hazard for Construction.

That said, there are several DtoN and HforC that Terrasond would like to bring special attention to. These features are believed to be persistent and to be in particularly problematic locations which are likely to endanger river operations or power conversion infrastructure.

Significant Obstructions							
Target Designation		ASPNAD83z2 Position		Geodetic Position		Shoal Depth	Volume
Contact ID	SSS Name	Easting ft	Northing ft	Latitude	Longitude	ft	ft^3
DtoN 01	Target0001	1768531.156000	3941554.296000	64.783229	-141.178802	1.6	91.3
HforC 02	Target0005	1767079.938000	3942115.584000	64.784815	-141.188056	7.2	4214.8
HforC 05	Not Seen in SSS	1766760.791000	3942261.595000	64.785225	-141.190090	8.0	854.7
HforC 11	Target0010	1766718.376000	3942397.822000	64.785599	-141.190351	6.1	2224.1
DtoN 02	Target0018	1765848.866000	3942796.253000	64.786719	-141.195892	-0.6	200.6
DtoN 07	Target0033	1765066.403000	3943944.963000	64.789886	-141.200814	-5.3	112.4

Table Six Table of Significant Obstructions

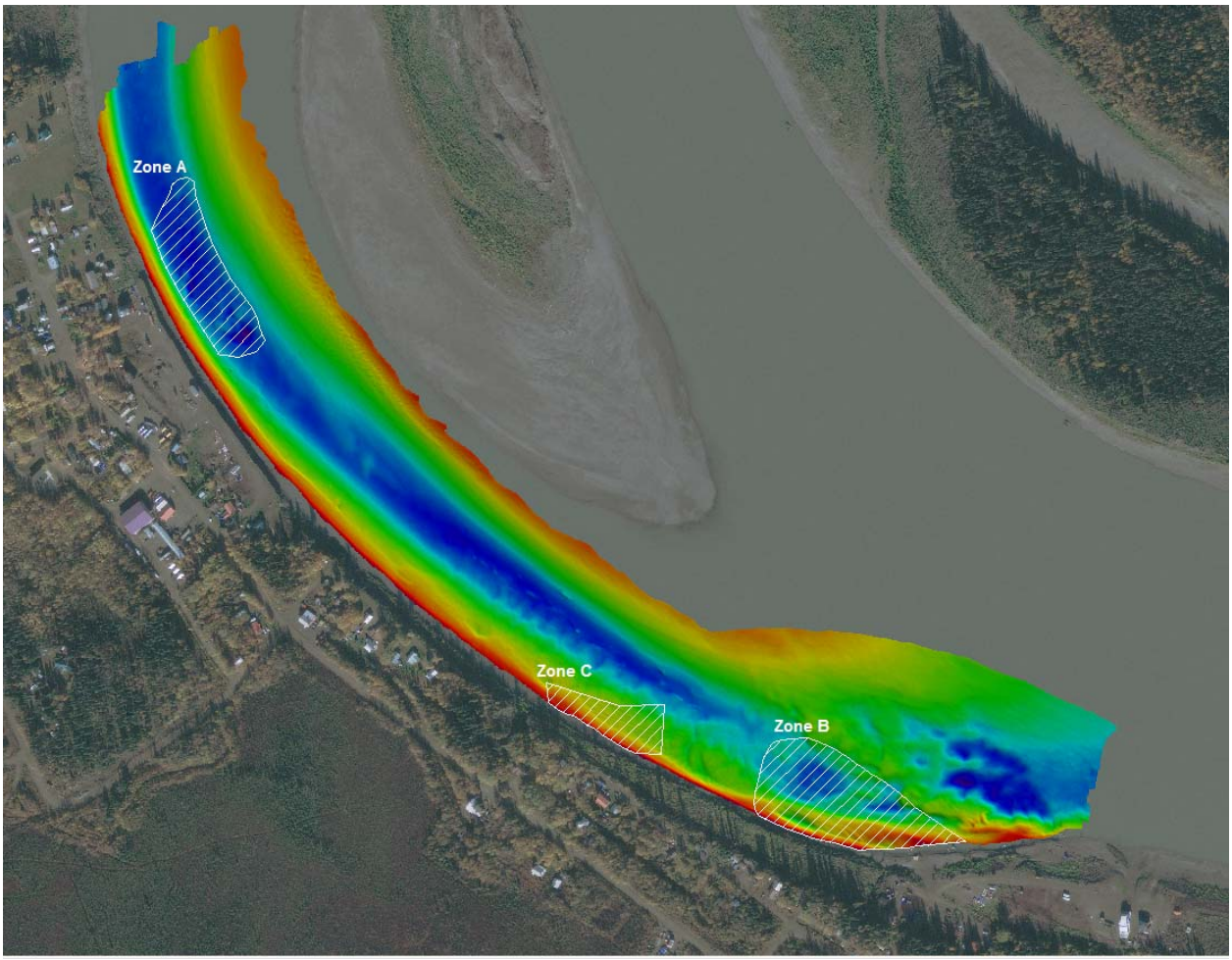
The obstructions listed in the Table of Significant Obstructions are hazards which present in locations where future river operations are likely to interact with the obstruction and/or the obstruction is interpreted to consist of more consolidated materials.



Graphic Q - Imagery of Significant Obstructions

2.3.4 *Zones of Caution*

Three areas within the project survey area were determined to be note worthy during the interpretation of the multibeam data. TerraSond does not believe that these zones will prohibit the development of the power conversion project, however, these zones potentially could contribute to problems with long term permitting and/or infrastructure survivability. TerraSond recommends avoiding these areas or implementing mitigation methodologies until more information is known about each area. TerraSond recommends periodic surveillance of these areas in order to identify change to the river bed over time.



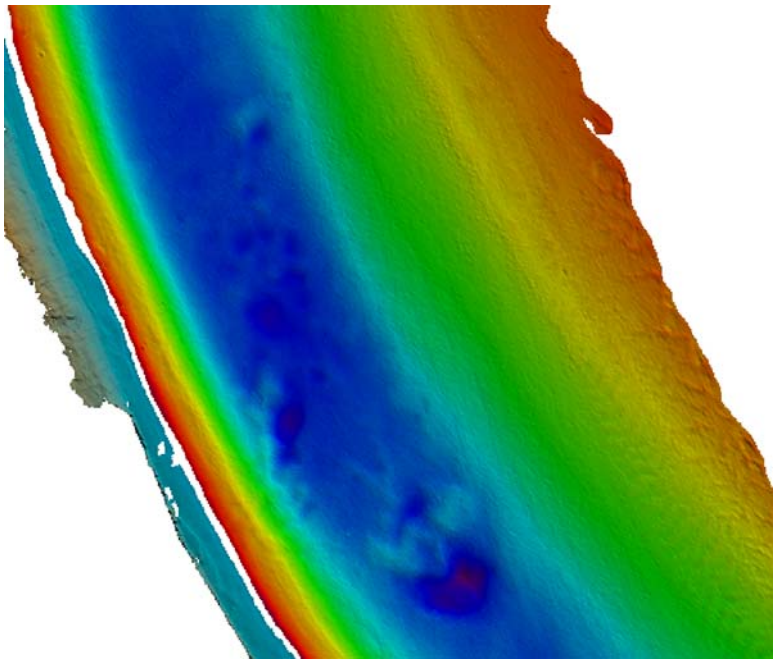
Graphic R - Warning Zones

Zone A – Disturbed Thalweg

Area A represents a disturbed Thalweg. It is unknown at this time if this is a natural result of the river turbulence due to the arc of the river or if this is a product of an ice gouge into the riverbed as the ice moved through the channel during the recent flood event. This survey demonstrates that this area was disturbed prior to the power conversion build out and cannot be associated with the future turbine installation. This survey will represent a baseline measurement for this location.

This represents a weakness in the riverbed structure. If this is a new feature from recent Ice gouge, this may become exaggerated over time or may simply fill in over time. If this is a result of river turbulence, this effect in the riverbed structure may become exaggerated with the installation of the mooring and turbine. Sediment transport (scour or deposition) is expected to occur over time at this location. New infrastructure may contribute to this process and

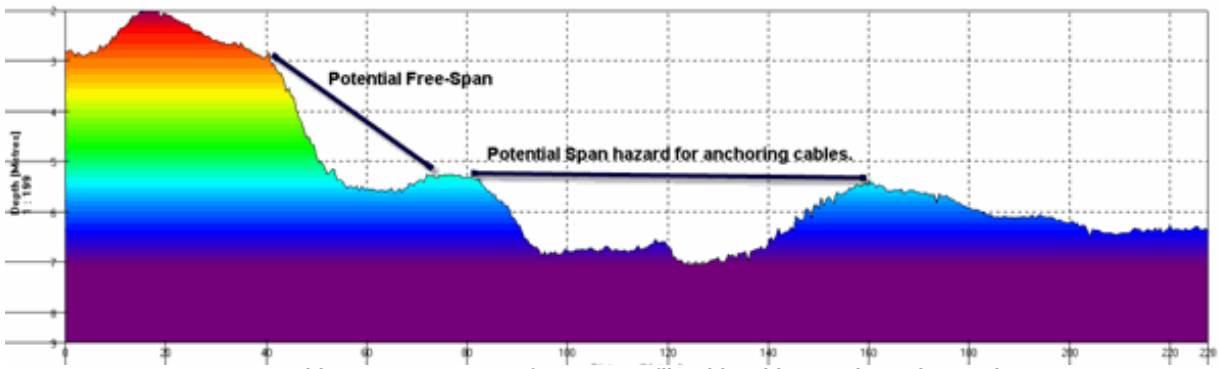
TerraSond recommends observing this site in future sediment transport studies after the installation of the power conversation turbine infrastructure.



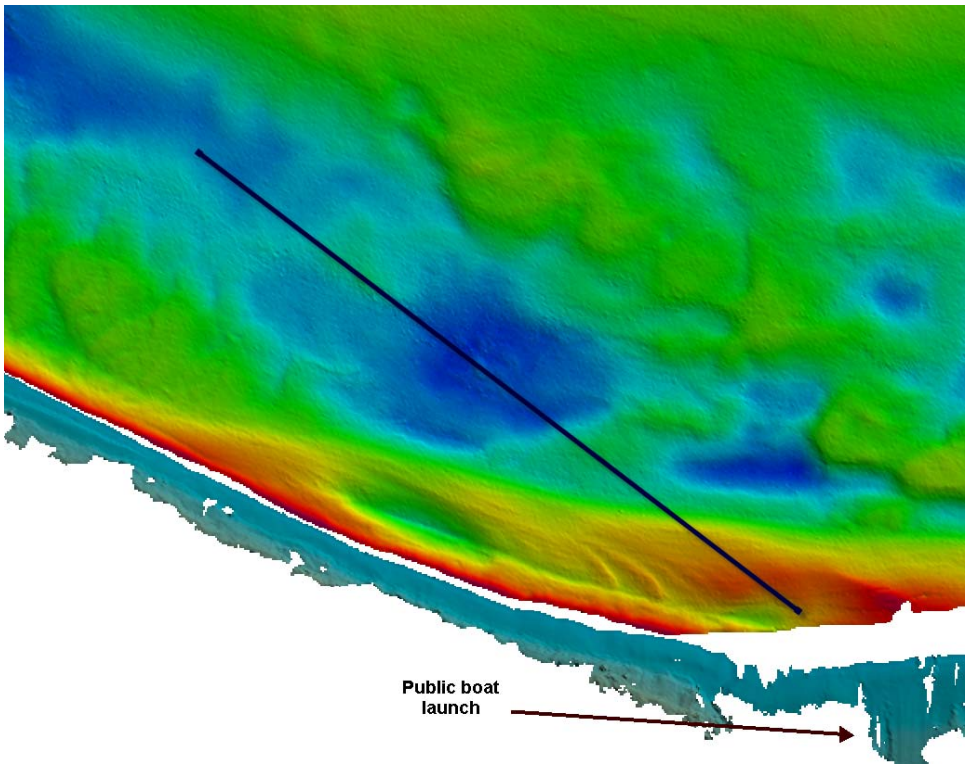
Graphic S - Image showing the river bed disturbance for Zone A

Zone B – Span Hazard for Cabling

Zone B represents a potential hazard for cabling. The profile indicates a location for a Free-Span as well as a likely site for a span. Although both represent potential hazards for cable survivability, the Span geomorphology indicates an area of significant and persistent erosion. This site may contain currents with rotational forces which may thrum or vibrate cabling. If this area can not be avoided by the anchor cables strategy intended for this site, then TerraSond recommends mitigation techniques such as tighter anchor spacing and/or maintenance strategies such as sand bag placement to reduce the likely hood for vibration.



Graphic T - Image of Zone B profile with cable span hazards noted

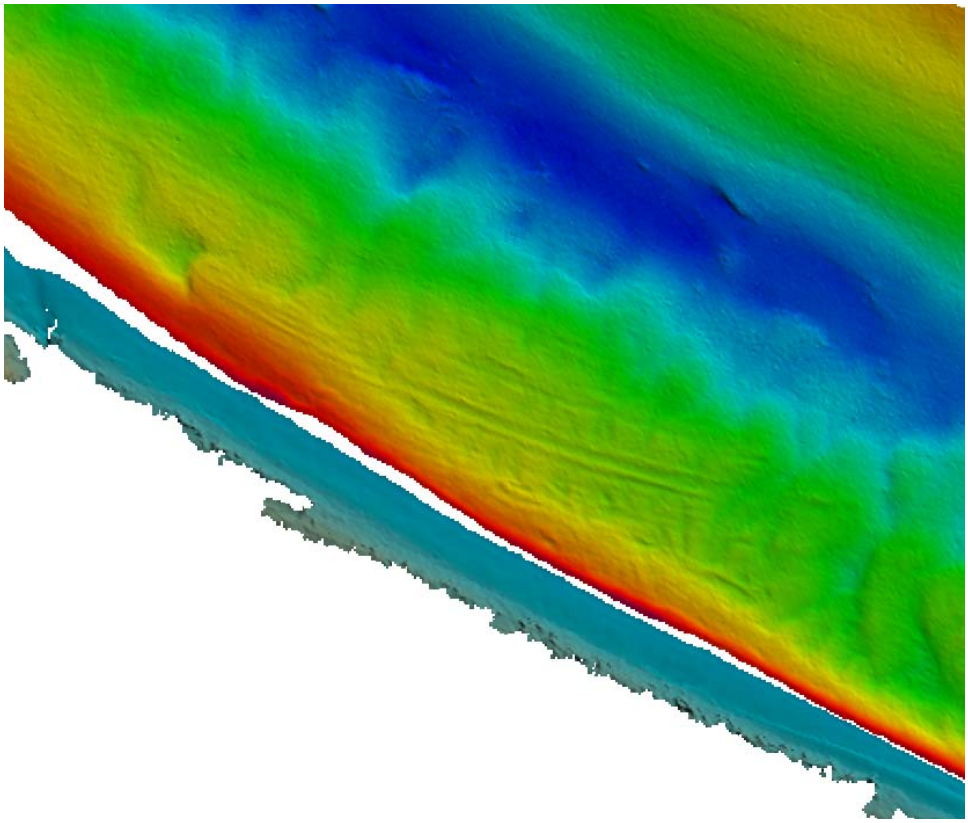


Graphic U - Zone B profile location

Zone C – Ice landing Zone

Zone C indicates significant force upon the riverbed in the form of ice scour marks concurrent with the flow of the river. This site may be a natural landing site for the ice during breakup events. This record may be the result of the unique catastrophic ice event of 2009 or it may be a natural landing for yearly ice movement in the arc of this river. TerraSond recommends avoiding

this area for persistent (multiyear) infrastructure such as anchoring systems or power connections.

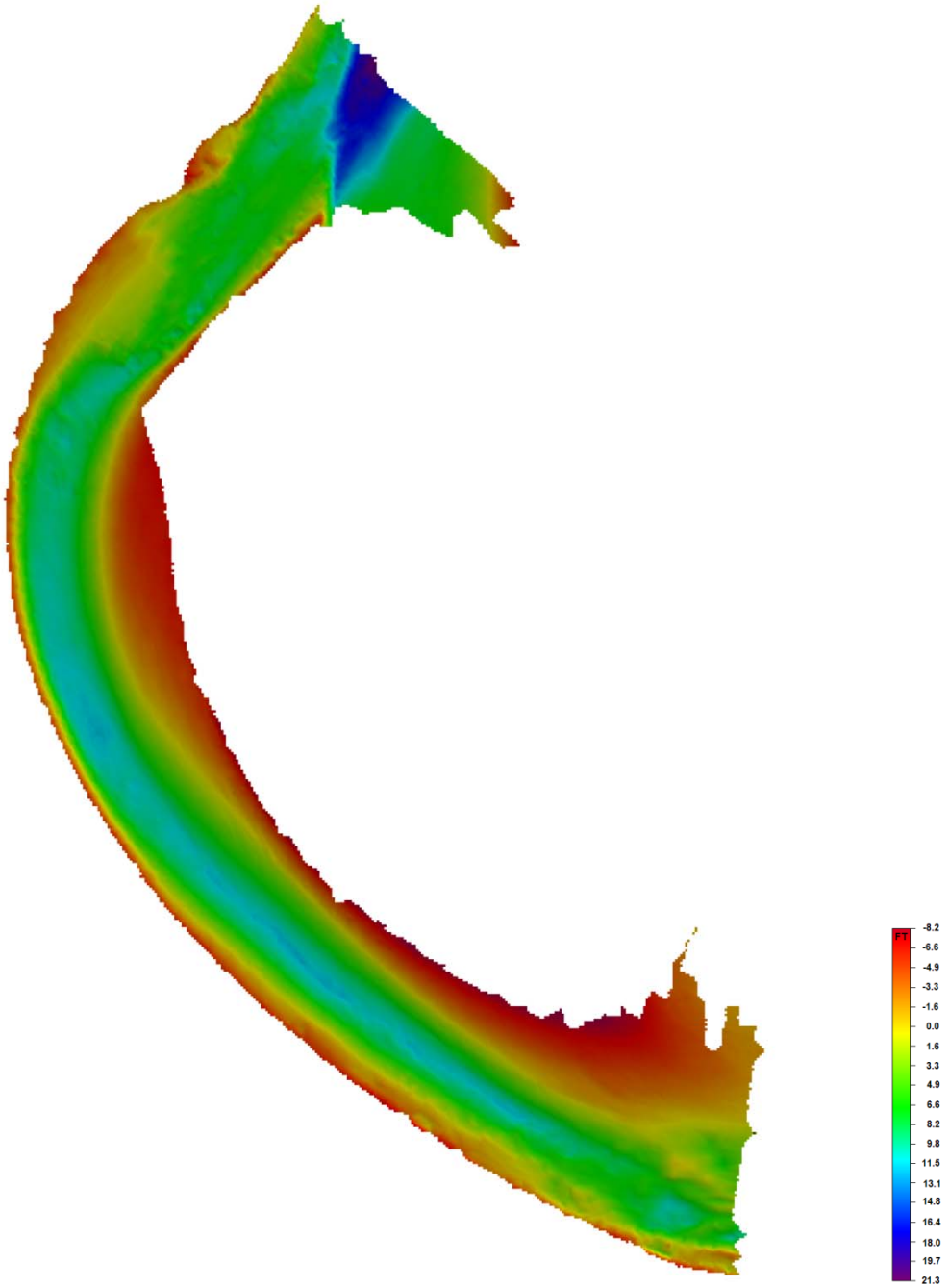


Graphic V - Ice scour indicates on bank indicates high chance for ice landing at Zone C

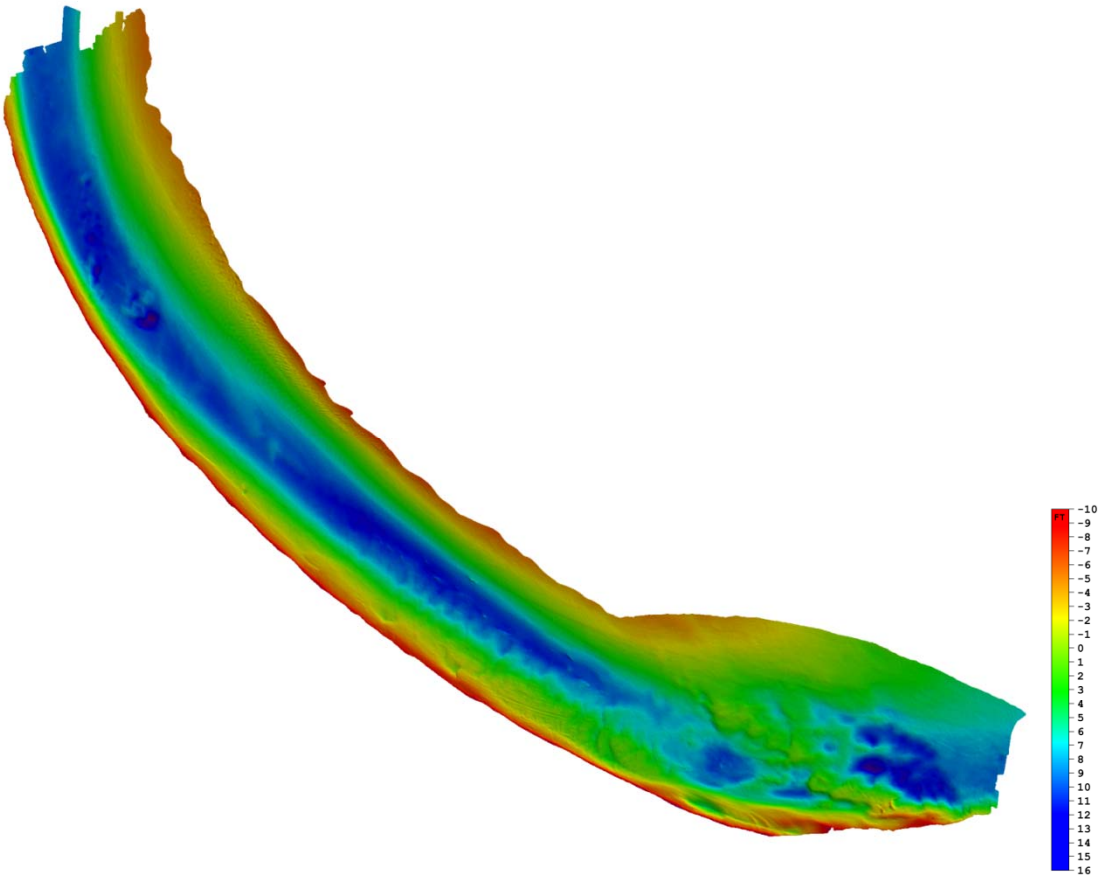
Planning of contingencies should include wake impact, evasion strategies, and break off or cutaway procedures. Windows of opportunity for operations of this nature can be identified in a desk top study for consideration which includes sea state and weather probability as well as vessel traffic forecast.

2.4 Bathymetric Comparison

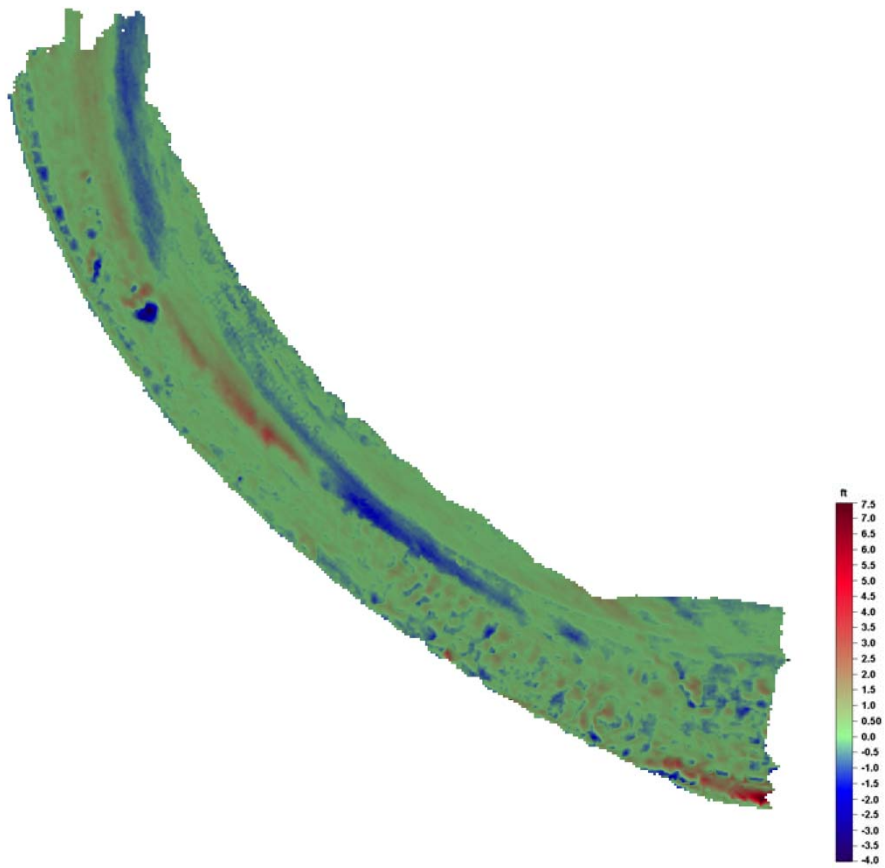
The bathymetry from both the 2007 and the 2009 data sets were compared and evaluated for change. It is important to recognize when viewing this image that the sparseness of the 2007 data does not directly correlate with the very dense data of 2009. Fine detail such as the main ice gouge was not satisfactorily measured in the 2007 survey to allow it to be fully described if it was present. This is also the case with the significant depositional accumulation in the southern portion of the survey area. The detail of the 2009 survey indicates a large accumulation of sediment in the surface difference computation (Graphic Y), yet, when compared with the 2007 data, it is clealy at the end of the survey zone and would not have been properly illustrated when the TIN surface was generated. Only large scale (> 20 m^2) differences in bathymetry can be considered to be valid in this graphic for the reasons state above.



Graphic W - 2007 depth scaled bathymetry



Graphic X - 2009 depth scaled bathymetry



Graphic Y - Color scaled representation of surface difference between the 2007 and 2009

The surface difference between the 2007 and the 2009 project show significant variation between the two surfaces, however, there is no evidence for channel wide changes or channel migration. The most significant changes occur along the center of the channel. The thalweg initially shows scour near the beginning of the island as the river flows down river toward the north. The thalweg then accrued sediment during the latter half of the thalweg.

The source of this material is not easily identified and several explanations would satisfy the results. The first and most probable explanation is that the material is sourced from upriver and lot locally. It is reasonable to interpret that the later portion of the arc in the river drags velocities. During the disturbed aftermath of the flood event significant sediment was available for deposition.

A likely local sediment from the scoured thalweg material at the beginning portion of the thalweg migrated down river a short distance during the most forceful flow epoch. Another explanation could be that a general slumping off Bell Island followed the gravitational flow lines into the thalweg. This idea is supported by the attrition of the island bank. The thalweg erosion would

require significant force to mobilize the cobble sediment identified in the 2007 geophysical interpretation and geological sampling effort. Sediment volume computations were beyond the scope of this project and TerraSond has not fully investigated either of these scenarios. TerraSond does believe that more definitive conclusions are available from this data if sediment transport studies are become a priority in future efforts.

Although it is not unreasonable to associate a changes in river bathymetry with the recent flood event, TerraSond does wish to point out that this a naturally dynamic environment and that the seasonal difference between the 2007 and 2009 surveys could also account for a difference of this small magnitude.

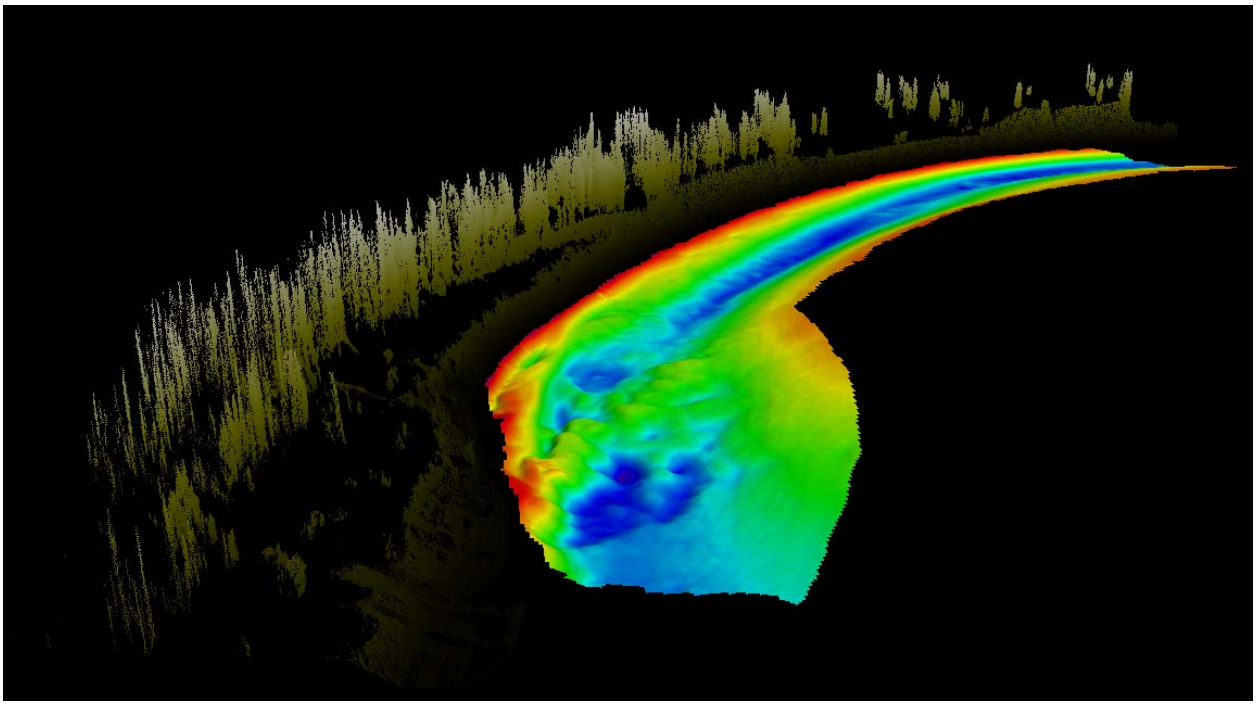
2.5 Important note

TerraSond understands that the information gathered for this project is intended to facilitate the planning of river construction projects and that our data may contribute to safe waterborne operations. This data is not to be used for navigational purposes. This data should not be used to replace any publication distributed by NOAA, nor does TerraSond assume any responsibility for safe navigation or safe marine operations. The distributions of the obstruction data recorded during July, 2009 may or may not contain valuable information regarding vessel navigation.

For that reason, TerraSond recommends avoiding contact locations, but does not guarantee that additional unobserved or uninterpreted hazards are within the boundaries of this project. TerraSond does not guarantee that interpreted obstructions are persistent nor that potential obstructions will be present at a future date. Natural/manmade hazards in this project area are dynamic and are known to be spatially transitory.

The use of products provided by TerraSond are only valid for the moment of acquisition and all forecasts, assumptions, or logical conclusions are wholly the responsibility of the user. The use of such products in conjunction with the products of agencies responsible for navigation safety (i.e. NOAA, USACE, USCG, etc.) is highly recommended.

3.0 SCANNING LASER & TERRESTRIAL SURVEY



Graphic Z - Side Scan Mosaic Image draped over 3D digital terrain model from MBES data.

On July 19, 2009, TerraSond mobilized *M/V Ducer*, a custom 19 ft aluminum survey vessel for marine based lateral LiDAR operations. The vessel mobilization took place at TerraSond's shop and was completed prior to expedition departure for Eagle, Alaska.

TerraSond was tasked with acquiring high density measurements of the left bank of the Yukon River. The goal for this measurement was to provide a baseline surface of the embankment prior to development. The data from the LiDAR is intended for planning purposes, future erosion and sediment transport studies, and future modeling efforts.

3.1 LiDAR Acquisition

On July 22, 2009 Terrasond collected laser data utilizing the Riegl LMS-Q120 system in Eagle Alaska. The system was fix-mounted to the top of the starboard cabin of the *M/V Ducer.*

Graphic AA - M/V Ducer in transit to acquire Vessel Mounted LiDAR data

The Riegl LMS-Q120ii 2D laser scanner measures with accurate non-contact line scanning by using a narrow infrared laser beam. The instrument makes use of the light speed and range measurement principles to provide very precise and accurate measurements of distance. It uses fast line-scanning by means of a high-speed optomechanical scan mechanism which provides fully linear, unidirectional, and parallel scan lines.

Simultaneously, a camera mounted to the vessel took event shots every 5 seconds for ground optical visualization. This visualization is very important during the processing portion of the work flow.

3.2 LiDAR Processing

TerraSond, Ltd. incorporates a systematic, rigorous approach to the editing and development of raw survey data received from the field. This ensured the maintenance of data integrity throughout the editing process.

On July, 30 2009, all data were transferred to the TerraSond Ltd. Palmer, AK office for calibration, processing and product development. A complete backup of the field project was created immediately before organization on the Terrasond server for further processing

3.2.1 *CARIS Processing*

CARIS Hydrographic Information Processing System (HIPS) version 7.0 was used for all data processing and adjustments necessary to produce final bathymetric products. The Caris HIPS workflow is designed to ensure that all edits and corrections made to the raw data, and all computations performed with the data followed a specific order and were saved separately from the raw data to maintain the integrity of the original data. TerraSond, Ltd. uses well defined procedures during HIPS processing; all actions are tracked to ensure that no steps are omitted or performed out of sequence.

3.2.2 *Vessel Editor*

The first component of the HIPS processing workflow requires establishment of a framework in which recorded navigation, vessel motion, raw (unprocessed) depths and vessel draft are referenced to a communal position. The HIPS Vessel Editor is an application used for viewing and editing the position and calibration of sensors installed on the vessel. This information is stored in the HIPS Vessel File (HVF). The HVF is divided into a number of distinct sections, each describing one type of sensor. The sections are time-tagged and multiple entries can be defined for different time periods. The HVF is based on a three-dimensional coordinate system which locates equipment within an X-Y-Z axis using a reference point on the vessel as the point of origin. The reference point for this survey is co-located with the motion sensor which is installed at the vessel's approximate center of gravity; the point at which the least amount of motion is experienced. The position of the Laser as well as the static draft (waterline) of the vessel is recorded in the HVF with respect to the reference point. Static draft values were measured on a daily basis for entry in the HVF to track changes in vessel draft caused by loading and fuel consumption. During data acquisition, Real-Time Kinematic (RTK) GPS positioning was referenced from the X-Y-Z coordinate of the GPS antenna phase center to the motion sensor within the vessel coordinate system. Therefore, all recorded navigation data is inherently referenced to the RP and the X-Y-Z coordinates of the GPS antenna phase center need not be entered in the HVF.

3.2.3 *Raw Data Conversion*

CARIS HIPS was used to create a folder structure organized by the project, vessel, and Julian day to store data. Raw Laser data was converted from its native Hypack format, ".hsx" files, into CARIS HIPS using the CARIS conversion wizard module. The wizard was used to create a directory for each line separating the ".hsx" files into sub-files which contain individual sensor information. All data entries were referenced using the time associated with the ".hsx" file to relate the navigation, azimuth, heave, pitch, roll and slant range sensor files.

3.2.4 *Navigation Editor*

Navigation data was reviewed using the CARIS Navigation Editor. The review consists of a visual inspection of plotted fixes noting any navigation gaps in the data. Additionally, vessel speed, distance between navigation fixes and course made good are examined for anomalies. If any anomalies are detected, the processor may choose to reject or interpolate the affected areas. The data in this project displayed no anomalies with respect to navigation.

3.2.5 *Attitude Editor*

Attitude data was reviewed using the HIPS Attitude Editor. The review consists of a visual inspection of the heave, pitch, roll and GPS (ellipsoidal) height which are displayed simultaneously in a graphical representation using a common x-axis scaled by time. The Attitude Editor, like the Navigation Editor, is used to identify anomalies and has the ability to interpolate or reject the affected areas. The data in this project displayed no anomalies with respect to attitude.

3.2.6 *Sound Velocity Editor*

Each sound velocity profile, or cast, was examined using the HIPS Sound Velocity Editor for potential outliers prior to its application in HIPS. Erroneous sound velocity changes will cause a concave or convex artifact within the sea floor representation. This artifact is caused by the sound velocity correction required for the outer beam forming computation. The data in this project displayed no anomalies with respect to sound velocity.

The sound speed adjustment in CARIS HIPS and SIPS uses slant range data, applies motion correctors to determine launch angles, and adjusts for range and ray-bending resulting in a sound speed-corrected observed-depths file. It is recommended that sound velocity correction be executed before cleaning the data. This is because the process applies the vessel motion data to the bathymetry, which makes cleaning the data easier in the interactive editors.

3.2.7 *Merging and Tide Computation*

Upon review of navigation, attitude and sound velocity, the next step in the HIPS processing workflow was to convert ellipsoidal heights to water level and subsequently project datum, mean lower low water (MLLW). Due to the fact that the data was acquired at the published MLLW the processor was able to apply a zero tide to the data.

3.2.8 *Subset Editor*

Following final processing and quality assurance of draft and GPS tide applications,
several area-based editing processes in CARIS HIPS Subset Editor were performed during the office review of survey soundings. During subset editing, the processor was presented with two and three-dimensional views of the soundings and a moveable bounding box to restrict the

number of soundings being reviewed. Using the two-dimensional window, soundings were viewed from the south (looking north), from the west (looking east) and in plan view (looking down). These perspectives, as well as controlling the size and position of the bounding box, allowed the operator to compare lines, view features from different angles, measure features, query soundings and change sounding status flags. Soundings were also examined in the three-dimensional window which could be rotated on any plane. A slight vertical exaggeration was increased as required to amplify trends or features. While HIPS does not allow for the deletion of any sounding, spurious soundings (noise) were flagged as rejected during subset editing. Soundings flagged as rejected are excluded from any final bathymetric product

3.2.9 *HIPS Calibration*

Calibration lines are a set of survey lines specifically designed to determine composite offset angles (roll, pitch and azimuth) for the transducer and motion sensor and the latency (time delay) from the positioning system. Due to the fact that the laser is positioned to look only out one side of the vessel main scheme lines were used in the calibration. Calibration values are determined in the following order:

Navigation Time Error (Latency): The navigation time error adjustment is performed on sets of two coincident lines, run at different velocities, over sloping terrain or a conspicuous topographic feature.

Transducer Pitch Offset: This adjustment is performed on sets of two coincident lines, run at the same velocity, over sloping terrain or a conspicuous object, in opposite directions.

Transducer Azimuth (Yaw) Offset: This adjustment is performed on sets of two lines, run over a conspicuous topographic feature. Lines should be run in opposite directions, with the same outer beams crossing the feature.

Transducer Roll Offset: This adjustment is performed on sets of two coincident lines, run over flat terrain, in the opposite direction.

The HIPS Calibration Tool provides the processor with along-track and across-track sounding profiles of calibration lines in which the displacement of the topographic feature is reconciled by adjusting correction values. Prior to HIPS calibration, the calibration lines are processed according to the aforementioned HIPS workflow to ensure that position and attitude data are reviewed. A cursory data cleaning is performed in subset editor as depth cleaning is not as vital because the processor is looking for trends and not individual spikes or anomalies.
The final calibration values for the laser are as follows:

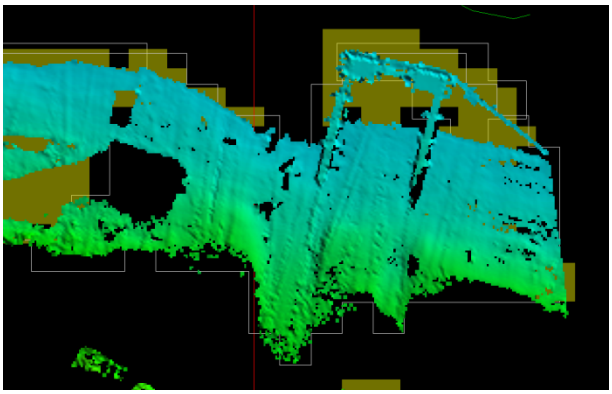
1. Latency 0.000
2. Pitch -3.000
3. Roll -1.500
4. Yaw -1.700

The calibration values are entered into the HVF and the data is re-merged to apply their corrections.

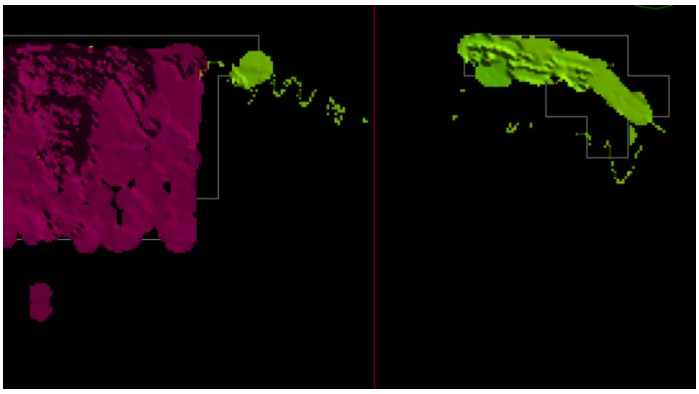
3.2.10 *Caris BASE Surfaces*

The CARIS HIPS Bathymetry Associated with Statistical Error (BASE) Surface is a 3-d, georeferenced image of a multi-attributed, digital terrain model. To build a BASE surface, HIPS assigns a set of gridded nodes at user-defined spacing and bounding coordinates. Each grid node is assigned a depth value based on nearby sounding values. All BASE Surfaces use range weighting to determine how a sounding is applied to a node. Range weighting is based on distance; soundings close to a node are given greater weight than soundings further away. Additionally, all BASE surfaces created for this project use a weighting scheme based on a beam's intersection with the seafloor; soundings formed by the outer beams are weighted less in the algorithm than more reliable nadir beams. BASE surfaces can be used to identify areas requiring further cleaning as well as comprise the final bathymetric product.

CARIS HIPS does not create a standard swath base surface for review of the laser data due to the stacking of the soundings and the orientation of the nadir beam. In place of the swath base surface a CUBE (Combined Uncertainty and Bathymetry Estimator) surface was used. Please review the screenshots below showing the difference in the swath vs. cube surfaces:



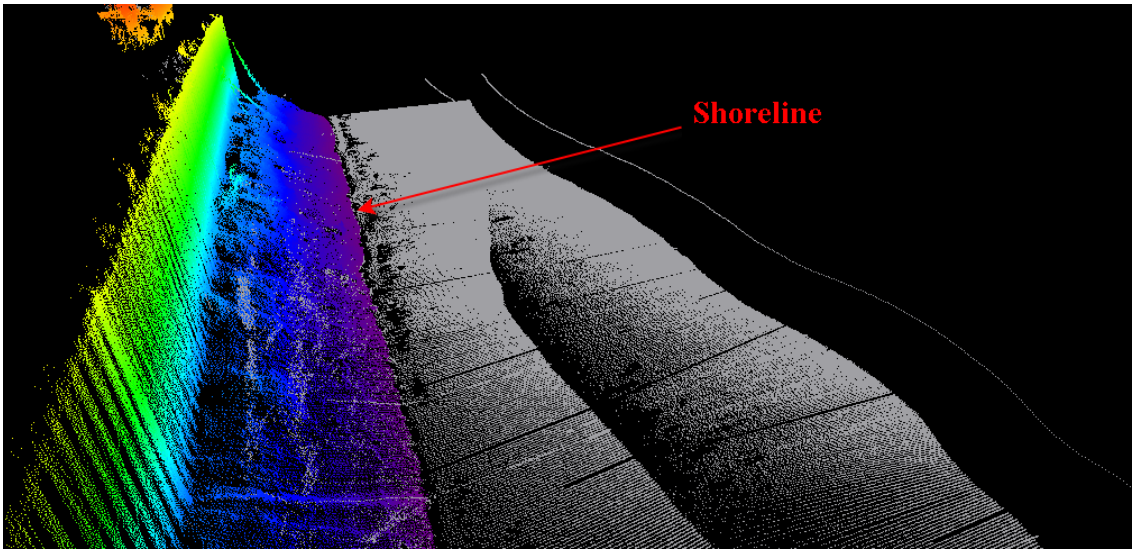
Graphic BB - LiDAR CUBE Surface



Graphic CC - Swath surface of same area

The base surface did not prove to be a valuable tool in the cleaning of the laser data. The optical images were used extensively when correctly identifying what information should be rejected from the record.

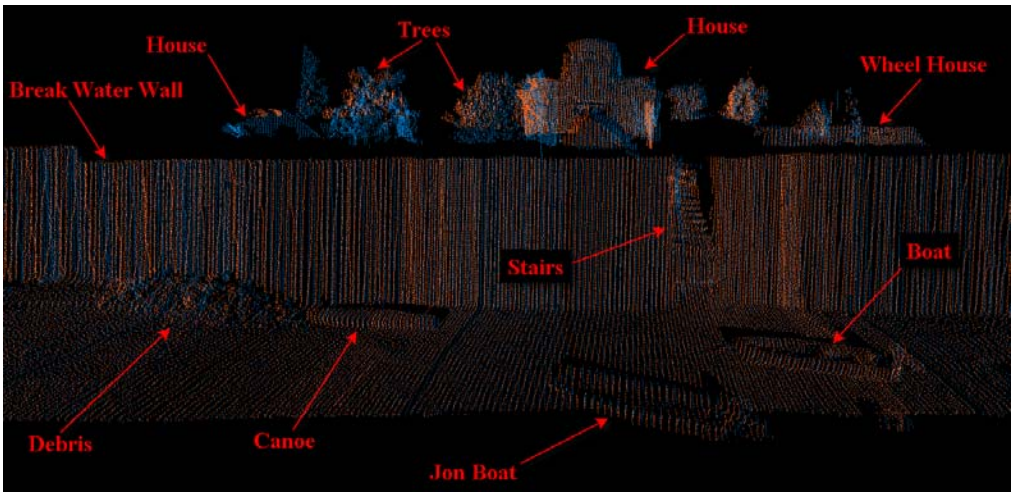
Using CARIS HIPS, the laser data was cleaned of all non earth objects (i.e. debris and man made objects) and specious points. The key to being able to clean the laser data is not to have a vertical exaggeration greater then 1 unit and to have the images that were collected during acquisition. Due to the fact that the laser does not penetrate the surface of the water we were able to define the shoreline with great detail and precision as seen in the screen shot below:



Graphic DD - Infrared LiDAR is highly effective when used to evaluate river stage

The following images show examples of information that was cleaned out of the data to create a “Bare Earth” model and how we were able to relate the real world to the point cloud data. Areas of interest found in this data were encompassed along the sheet pile wall.

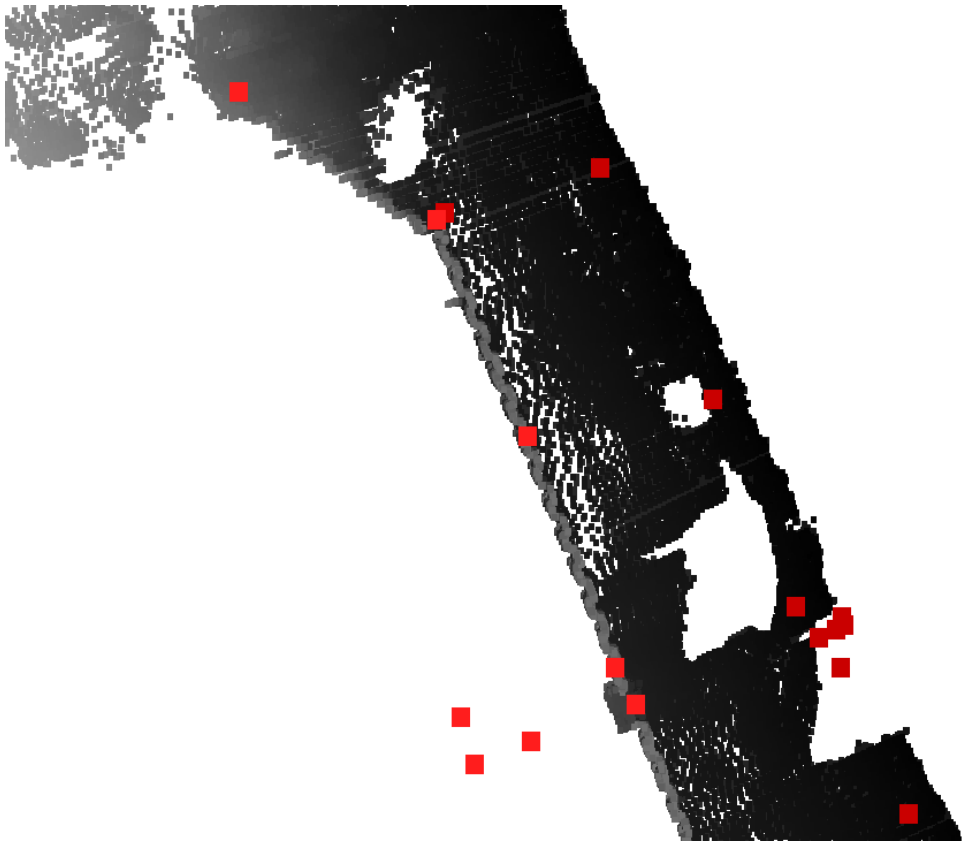
Graphic EE - Interpretation of optical photo used for interpretation of LiDAR



Graphic FF - LiDAR interpretation

TerraSond processors also created a cleaned data set as well. This data set contained all the information (trees, houses, boats, etc.) minus the spurious soundings found in the data.

The terrestrial survey was used to verify the accuracy of the LiDAR data. Select GPS static points were selected and used to verify the position of the LiDAR measurements. All three dimensions were considered while accomplishing this quality assurance.



Graphic GG - Comparison of terrestrial survey points (red) with LiDAR data (black->grey)

Bathymetric Products

While the HIPS workflow allows for application of vertical changes (which was not needed for this project) in order to perform datum transformations and adjustments, the software does not allow for horizontal shifting. No “HERE COORDINATE” was used during acquisition. Static coordinates from the 2007 survey were applied into the GPS Base Station. The horizontal control was established using a constrained network using three CORS stations as the held control. The three CORS stations that were held in the network were CENA (Central), FAI1 (Fairbanks), FAIR (Fairbanks).

From the original survey in 2007 it was concluded that the monument PINK did not move (discussed in more detail in Section 1.1). This was concluded through the analysis of the OPUS solution from 2007 compared to the OPUS solution of 2009. While the monument itself did not move a strengthen control network was created with CORS stations and other monumentation placed in the area. The strengthening of the network and addition monumentation assigned new coordinated values to the control. This included a horizontal difference from the autonomous position. The horizontal position of the 0.50 meter resolution BASE surface grid nodes needed to be shifted by the following values:

Easting: 4.046 feet
Northing: -2.664 feet

The full resolution of the point cloud laser data was exported to X-Y-Z ASCII format in feet, and then imported into Terramodel. The ASCII file was horizontally shifted by the above values. Terramodel is a drafting and analysis tool used for analyzing three dimensional terrestrial data. The horizontal projection of the dataset is Alaska State Plane Zone 5 NAD83 and all soundings are vertically referenced to MLLW. All units are expressed in feet. At this point, the positional referencing of the data was final and ready for development of Fledermaus deliverables.

Terrasond has produced two edited point clouds for AP&T. The first is an Edited LiDAR Point Cloud which represents a data set that still contains the measurements of temporal items like boats, trucks, building, and trees. The second is a Bare Earth Model which represents a data set that has had all temporal items removed. The bare Earth Model represents the direct distances needed to measure by, however, it often has very sparse information because the measurements of the points that did not make it to the earth for reflection have all be removed from the data set.

Bare Earth Model

The finalized X-Y-Z dataset was imported to Fledermaus PRO v7.0 and gridded at 0.50 meter resolution and included as part of the composite Fledermaus product submitted with this project.

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APPENDIX A

GRAPHIC CHARTS AND DRAWINGS

APPENDIX B

3D DIGITAL PRESENTATION INSTRUCTIONS