Peace River Project Water Use Plan

Williston Reservoir Bathymetry

Reference: GMSWORKS 25

Williston Reservoir Bathymetric Mapping

Study Period: June 2010 to June 2013

Final

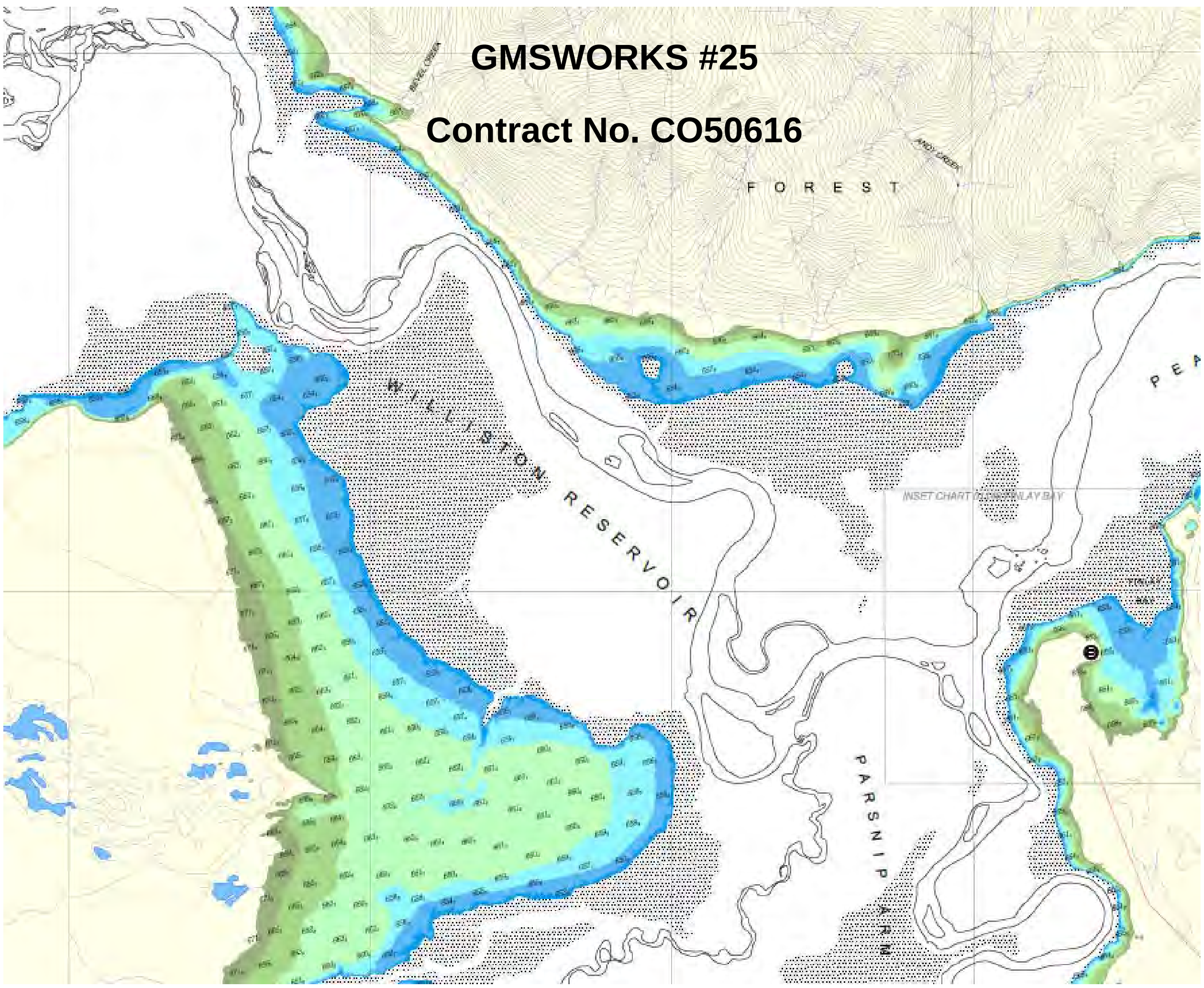
Terrasond Precision Geospatial Solutions

December 31, 2013

WILLISTON RESERVOIR
BATHYMETRIC MAPPING

GMSWORKS #25

Contract No. CO50616



Project Report

Report Date: December 31, 2013

TERRASOND
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APPENDICES

1.0 PROJECT LOCATION

Williston Reservoir is a reservoir in central British Columbia impounded by the WAC Bennett Dam. The southernmost part of the reservoir is 180 km north of Prince George, BC. It consists of three main arms about a central confluence. The Finlay Arm to the north and the Parsnip Arm to the south run generally southeast-northwest in the Rocky Mountain Trench. The Peace Arm runs to the east through the Rocky Mountains and terminates at the WAC Bennett Dam near Hope, BC. Each arm is approximately 120 kilometers long and varies from two up to ten kilometers wide. The entire perimeter at the waterline is roughly 1420 kilometers.

The reservoir is remote with few facilities on the water and limited road access provided by logging roads primarily along the Finlay and Parsnip Arms. The town of Mackenzie is on the south end and the First Nations village of Tsay Keh Dene is on the north end of the Reservoir.

The normal operating draft of the reservoir is 12 meters year round with the lowest level occurring in the first part of May. The water level rises rapidly from May through July reaching a peak refill rate of up to 25 centimeters per day at the beginning of June. The highest water levels typically occur in the beginning of August and the remains fairly consistent with the winter drawdown occurring November through April.

Figure 1 - Williston Reservoir (image Google Earth)

2.0 SCOPE OF WORK

2.1 Terms of Reference

The Terms of Reference (TOR) from April 21, 2008 (Included in Appendix J) was developed to create an accurate bathymetric map for Williston Reservoir from full pool to the 652.27 meter elevation. The information derived from the bathymetric data is intended for issues such as reservoir transportation and safety, erosion control, dust control, debris management, tributary access and wetland habitats.

The work plan developed in the TOR consisted of using a two-phased approach combining airborne LiDAR mapping and vessel-based multibeam bathymetric mapping to achieve a seamless dataset in the project area. The first phase was to collect airborne LiDAR mapping of the de-watered foreshore during the spring of 2009 at low water levels. The second phase was to conduct a vessel-based, multibeam echosounder (MBES) survey during high water in the late summer of 2010.

The TOR envisioned that, depending on the LiDAR coverage, MBES would be able to overlap with the LiDAR data and carry the mapping offshore to the 652 meter elevation with one pass around the perimeter. TerraSond budgeted for two survey passes to ensure adequate coverage.

Pre-inundation mapping of the reservoir provided after award of the contract showed that a large portion of the reservoir would not be able to be mapped with two passes and would require significantly more hydrographic survey effort. A large number of areas were identified with very shallow side slopes, resulting in a larger horizontal band of area between the 663 meter elevation and the 652 elevation.

This, in combination with low water levels in 2010 created a condition that would have required as much as four times the original estimate of 25 days of field data collection. (The MBES swath coverage is a function of the water depth and shallower water results in less swath coverage - requiring a greater number of lines/passes to map a given area than would be required with greater water depths.)

In addition to 14 days of multibeam data acquisition that were added to original contract, BCHydro authorized the use of photogrammetric mapping to be incorporated with the LiDAR and bathymetric datasets as part final seamless dataset. Photogrammetric data from 2004 in the Finlay Arm and new photo missions flown of the entire reservoir in 2011 were incorporated.

3.0 SURVEY TEAM

The survey team consisted of the following companies and roles:

TerraSond Limited (prime contractor) provided the project management, data acquisition and field management staff, sonar operation, data processing and deliverable preparation roles.

P. Rontu Surveys of Port Coquitlam provided expertise and field support for the horizontal and vertical control surveys and multibeam data acquisition services.

Peace Navigation of Mackenzie, BC provided camp barge and logistic support.

Chu Cho Industries owned by the Tsay Keh Dene First Nations Band and its development corporation, provided survey vessel operators for the multibeam acquisition phase.

Cappella Geomatics of Vancouver BC provided field staff during the horizontal and vertical control recovery and survey phase of the survey.

VEP Industries of Mackenzie BC provided remote radio communications and daily check-out and check-in of the survey team while on the reservoir.

4.0 SURVEY DATES

Data collection was completed in three separate phases. A control survey was conducted ahead of the multibeam acquisition in 2010.

Low water levels (664 full pool) in 2010 limited multibeam data collection to Finlay Arm, where existing 2004 photogrammetry extended to 656 m.

The remainder of the reservoir was surveyed in 2011 with multibeam bathymetry and photogrammetry (BC Hydro).

Table 1- Survey Acquisition dates.

Dates	Description
June 15 – June 30, 2010	Initial site visit and survey control
August 7 – August 17, 2010	Survey Finlay Arm
August 14 – September 1, 2011	Survey Peace, Ospika, and Omineca Arms
September 2 – September 15, 2011	Survey Manson and Parsnip Arms

5.0 HORIZONTAL CONTROL

5.1 Horizontal Datums

All data and products produced from this survey use the following datums and projections:

Horizontal: North American Datum of 1983, Canadian Spatial Reference System 2010, NAD83 (CSRS 2010), Universal Transverse Mercator, Zone 10 North
Units: Meters

5.2 Horizontal Accuracy

Horizontal and vertical accuracy specifications for the survey are defined in the Canadian Hydrographic Services Standards for Hydrographic Surveys, 2005. The survey order is "Special" and the corresponding sounding accuracies at the 95% confidence level are provided below:

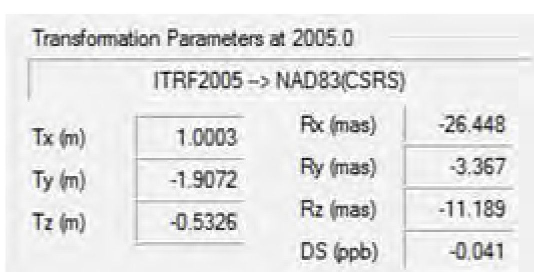
Horizontal Accuracy: 2 meters

5.3 Horizontal Control and Verification

5.3.1 Differential GPS Positioning

The horizontal position of each sounding is based on the position of the vessel as determined by a Global Navigation Satellite System (GNSS) receiver, also commonly referred to as a GPS. The GPS system that was used for the survey was the NAVCOM SF3050, which provided 10 centimeter horizontal accuracy throughout the entire reservoir using the StarFire™ Global Satellite-Based Augmentation System (GSBAS).

StarFire™ utilizes a network of more than 40 GNSS reference stations around the world to compute GNSS satellite orbit and clock corrections. These corrections are broadcast via geostationary satellites, providing worldwide coverage and enabling precise real-time navigation without the need for local ground base stations. The NAVCOM SF3050 output geographic positions relative to the International Terrestrial Reference Frame 2005 (ITRF2005). This data was transformed to NAD83 (CSRS 2010) using a single seven parameter transformation for the entire reservoir, shown in Figure 2.



Transformation Parameters at 2005.0

ITRF2005 --> NAD83(CSRS)

Tx (m)	1.0003	Rx (mas)	-26.448
Ty (m)	-1.9072	Ry (mas)	-3.367
Tz (m)	-0.5326	Rz (mas)	-11.189
		DS (ppb)	-0.041

Figure 2 - Seven parameter transformation from ITRF2005 to NAD83 CSRS 2010.

(Natural Resources Canada (NRCAN) TRX 1.0 software was used to generate the transformation.)

5.3.2 Control Recovery

Verification of the accuracy of the GPS system and the validity of the transformation matrix was conducted at Finlay Bay and at the extreme ends of the reservoir at Tsay Keh Dene, Mackenzie and WAC Bennett Dam. This was done to verify both the accuracy and ensure broad spatial coverage of the GPS systems used on the survey vessels was available.

The first step was to establish control points at these locations and assign coordinates using survey methods with a higher order of accuracy. Rather than set new points, existing BC Hydro control points were recovered and resurveyed. Surveyed values were compared against record coordinate values for the control points provided by BC Hydro in the *"Williston Lake Targets - Adjusted.CSV file".*

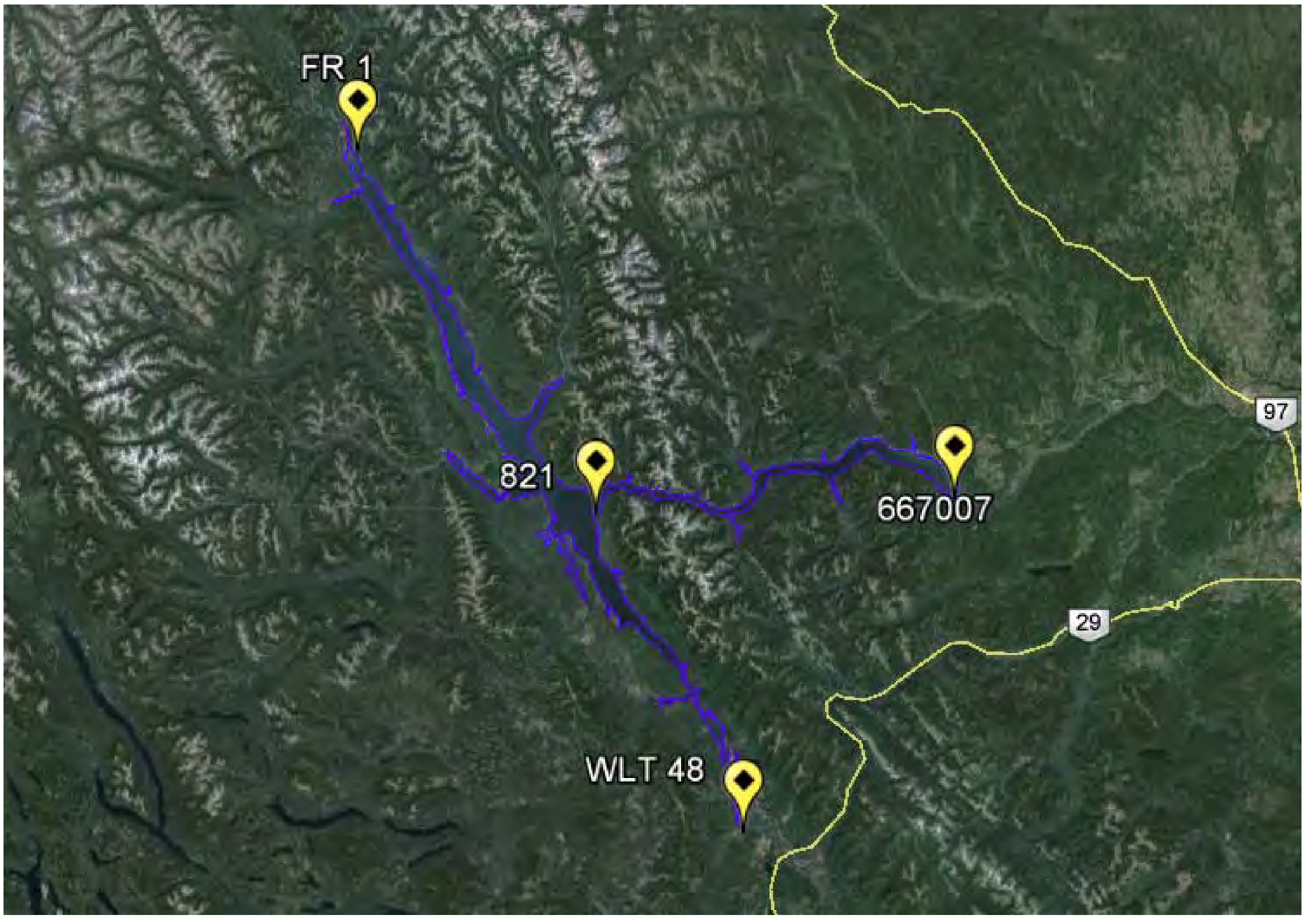


Figure 3-Control point locations used for positioning verification.

Each of the control points were recovered in the field and surveyed using static GPS observation methods on multiple days. The raw RINEX files were submitted to NRCan's Precise Point Positioning (PPP) service to get processed coordinates. The results of the observations and comparison with BC Hydro Record values are provided in Table 2 - Record Horizontal Control Verification.

Table 2 - Record Horizontal Control Verification

Station	Date	Obs. Length	Latitude	Longitude	Northing	Easting	Ellip Ht	EL
667007	6/16/2010	5:50	56 00 36.3099	122 11 19.1224	6207499.136	550588.619	709.476	721.999
667007	6/18/2010	26:30	56 00 36.3100	122 11 19.1225	6207499.140	550588.617	709.477	722.000
	Total	**32:20**	**Hrs**	**PPP Average**	6207499.139	550588.617	709.477	722.000
				BCHydro Record	6207499.126	550588.557	709.527	722.050
				Deltas	**0.013**	**0.060**	**-0.050**	**-0.050**

Station	Date	Obs. Length	Latitude	Longitude	Northing	Easting	Ellip Ht	EL
821	6/15/2010	6:45	55 58 49.5984	123 48 25.5764	6204197.074	449637.859	675.679	685.388
821	6/16/2010	5:30	55 58 49.5986	123 48 25.5764	6204197.080	449637.859	675.684	685.393
821	6/21/2010	1:30	55 58 49.5984	123 48 25.5771	6204197.074	449637.847	675.656	685.365
821	6/18/2010	17:00	55 58 49.5989	123 48 25.5765	6204197.090	449637.858	675.683	685.392
	Total	**30:45**	**Hrs**	**PPP Average**	6204197.084	449637.858	675.681	685.390
				BCHydro Record	6204197.068	449637.851	675.691	685.400
				Deltas	**0.016**	**0.007**	**-0.010**	**-0.010**

Station	Date	Obs. Length	Latitude	Longitude	Northing	Easting	Ellip Ht	EL
WLT48	6/16/2010	10:00	55 10 29.0527	123 09 04.9327	6114246.699	490359.201	712.281	724.039
WLT48	6/20/2010	5:00	55 10 29.0531	123 09 04.9354	6114246.712	490359.153	712.232	723.990
WLT48	6/15/2010	8:00	55 10 29.0526	123 09 04.9317	6114246.696	490359.218	712.261	724.019
	Total	**23:00**	**Hrs**	**PPP Average**	6114246.701	490359.196	712.263	724.021
				BCHydro Record	6114246.688	490359.215	712.285	724.043
				Deltas	**0.013**	**-0.019**	**-0.022**	**-0.022**

Station	Date	Obs. Length	Latitude	Longitude	Northing	Easting	Ellip Ht	EL
FR-1	6/19/2010	7:00	56 52 57.2957	124 54 32.8813	6305939.165	383667.842	691.947	699.294
FR-1	6/19/2010	5:45	56 52 57.2955	124 54 32.8800	6305939.158	383667.864	691.928	699.275
	Total	**12:45**	**Hrs**	**PPP Average**	6305939.162	383667.852	691.938	699.285
				BCHydro Record	6305939.220	383667.839	691.891	699.238
				Deltas	**-0.058**	**0.013**	**0.047**	**0.047**

The coordinates obtained from the PPP solution all agreed well with the record values except for discrepancies in the easting of 6 centimeters at station "667007" and 6 centimeters in the northing at station "FR-1".

Recovery notes, photos and stations forms are provided for each of these control points in Appendix C.

5.3.3 Real-Time Positioning Verification

The vessel positions during the bathymetric survey were measured with the NAVCOM 3050 GPS receivers receiving the SBAS StarFire, Real-Time GIPSy (RTG) correction. Utilizing a satellite based correction eliminated the requirement to establish and maintain local GPS base stations around the reservoir.

The next step of the verification was to setup the NAVCOM 3050 GPS receivers and antennas at each of the control points and log the real-time output from the system as if it were installed on the vessel. The GPS were configured to output the same position data stream (NMEA GGA) used on the vessel and logged for approximately one hour. The results of this comparison between the real-time outputs with the record BC Hydro control values are given below in Table 3.

Table 3 - Real-time positioning verification.

	BC Hydro Record Value		Real-Time Position Average		Delta	
Station	**Northing**	**Easting**	**Northing**	**Easting**	**Northing**	**Easting**
667007	6207499.126	550588.557	6207499.111	550588.571	-0.015	0.014
821	6204197.068	449637.851	6204196.925	449637.729	-0.143	-0.122
WLT48	6114246.688	490359.215	6114246.502	490358.863	-0.186	-0.352
FR-1	6305939.220	383667.839	6305939.131	383667.939	-0.089	0.100
				Average Deltas	**-0.108**	**-0.090**

The results show that the real-time position output was at times outside the manufacturer's specification of 10 centimeters horizontal accuracy but certainly within the 2 meter error budget for the horizontal positioning for an individual sounding.

Summary reports and graphical position plots from the verification tests are provided in Appendix D.

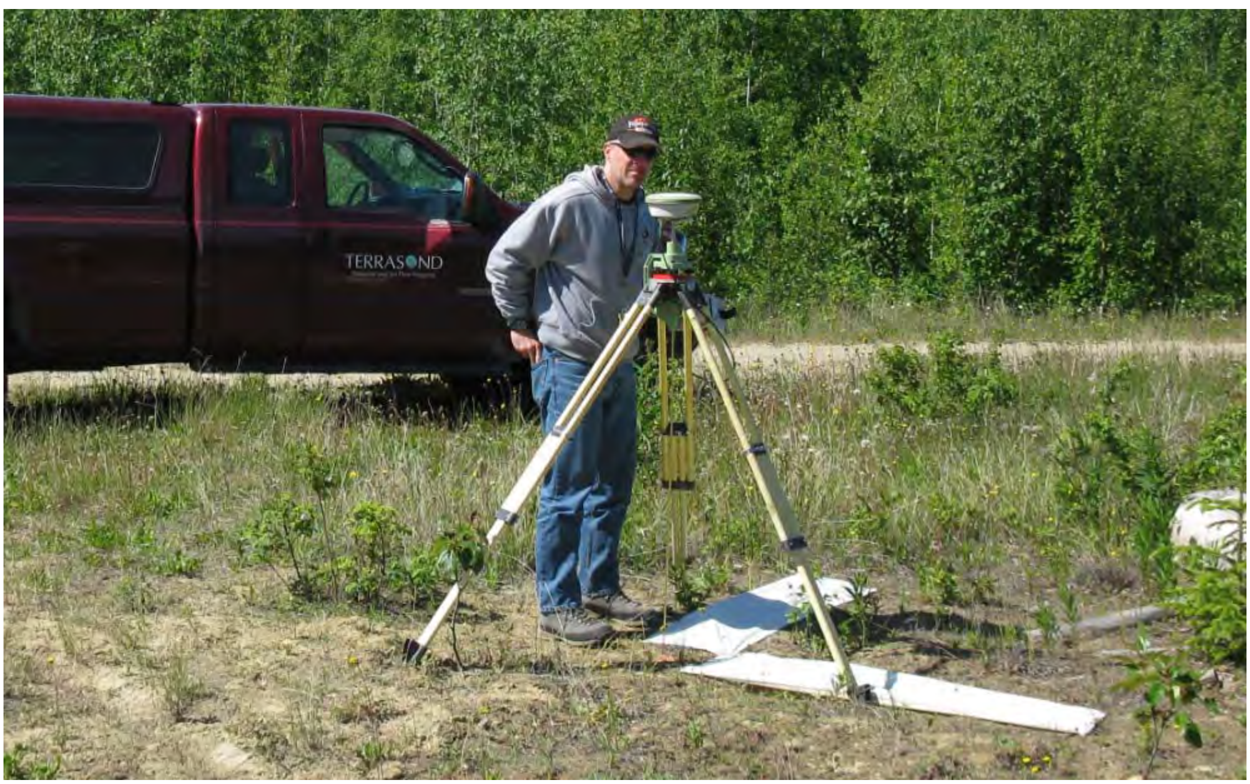


Figure 4 - Verifying control at Station 821.

6.0 VERTICAL CONTROL

6.1 Vertical Datums

The vertical datum for the charting data and products produced from the survey is the Canadian Geodetic Vertical Datum of 1928 (CGVD28). All units are in meters.

6.2 Vertical Control Survey

Soundings were corrected from the water surface elevations measured by water level gauges to create the final point elevations. This section of the report describes the methodology and procedures used to measure the water surface elevations. Sounding accuracy requirements for the survey were between 25 to 29 cm, depending on the depth. The error budget for water level monitoring was 5 cm.

While Williston is a reservoir with a surface that is presumably flat, or parallel with the geoid and CGVD28 datum, there are natural and external forces that would cause local variations from this "flat" condition. Wind set-up, atmospheric pressure gradients, net discharge and inter-day draw-down at the WAC Bennett dam were assumed to have an impact on the short and long term water level variations and differentials within the reservoir. The phenomenon is known as seiche and is primarily influenced by atmospheric pressure differentials over the reservoir. The mechanics of the phenomena were beyond the scope of the survey; however it was important to measure the affects accurately in order to correct the soundings appropriately.

6.3 Water Level Gauge Locations

In order to ensure water levels were measured with an accuracy of 5 cm's or better throughout the reservoir, it was determined that it would be necessary to set gauges at the extreme ends of Williston Reservoir near Mackenzie in the Parsnip Arm, Tsay Keh Dene in the Finlay Arm, the WAC Bennett Dam in the Peace Arm and one at Finlay Bay.

Gauge sites were established near the locations of the horizontal control points described in the preceding section and given a three letter identifier based on their location. The proximity to the horizontal control was to allow for a comparison between GPS derived elevations and the elevations determined by gauge observations for benchmarks established at the gauge sites

Table 4- Water Level Gauge Sites and operating dates.

Gauge Name	Function	General Location	Dates of Operation
DAM	Primary	WAC Bennett Dam	August 5 – November 11, 2010 August 12 – November 12, 2011
BAY	Secondary	Finlay Bay	August 7 – September 4, 2010 August 13 - November 11, 2011
KEH	Secondary	Tsay Keh Dene	August 7 – August 18, 2010
MAC	Secondary	Mackenzie	August 10 – November 10, 2011

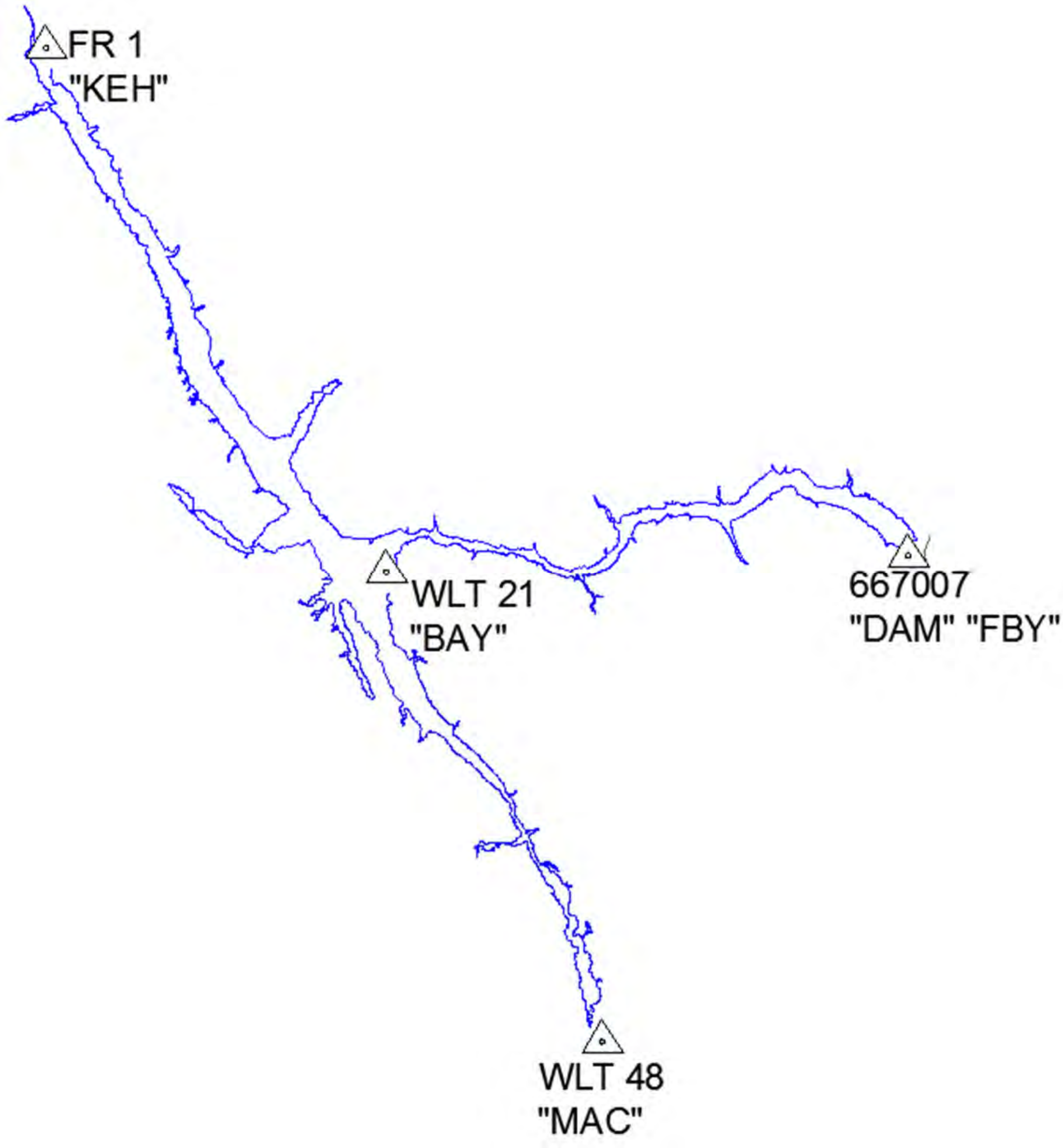


Figure 5- Water Level Gauge Sites.

6.4 Primary Gauge Site

The gauge site DAM was selected as the primary gauge site. DAM was the only site near a control point (667007) with a published Geodetic Survey of Canada (GSC) CGVD28 elevation. As such, the GSC monument "667007" is the basis of all elevations and soundings collected for this survey.

In both 2010 and 2011, the gauge was installed on a weighted stand in about 8 meters of water on the north side of the dam and marked with a buoy. The elevation of the gauge was set by differential levels from "667007" monument to the waterline near the gauge. Water level observations were made every 6 minutes for an hour coinciding with the measurements from the gauge. In post processing, corrected gauge readings (water height above the gauge sensor) were subtracted from the water surface elevation measured with differential levels to compute a gauge elevation. An average elevation was computed from all of the water level observations. Final water level data from the gauge was created from gauge readings corrected to the gauge elevation.

Table 5 - Opening water level observations at WAC Bennett Dam, 8/5/2010.

Local Time	Leveled Water Surface Elevation	Corrected Gauge Reading	Gauge Elevation	Gauge Water Surface Elevation
13:06	664.705	6.616	658.090	664.703
13:12	664.707	6.615	658.093	664.702
13:18	664.702	6.616	658.086	664.703
13:24	664.704	6.616	658.088	664.703
13:30	664.703	6.614	658.089	664.701
13:36	664.701	6.611	658.090	664.698
13:42	664.693	6.609	658.085	664.696
13:48	664.692	6.605	658.087	664.692
13:54	664.683	6.603	658.080	664.690
14:00	664.686	6.603	658.083	664.690
		Computed Average Gauge Elevation	**658.087**	

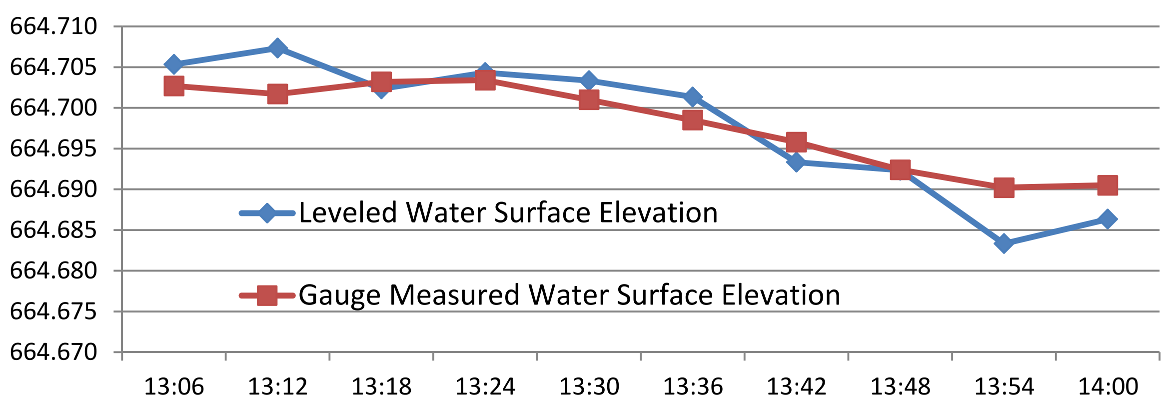


Figure 6- Actual water surface elevation and gauge-measured elevation at WAC Bennett Dam.

6.5 Secondary Gauge Sites

Once the elevation of the primary gauge had been established and gauge readings corrected to the CGVD28 datum, elevations were propagated from the primary site to the secondary sites through the use of a water level transfer. A water level transfer assumes that the water level elevations at the primary site and the secondary site are equal; the surface is level. However, the effects of seiche can cause this to not be the case, resulting in some unknown slope of the water level between the two sites.

While instantaneous water levels observed at the two sites may be different, the assumption is that the average water level over a long term experienced at the two sites is equal.

The elevations of the gauges at all the secondary sites were set using the long-term water level transfer method. Secondary sites at Finlay Bay (BAY) and Tsay Keh Dene (KEH) were set in 2010. BAY was re-established in 2011 and a new site at Mackenzie (MAC) was set in 2011. A gauge was set at Tsay Keh Dene in 2011 but was lost and not recovered.

Figure 7- Survey boat and buoy attached to gauge in Finlay Bay.

The gauge elevations were established by calculating the mean water level from DAM (Primary) and subtracting the mean gauge reading from each of the secondary sites over the same corresponding long-term period. As with the primary, final water surface elevations were created from gauge readings added to the gauge elevation. Final water levels computed for each of the sites are shown in Figure 8 and Figure 9. Details for the water level transfers are provided in Table 6.

Table 6- Water Level Transfers to Secondary Gages.

Site	Begin	End	Observations	Mean Water Level (DAM)	Mean Corrected Gauge Reading	Final Gage Elevation
BAY	08/07/10	09/04/10	6917	664.728	5.344	659.384
KEH	08/07/10	08/18/10	2623	664.757	8.461	656.296
BAY	08/13/11	11/11/11	21584	671.106	11.291	659.816
MAC	08/13/11	11/10/11	21390	671.111	4.559	666.552

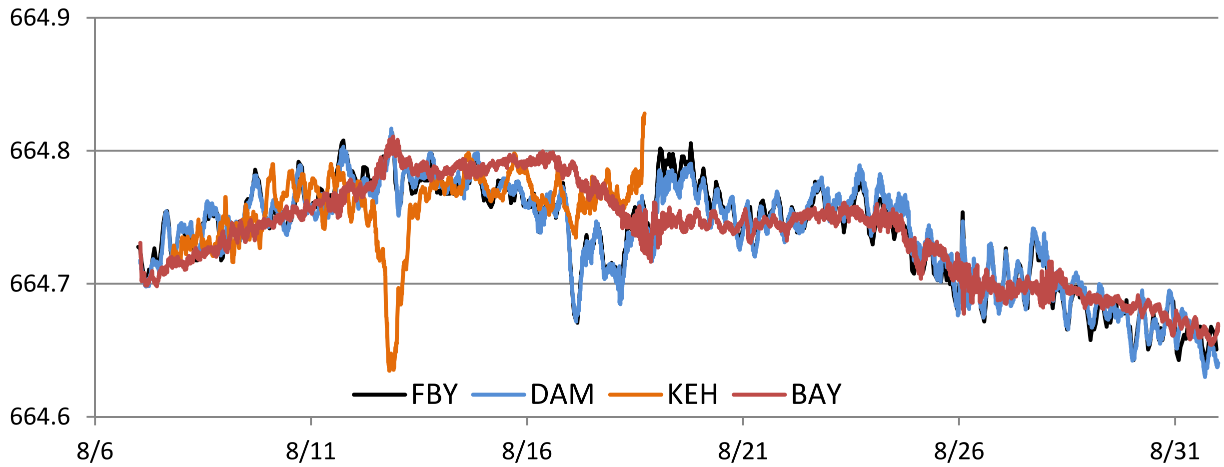


Figure 8 - 2010 water level plots.

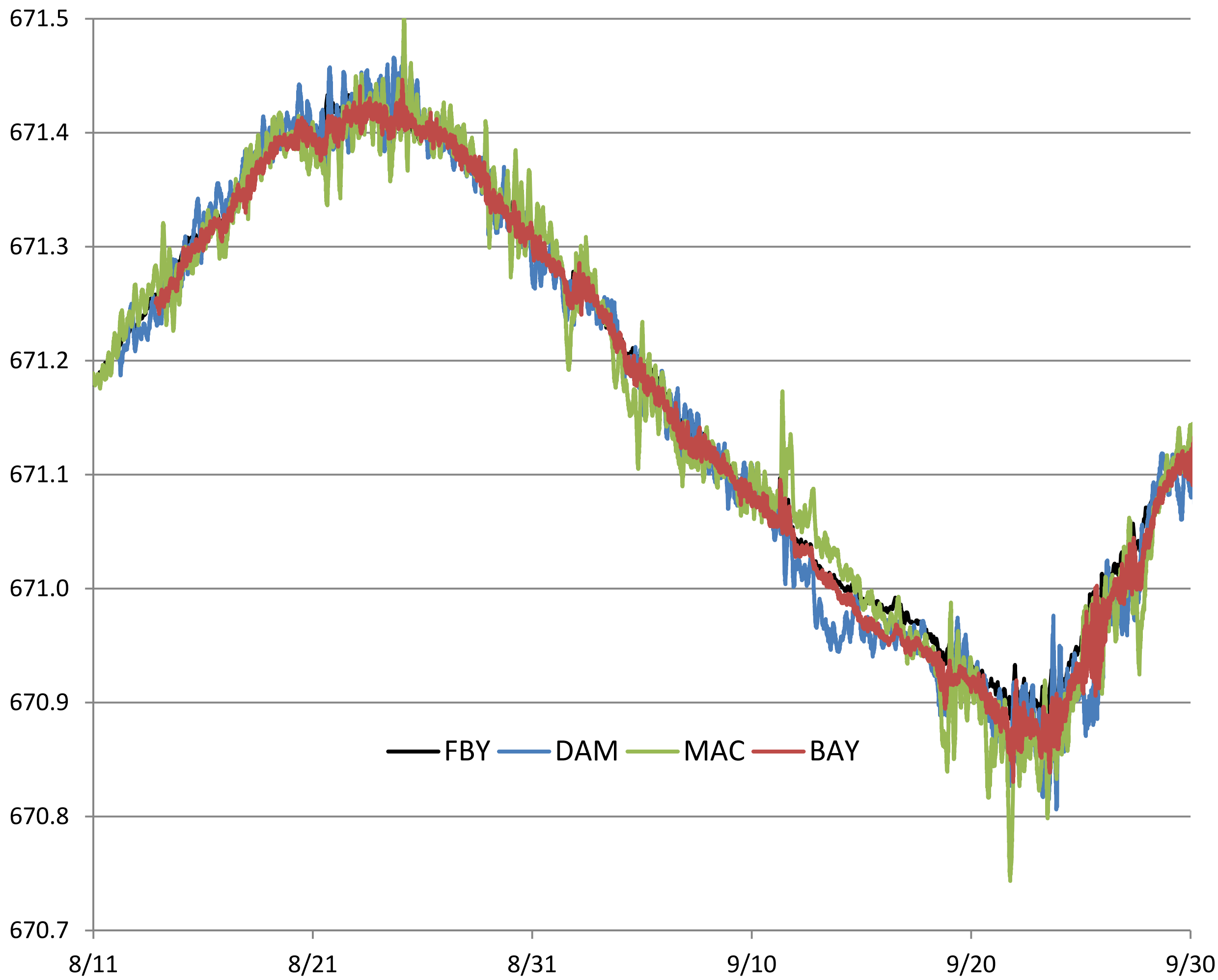


Figure 9 - 2011 water level plots.

6.6 Benchmark Establishment

Benchmarks were established by TerraSond near each of the tide gauge sites in order to provide a means of quality assurance of the gauges as well as provide vertical references for future gauge installations if necessary.

Benchmark elevations at DAM were established through closed level loops holding the record elevation at GSC monument "667007" of 722.050 meters. Benchmark elevations at the secondary sites were established by levelling operations from the water surface to a primary bench mark at each site. Closed level loops between the primary and secondary benchmarks at each site were conducted to establish elevation for the secondary bench marks.

Final benchmark elevations are provided in Table 7. Other temporary benchmarks were established over the course of the survey but only those easily identifiable and considered stable for long term use are presented. All elevations are relative to CGVD28 and have an absolute accuracy on the order of +/- 15 millimeters based on "667007". Relative accuracy of the benchmarks within each gauge site is +/- 2 millimeters. Benchmark descriptions and locations are provided in Appendix E.

Table 7-Final benchmark elevations.

DAM		BAY		KEH		MAC	
Benchmark	**Elevation**	**Benchmark**	**Elevation**	**Benchmark**	**Elevation**	**Benchmark**	**Elevation**
667007	722.050	**821**	685.737	**FR-1**	699.588	**WLT 48**	724.383
IPEC 2	722.055	**BAY A**	673.322	**IVOR**	679.751	**MAC A**	677.183
DAM A	680.412	**BAY B**	668.994	**KEH A**	679.768	**MAC B**	672.953
DAM 3	680.492	**BAY C**	669.162			**MAC C**	674.082
DAM 4	680.118					**MAC D**	674.094

The table above provides a good estimate of the overall accuracy of the water level monitoring program and vertical control for the survey. Two completely independent tide gauge installations were done in 2010 and 2011 and the elevation established for "BAY A" in 2010 and checked/resurveyed in 2011 agreed to within 16 millimeters over a distance of 115 kilometers.

Table 8 – "BAY A" elevation checks.

Date	Time (UTC)	Observations	Mean	2 Sigma	Delta	Function
8/07/2010	1:42	9	673.322	0.005		2010 Opening (Held)
8/11/2010	17:00	10	673.338	0.003	0.016	Intermediate Check
8/19/2010	15:42	10	673.326	0.012	0.004	Closing Check
8/13/2011	20:36	11	673.310	0.003	-0.012	2011 Opening Check
8/28/2011	23:30	11	673.316	0.008	-0.005	Intermediate Check
8/28/2011	17:36	10	673.312	0.004	-0.010	Closing Check
	Average		673.321			
	2 Sigma		0.021			
	Average "BAY A" Elevation from 2010		673.328			
	Average "BAY A" Elevation from 2011		673.313			
		Delta	-0.016			

The water level observations used to establish the elevations at the primary benchmarks at each of the three secondary gauge sites are provided in the tables below.

Table 9- Primary benchmark "BAY A" elevation determination at gauge site BAY.

DATE	TIME (UTC)	BAY Water Level	Waterline to "BAY A"	"BAY A" Elev
8/7/2010	1:36	664.720	8.6065	673.327
8/7/2010	1:42	664.714	8.6065	673.321
8/7/2010	1:48	664.710	8.6165	673.326
8/7/2010	1:54	664.708	8.6165	673.324
8/7/2010	2:00	664.702	8.6165	673.318
8/7/2010	2:06	664.704	8.6165	673.321
8/7/2010	2:12	664.706	8.6165	673.322
8/7/2010	2:18	664.703	8.6165	673.320
8/7/2010	2:24	664.705	8.6165	673.321
8/7/2010	2:30	664.705	8.6165	673.322
			Average	**673.322**
			2 Sigma Std Dev	**0.006**

Table 10- Primary benchmark "MAC B" elevation determination at gauge site MAC.

DATE	TIME (UTC)	MAC Water Level	Waterline to "MAC B"	"MAC B" Elev
11/10/2011	12:24	670.608	2.347	672.955
11/10/2011	12:30	670.612	2.346	672.958
11/10/2011	12:36	670.603	2.345	672.948
11/10/2011	12:42	670.611	2.346	672.957
11/10/2011	12:48	670.605	2.346	672.951
11/10/2011	12:54	670.605	2.347	672.952
11/10/2011	13:00	670.610	2.347	672.957
11/10/2011	13:06	670.599	2.346	672.945
11/10/2011	13:12	670.609	2.346	672.955
11/10/2011	13:18	670.602	2.346	672.948
			Average	**672.953**
			2 Sigma Std Dev	**0.009**

Table 11- Primary benchmark "IVOR" elevation determination at gauge site KEH.

DATE	TIME (UTC)	KEH Water Level	Waterline to "IVOR"	"IVOR" Elev
8/13/2010	23:36	664.781	14.970	679.751
8/13/2010	23:42	664.782	14.968	679.750
8/13/2010	23:48	664.780	14.972	679.752
8/13/2010	23:54	664.781	14.970	679.751
8/14/2010	0:00	664.784	14.967	679.751
8/14/2010	0:06	664.782	14.970	679.752
8/14/2010	0:12	664.781	14.970	679.751
8/14/2010	0:18	664.783	14.970	679.753
8/14/2010	0:24	664.782	14.970	679.752
8/14/2010	0:30	664.782	14.970	679.752
8/14/2010	0:36	664.782	14.970	679.752
8/14/2010	0:42	664.780	14.972	679.752
8/14/2010	0:48	664.781	14.970	679.751
			Average	**679.751**
			2 Sigma Std Dev	**0.002**

Figure 10 - Taking water level observations in the Parsnip Arm.

6.7 Comparison with GPS derived Elevations

Static GPS observations conducted during the horizontal control surveys at “667007”, “821”, “FR-1” and “WLT-48” produced accurate ellipsoid heights relative to NAD83 CSRS 2010 ellipsoid. These were converted to the CGVD28 datum through the application of a geoid model. Differential levels conducted from the primary benchmarks at each of the gauge sites to these control stations allowed for the comparison of the record elevation values from BC Hydro, GPS-derived elevations and elevations established from the water level gauges.

Table 12- Primary Control Elevations

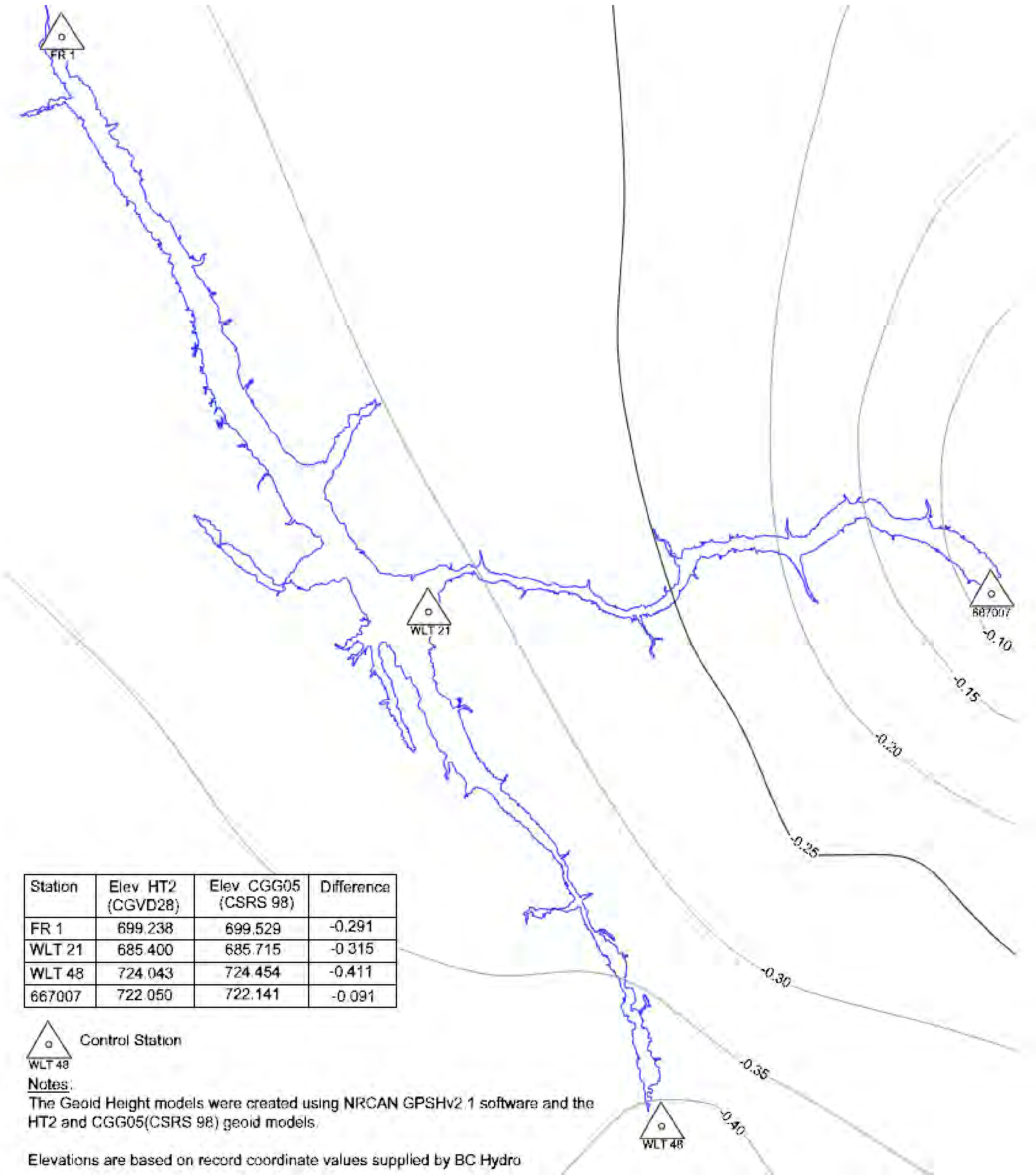
Station	TerraSond Levelled	BC Hydro (Record)	TerraSond GPS (HTV2.0)	TerraSond GPS (CGG05)	TerraSond GPS (CGG10)	TerraSond GPS (CGG2013)
667007	722.050	722.050	722.000	722.104	722.023	722.089
821	685.737	685.400	685.390	685.718	685.603	685.648
FR-1	699.588	699.238	699.285	699.589	699.504	699.552
WLT-48	724.383	724.043	724.021	724.444	724.325	724.362
		Delta elevation compared to TerraSond levelled values				
667007		0.00	-0.05	0.05	-0.03	0.04
821		-0.34	-0.35	-0.02	-0.13	-0.09
FR-1		-0.35	-0.30	0.00	-0.08	-0.04
WLT-48		-0.34	-0.36	0.06	-0.06	-0.02
	Average Δ	**-0.26**	**-0.27**	**0.02**	**-0.08**	**-0.03**

It became apparent from the analysis of the data in Table 12 that the HTv2.0 model, when applied to GPS ellipsoid heights, poorly approximated a gravimetric surface across the entirety of the reservoir. Discrepancies of greater than 30 centimeters were seen in the Finlay and Parsnip Arms. This was of no consequence to the bathymetric soundings, because the water levels data used to correct the soundings did not rely on any geoid model. However, the LiDAR and photogrammetric data that was combined with the bathymetry was all based on CGVD28 control derived from the HTv2.0 model, resulting in a vertical discrepancy between the two datasets where they overlapped.

6.8 GEOID Model CGG2005

HTv2.0 is a hybrid geoid model created to approximate the height between the NAD83 CSRS ellipsoid and the CGVD28 vertical datum. GPS-derived NAD83 (CSRS98) ellipsoidal heights and levelling-derived CGVD28 orthometric heights, in addition to CGG2000 geoid heights, provided the basis for establishing this height transformation. The model has been found to have large-scale distortions, and suffers from sparse coverage of CGVD28 control stations in more northern portions of Canada. It is possible that the model incorporated control stations along the John Hart Highway with CGVD28 elevations that were either erroneous or are being subject to isostatic rebound in the Rocky Mountains.

Based on the discrepancies found in the HTv2.0 model in the control survey it was decided to use the CGG2005 model to correct the LiDAR and photogrammetric points. GPS-H, maintained by the Geodetic Survey branch of NRCan, was used to correct the points by backing out the HTv2.0 model and re-applying the CGG2005 model to the topographic LiDAR and photogrammetric datasets.



Station	Elev. HT2 (CGVD28)	Elev. CGG05 (CSRS 98)	Difference
FR 1	699.238	699.529	-0.291
WLT 21	685.400	685.715	-0.315
WLT 48	724.043	724.454	-0.411
667007	722.050	722.141	-0.091

Figure 11 - Elevation differences between HTv2.0 and CGG2005 model in project area.

7.0 EQUIPMENT

7.1 Survey Vessels

Two vessels of similar size and capability were used to perform the survey of Williston Reservoir. These were the *R/V Carta* provided by TerraSond, and the *M/V McKellar* provided by BC Hydro. The vessels were outfitted with identical survey equipment.

The *R/V Carta* is TerraSond's 27 foot, custom-built, shallow-draft aluminum survey platform, equipped with an over-the-side multibeam pole mount that is bolted into place during the survey.

The *M/V McKellar* is a 24 foot aluminum vessel that was provided for the survey by BC Hydro. The *M/V McKellar* was mobilized for the project with a custom over-the-side multibeam pole mount capable of retraction for transit and other non-survey activities.

Figure 12 - The *R/V Carta* on the shore in the Ingenika Arm.

Figure 13 - The *M/V McKellar* surveying in the Ingenika Arm.

7.2 Survey Sensors

The vessels were mobilized in Mackenzie, B.C. The survey equipment was installed, measured, and tested prior to commencing the survey. Quality assurance checks were done to verify the sensor locations and draft measurements. Table 13 below provides basic information of the primary sensors used for the survey. Vessel offsets for the sensors were surveyed by TerraSond and are included in the vessel sections of this report.

Table 13 - Multibeam Survey Equipment List

Component	Model	Description
Multibeam Echosounder	Reson Seabat 8101	101 beams, 240 kHz, 1.5° beam width, 150° swath coverage
Inertial Navigation System / Heading	CodaOctopus F185	Position, heave, pitch, roll and heading sensor.
Primary Positioning	NAVCOM Starfire 3050	GNSS Receiver with Real-Time Gypsy (RTG) satellite-based correction
Sound Velocity Profiler	AML SVPlus	Internal recording, 500dBar instrument for measuring sound velocity profiles.
Acquisition PC	Custom Rackmount	Windows XP computer with all required software
Acquisition Software	QINSy 8.0	Hydrographic data acquisition and navigation software.

7.2.1 Camp Barge

In addition to the *R/V Carta* and *M/V McKellar* vessels, there was also a mobile camp barge operated by Peace Navigation that was utilized as a live-aboard for the crew while field operations were underway. The barge also carried large fuel tanks with gasoline and diesel fuel that could be pumped with a standard fuel pump into the vessels' fuel tanks. This provided the safest and most efficient way to refuel the survey vessels.

Figure 14 - Camp Barge used during field operations for 2010 in the Ingenika Arm

8.0 Tide Gauge Deployment

Tide gauges were deployed at key locations on Williston Reservoir. The following equipment was used to record water and atmospheric data during the survey:

Table 14 - Tide monitoring equipment

Component	Model	Description
Tide Gauge	Seabird SBE26 Plus	Water pressure and temperature sensor
Atmospheric Gauge	Kestrel 4000	Portable pressure, altitude, temperature, and wind sensor

The Seabird SBE26 Plus gauges were secured flat to anchors and lowered to the bottom of the lake from a vessel in at least 15 meters of water. They were then tethered to a buoy or the line was run to a site on land. A Kestrel 4000 was placed nearby to monitor atmospheric changes. It was important that the equipment remain undisturbed for the length of the survey so measures were taken to mask the equipment locations.

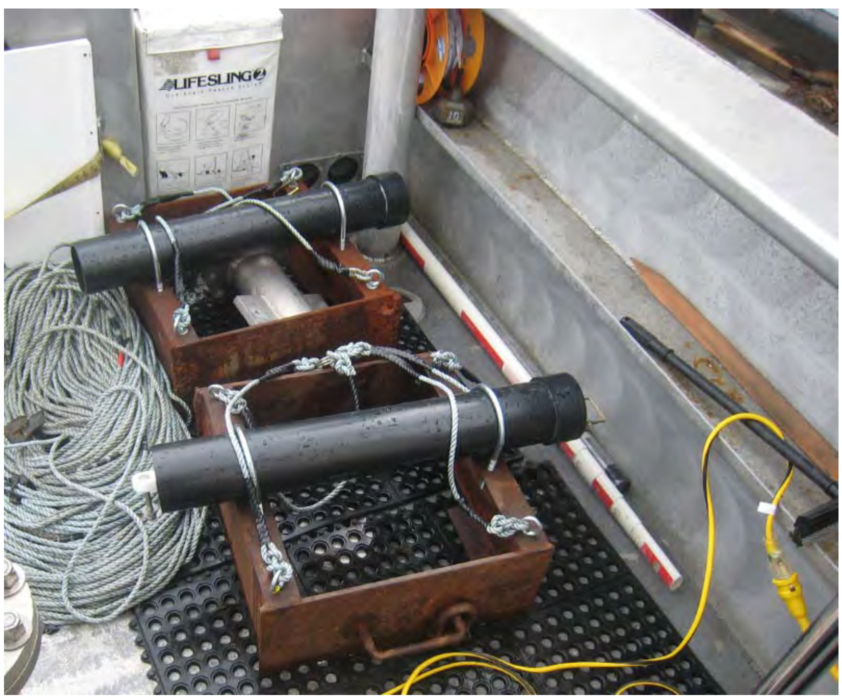


Figure 15 - Seabird SBE26 Plus secured to mount.

The Kestrel 4000 Pocket Weather Trackers were placed in close proximity to each of the tide gauges. The purpose of the Kestrel was to monitor barometric pressure in order to separate out the atmospheric effects on the local water level detected by the Seabird water pressure (tide) gauge.

9.0 ACQUISITION PROCEDURES

The survey was conducted to meet or exceed the Canadian Hydrographic Services standards for a Special Order Survey (2005). These standards required the use of multibeam echosounding techniques. The controlling requirements of the survey were 100% ensonification of the reservoir bed, the ability to detect 1 x 1 x 1 meter obstructions, a horizontal sounding accuracy of 2 meters at the 95% confidence level and 26-centimeter depth accuracy (idealized for an average 8 meter water depth).

9.1 General Method

The vessels started in 2010 in the north end of Williston Reservoir, advancing south along the opposite shorelines, completing bays and arms when encountered. The vessels started in the Peace Arm for the 2011 season, generally working towards the central lake then heading south. Activity summaries are available later in this section. In general, the camp barge stayed close to where the survey vessels were surveying in order to reduce transit times. Ideally the barge found a location that was sheltered from the weather and in a central spot to reduce the number of times the barge needed to move.

The barge typically tied up so that its retractable ramp on the bow could be deployed onto the land and stays could be tied to fixed objects on land. This allowed for a secure, stable setup for the barge to moor for multiple days. The two survey vessels would be tied near the stern of the barge on either side of barge, or if necessary, tied together on the lee side of the barge.

9.2 Survey Dates Summary

Table 15 and Table 16 below provide a brief summary of the survey dates and activities.

Table 15 - 2010 Survey Dates Summary

Date	Activity
August 3-5	Camp Barge and Vessel Mobilization in Mackenzie.
August 6	Transit to Ingenika Arm
August 7	Multibeam Calibrations
August 7-18	Survey of Finlay Arm
August 19	Demobilization

Table 16 - 2011 Survey Dates Summary

Date	Activity
August 10-12	Camp Barge and Vessel Mobilization in Mackenzie.
August 13	Transit to Peace Arm
August 13	Multibeam Calibrations
August 14-21	Survey of Peace Arm
August 22-31	Survey of Finlay Arm, Ospika Arm, Omineca Arm
Sept 1-8	Survey of Manson Arm, Central Lake
Sept 9-15	Survey Parsnip Arm
Sept 15-16	Demobilization

9.3 Real-Time Coverage

The vessels were outfitted with identical survey equipment and software designed to allow the vessel driver and Hydrographer to see the data collected in real-time. The in-shore limits of the survey were either the offshore extent of the 2004 and 2011 photogrammetry or the 2009 LiDAR. The line was displayed on the real-time coverage map. The offshore limit was the 650 elevation contour.

The color map was deliberately set to highlight when multibeam had met the existing LiDAR/Photogrammetry elevation (in red) or the target depth of 650 meters (in grey). See Figure 16 below for a sample of real-time multibeam "painting" requiring four or more passes to achieve full coverage.

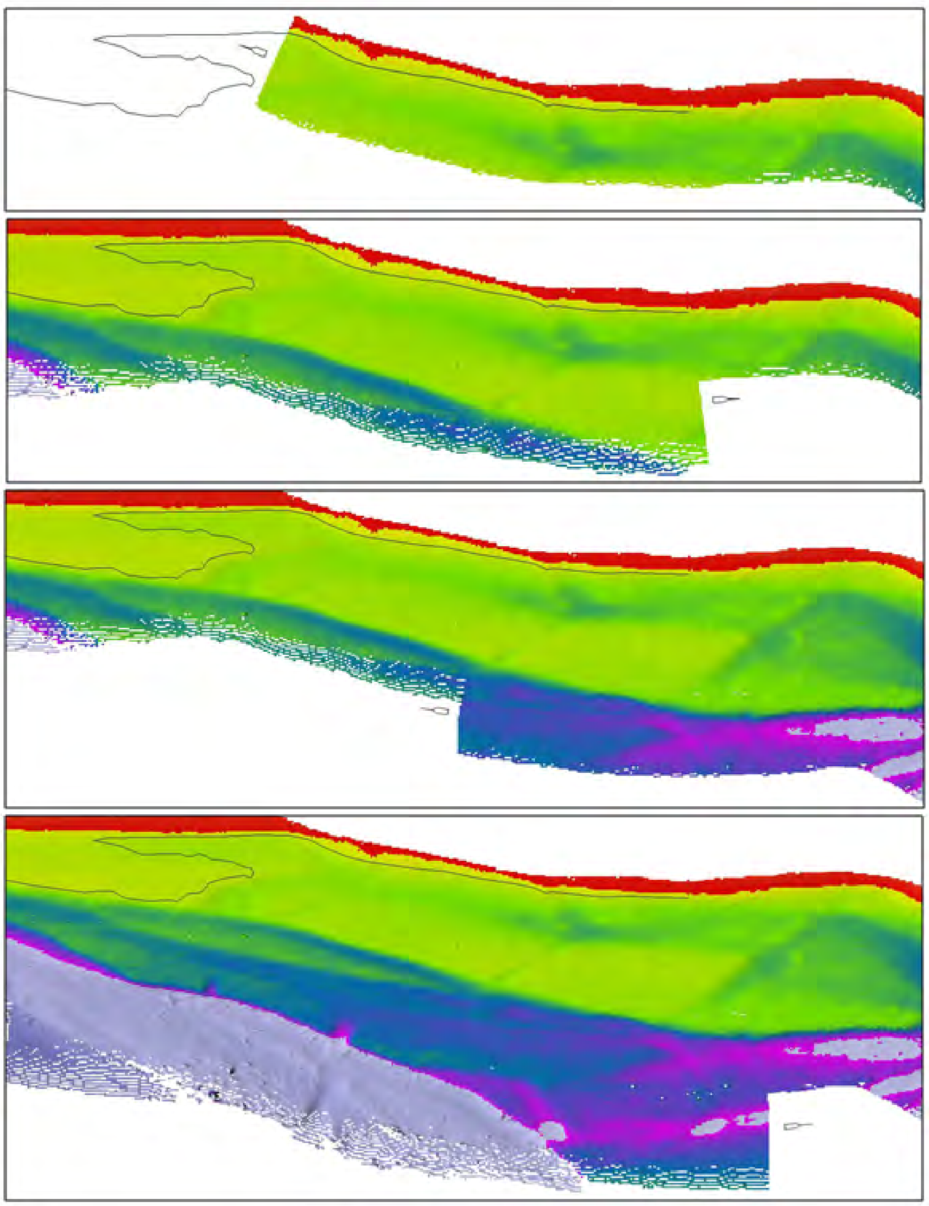


Figure 16 - Example of real-time survey coverage in the Nation arm.

9.4 Number of Passes

The number of multibeam survey lines was a function of the water depth and the distance from the inshore limit of photo and LiDAR coverage. Multibeam swath coverage is a function of the water depth and deeper water results in greater swath coverage. With an elevation range rather than a specific geographic area defining the scope of the Williston project, the shoreline side-slope angles define the extent of the survey area. With steep slopes the project area is smaller and it takes fewer lines to get the required coverage. Shallower slopes increase the project area and the number of survey lines.

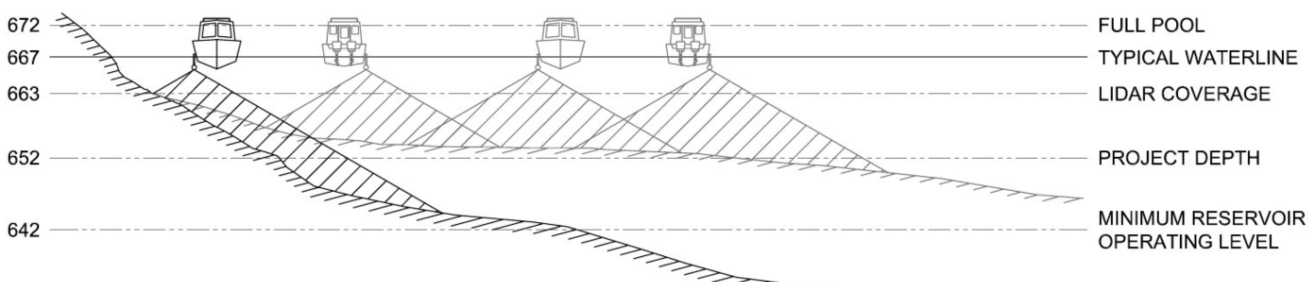


Figure 17 - Slope-dependent survey passes.

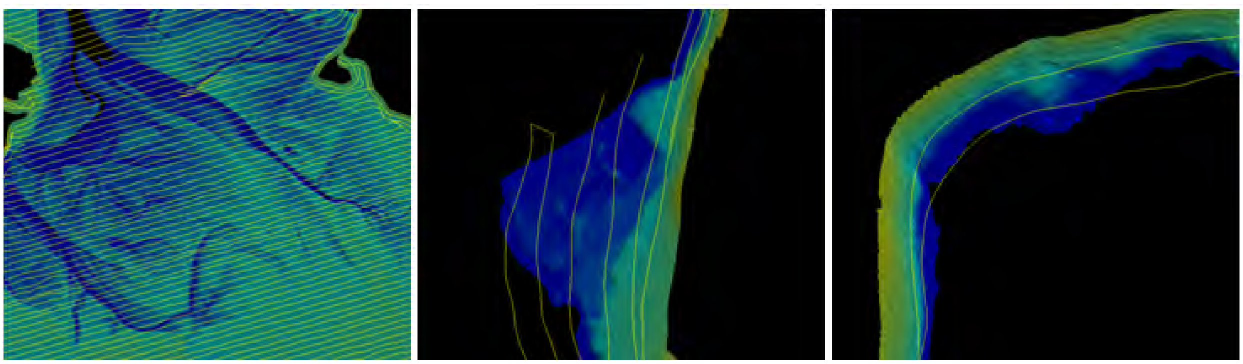


Figure 18 - Example of survey passes (yellow lines) in the Parsnip Arm

Table 17 below summarizes the total acquisition statistics for 2010 and 2011 of the *R/V Carta* and *M/V McKellar*. It excludes Patch, Cross, and Rejected lines.

Table 17 - Summary of Vessel Acquisition Statistics

	Vessel	# LINES	MBES KM	AVG SPEED (km/hr)	ONLINE TIME (hr)
2010	Carta	835	911	11.8	78
	McKellar	484	501	9.2	56
2011	Carta	2871	2795	11.9	232
	McKellar	1692	1740	10.0	174
Combined	Carta	3706	3706	11.9	309
	McKellar	2176	2241	9.9	230
	Total	**5882**	**5948**	**10.9**	**539**

10.0 CORRECTIONS TO SOUNDINGS

10.1 Patch Test Calibrations

A patch test is a set of systematic lines that are run to determine the alignment errors between the motion reference unit and the multibeam.

A patch test was conducted at the beginning of the project for both vessels each year and at periodic intervals to monitor the values.

Roll, pitch, yaw and latency patch lines were run and biases determined using the Caris HIPS calibration utility. Patch test results as well as the Caris HIPS vessel offsets are shown in tables below.

Table 18 - *R/V Carta* Patch test results.

Date	Time	X (m)	Y (m)	Z (m)	Pitch (°)	Roll (°)	Yaw (°)
2010-219	00:00	1.294	-0.785	0.983	-2.80	0.23	-0.70
2011-224	00:00	1.294	-0.785	0.983	-3.00	-0.47	-1.70
2011-242	20:02	1.294	-0.785	0.983	-3.00	-0.19	-1.70
2011-253	12:00	1.294	-0.785	0.983	-3.00	-0.25	-1.70
2011-255	12:00	1.294	-0.785	0.983	-3.00	-0.18	-1.70
2011-258	12:00	1.294	-0.785	0.983	-3.00	-0.25	-1.70

Table 19 - *M/V McKellar* Patch test results.

Date	Time	X (m)	Y (m)	Z (m)	Pitch (°)	Roll (°)	Yaw (°)
2010-219	00:00	-1.519	-0.178	0.504	0.55	3.22	1.70
2011-225	00:00	-1.519	-0.178	0.504	-1.20	2.62	0.00
2011-232	12:00	-1.519	-0.178	0.504	-1.20	2.77	0.00
2011-238	12:00	-1.519	-0.178	0.504	-1.20	2.82	0.00
2011-247	12:00	-1.519	-0.178	0.504	-1.20	2.92	0.00
2011-251	12:00	-1.519	-0.178	0.504	-1.20	2.82	0.00
2011-256	12:00	-1.519	-0.178	0.504	-1.20	2.72	0.00

10.2 Sound Velocity Casts

10.2.1 Method

Sound velocity casts were collected during the acquisition phase of the 2010-2011 survey. The casts used the AML SV Plus to measure the sound velocity, temperature and pressure through the water column. Sound velocity casts were taken at the beginning of each day and at an approximate two-hour interval throughout the day. The spatial distribution of the casts can be seen in Figure 20 below. A total of 386 casts were collected throughout the duration of the survey.

Table 20 - Sound velocity casts by vessel and year.

Year	Vessel	# of Casts
2010	Carta	52
2010	McKellar	38
2011	Carta	169
2011	McKellar	127

Sound velocity casts were defined by the "up cast" portion to allow for the probe to acclimatize to water conditions and improve accuracy. Further processing included applying a 25 centimeter binning to the data to smooth and reduce the data set.

The sound velocity measurements are applied during the processing phase in Caris HIPS to develop beam steering and accurately place soundings. Final cast data is included with the electronic deliverables.

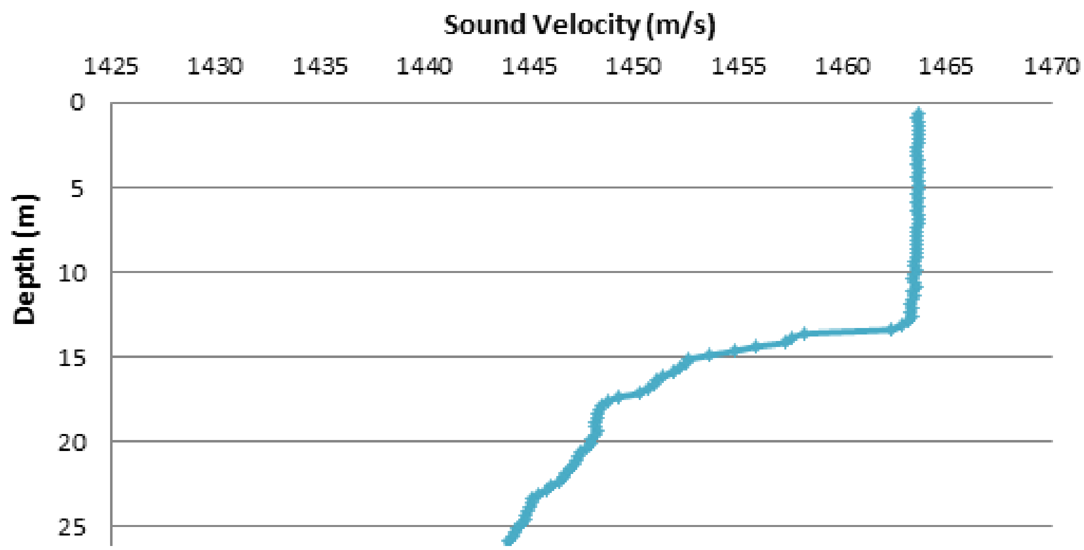


Figure 19 - Example of sound velocity profile in Williston Reservoir.

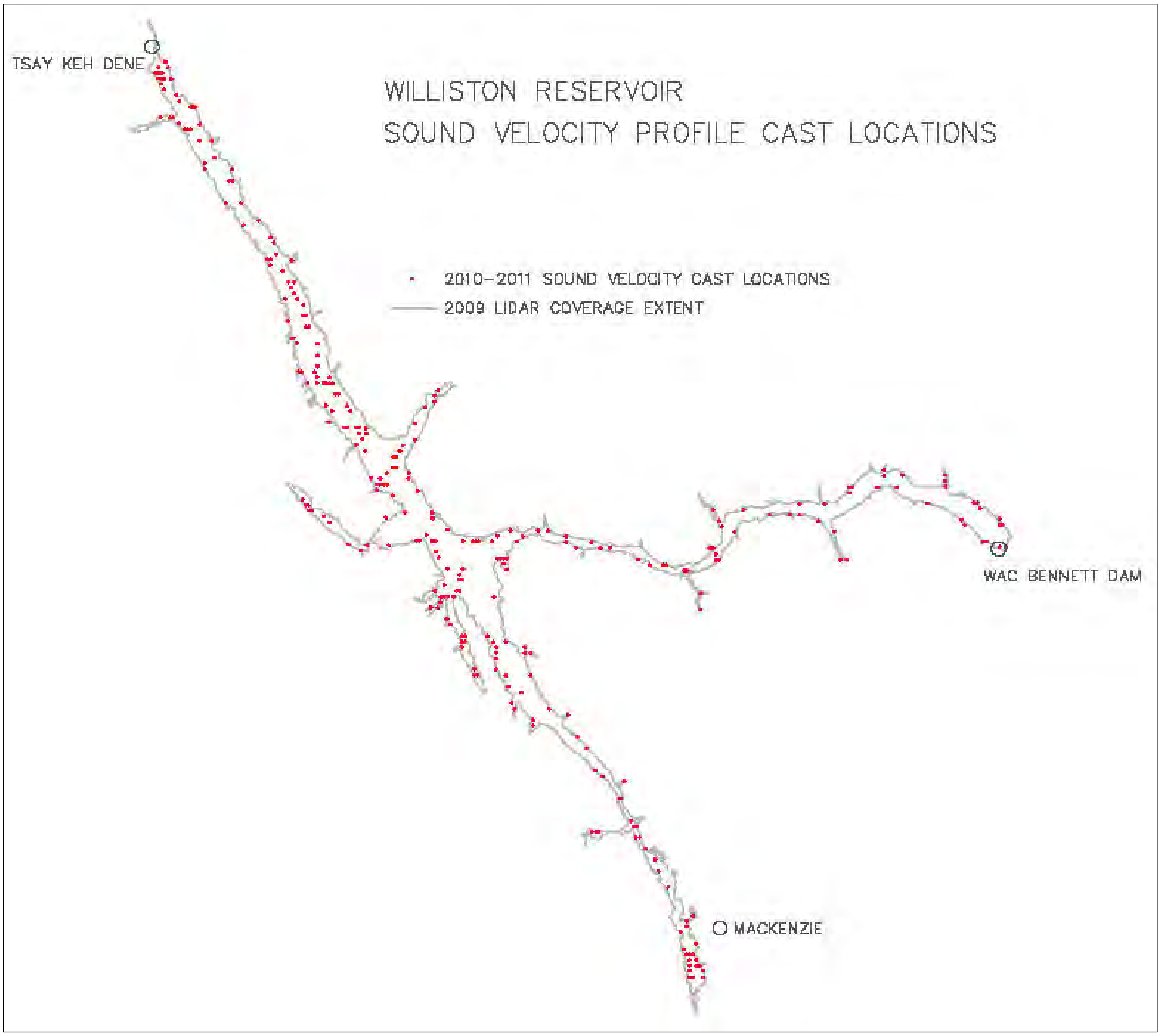


Figure 20 - Distribution of the 2010-2011 sound velocity casts.

10.3 Squat Settlement

10.3.1 Method

Squat settlement is a term describing the way a vessel sinks or rises at various speeds. In general a vessel will "squat" or lower into the water as its speed increases until it gets to a point where it begins to rise again as it heads toward a point of planing at high speeds. Though the values are small due to the size of the survey vessels, it is still significant enough to account for in a post-processed survey environment. During tests, the vessel should be in a survey-ready state with its sonar in the water and all equipment and personnel in place.

In the field, the following method was used to attain squat settlement values.

1. Bring the vessel to a stop and let it settle.
2. Drift for 60 seconds to determine any tidal or swell fluctuations.
3. Increase speed to a minimum RPM (commonly called "idle") and maintain course and speed for at least 60 seconds.
4. Bring vessel to a stop and allow to settle for 60 seconds

The previous 4 steps were repeated at gradually increasing intervals of 100-200 RPM (depending on the vessel's RPM range) that covered all potential survey speeds as well as a few intervals beyond typical speeds to help determine the squat curve (Appendix G).

The squat values were processed after completion of the survey. The squat settlement values were calculated by comparing the speed of the vessel to the PPK elevation of the vessel at that speed. This data is combined with tide gauge data to reduce the effect of tidal and swell fluctuations on the data. This data is averaged over the period of time the vessel is in motion. When the vessel is at rest, its vertical data can be used in comparison to the tidal data to further reduce the effects of tide and swells.

Table 21 - Squat Settlement Calculations

Carta		McKellar	
Draft (m)	Speed (m/s)	Draft (m)	Speed (m/s)
0.000	0.000	0.000	0.010
0.001	0.500	0.001	0.500
0.002	1.000	0.002	1.000
0.002	1.500	0.004	1.500
0.006	2.000	0.010	2.000
0.018	2.500	0.030	2.500
0.036	3.000	0.040	3.000
0.044	3.500	0.042	3.500
0.044	4.000	0.042	4.000
0.042	4.500		

10.4 WATER LEVEL PROCESSING

10.4.1 Method

Tide gauges used were Seabird SBE 26plus internal recording water level recorders. They were programmed to take measurements at six minute intervals over the duration of the survey. The gauges were mounted in a frame and deployed on the reservoir bed and marked with a buoy.

10.4.2 Processing

The gauges record absolute pressure that is converted to a depth by removing the atmospheric partial pressure component and applying a density and gravity correction. Atmospheric pressure was monitored with a Kestrel weather gauge at the site that recorded pressure at one hour intervals.

1. Download and extract the Seabird water pressure data using SeaSoftWaves software to create a raw tide model.
2. Download and extract the Kestrel atmospheric data using Kestrel Communicator to create a raw atmospheric pressure model.
3. Convert the Kestrel barometric pressure data to Station Pressure using the formula supplied by Kestrel. Use 667 meters as the standard elevation:

$$Z(P) = Ao * (1 - (P/P_{msl})^K)$$

Z = Altitude
P = Pressure
P_{msl} = Pressure at Sea Level
Ao = Constant: 44.3307
K = Constant: 0.19026

4. Format the station pressure into a barometric pressure (BP) file.
5. Apply density correction (1.0000 kg/m^3) and gravity correction (9.81 m/s^2)

The methods used to establish water level datums is described in the Vertical Control Section of the report relied on the processed gauge readings described above.

The water level used to correct any sounding was the weighted average value of the two closest gauges depending on the vessels distance from the gauge site.

11.0 CARIS PROCESSING

11.1 Bathymetry Processing Procedure

Multibeam data was processed using Caris HIPS version 7.1. HIPS provides data processing tools that allow you to take the raw sensor data recorded during data acquisition and create a final sounding set. The HIPS workflow was composed of the following steps:

1. Vessel Configuration File. A layout of sensor offsets and patch values for both vessels is created. Also included is a Total Propagated Uncertainty (TPU) model based on measurements and manufacturer specifications to be applied in the CUBE process. Additionally, the Squat Settlement calculations are applied as the Dynamic Draft.

2. Data Conversion. Raw data is converted from the native QINSy format to a HIPS format.

3. Sensor Editing. Sensor data such as heave, pitch, roll and navigation is reviewed. The data is edited for spikes, smoothed, interpolated or rejected if necessary.

4. Sound Velocity Processing. Sound velocity processing converts the soundings from raw beam angle and time of flight measurements to soundings based on the sound velocity profile (SVP) of the water column and vessel attitude measurements. The Sound Velocity files (*.svp) represent a combined dataset of all sound velocity casts taken in the field and are comprised of Date, Time, Location, Depth, and Sound Velocity. Sound velocities were applied using "Nearest in Distance within Time 4 Hours," allowing for the closest (and most representative) cast to be used regardless of the vessel that took the measurement.

5. Tide Processing. The processed tide station data is applied to all survey lines. During the final processing of the bathymetric data, a weighted averaging algorithm is used to apply the tide station data according to the zoning definition file (*.zdf).

6. Patch Test. Develop values for the multibeam to account for non-zero Pitch, Roll, Yaw, and Latency biases. These values are fed back into the Vessel Configuration File to be merged into all soundings. See Tables 19 and 20 for determined values.

7. Merging. Water level and other vertical corrections are applied to the soundings. The soundings are converted from time, beam and ping format referenced to the vessel location, to a fully geo-registered sounding.

8. Swath Editing. Soundings from individual lines are cleaned in the Swath Editor. The Swath Editor allows the hydrographer to examine and reject erroneous data and filter lines based on depth and swath limits.

9. Subset Editing. Subset editing is the final step in the data cleaning process. The Subset Editor allows the hydrographer to view data from multiple survey lines in a region in a single 2D and 3D spatial editor.

10. Surface Processing. After the data has been cleaned and finalized, HIPS creates a gridded surface from the data called a CUBE surface. The horizontal resolution of the surface is user specified and depends on the resolution of the acquired data and the accuracy requirements.

In order to minimize the amount of time spent cleaning "noise" and "fliers" from the data in later steps, several filters were applied to each line after being merged. A list of these filters may be found in Table 22. Once the data had been merged and filtered, each line was cleaned for remaining fliers and noise in Swath Editor. Any sounding or group of soundings that could be potential trees was kept for later review in Subset Editor.

Table 22 - Filters Applied to Individual Lines Prior to Cleaning.

Type of Filter	Settings
Depth	Reject soundings outside range of 2-22 meters
Angle from Nadir	Reject soundings past 65° to port or starboard
Quality Flags	Reject soundings with Quality Flags = 0 or 1

Ten kilometer by ten kilometer fieldsheets were created to divide the data into manageable sizes for cleaning in Subset Editor. An example of the fieldsheet layout in Caris can be seen in Figure 21 below. Combined Uncertainty and Bathymetry Estimator (CUBE) surfaces were created at a resolution of 1 meter, with a depth range of -700 to -650 meters. CUBE surfaces were built with the density and locale disambiguation method; other CUBE parameters from the configuration file are shown in Table 23 below.

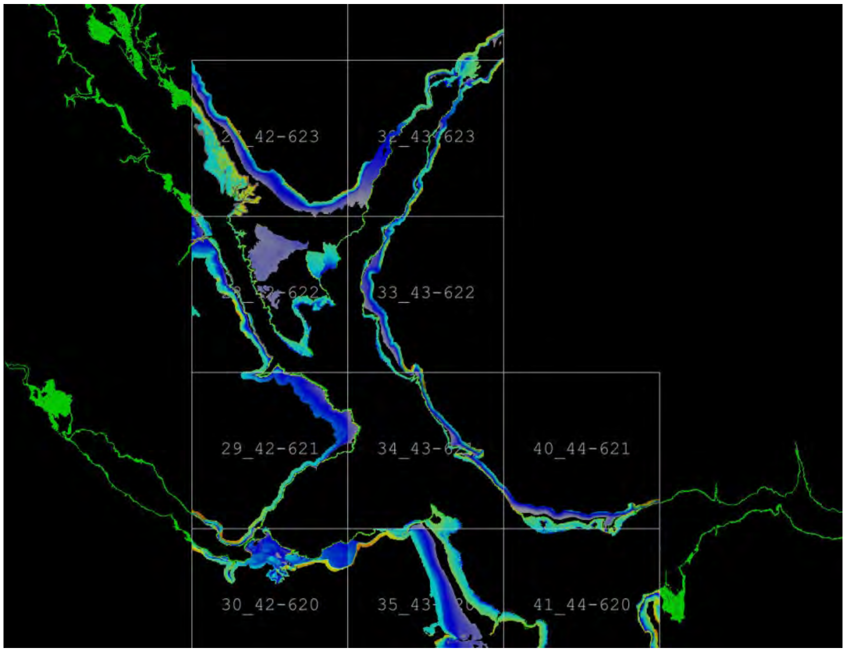


Figure 21 - Example of 10 kilometer fieldsheets in Caris.

Table 23 - Parameters for creation of 1-meter resolution CUBE surfaces.

CUBE PARAMETERS			
Surface Creation		*Disambiguation*	
Estimate Offset	4.00	Density Strength Limit	2.00
Capture Distance Scale	5.00%	Locale Strength Maximum:	2.50
Capture Distance Minimum	0.5 m	Locale Strength Radius	1 pixel
Horizontal Error Scalar	2.95		

Once CUBE surfaces were created, the data was cleaned in Subset Editor. While cleaning was taking place, the CUBE surface was turned on to aid in discriminating between noise and possible trees. Potential trees were marked as "Examined." See Figure 22 below for an example of a CUBE surface and trees marked "Examined" in Subset Editor.

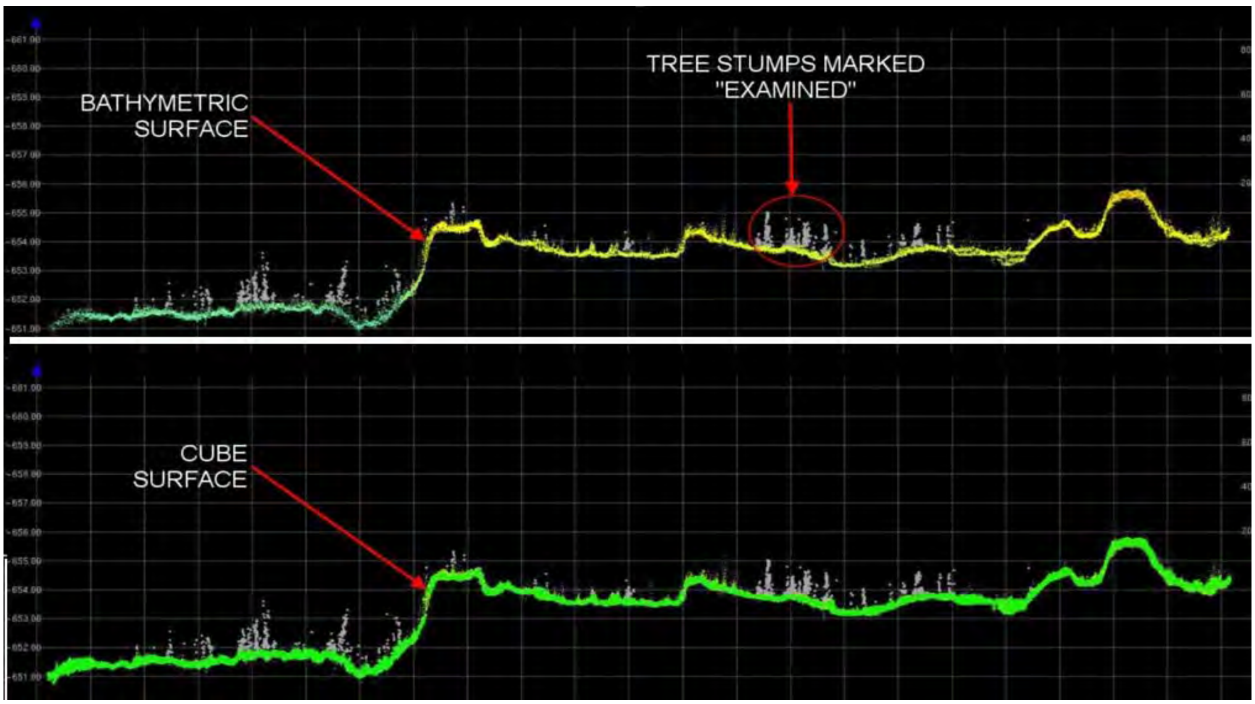


Figure 22 - Views in Subset Editor of a bathymetric surface (top) and a CUBE surface (bottom). Data shown in grey are trees marked "Examined."

After data was cleaned, the CUBE surfaces were recomputed to look for areas needing further attention from the data processor. Once satisfied, the data processor created final surfaces for each 100 km^2 fieldsheet. Point sets were then created by exporting the CUBE surfaces using Caris HIPS' data export tool. For each fieldsheet two point sets were created: a 1-meter gridded resolution "bare earth" point set containing only "Accepted" soundings and a 1-meter gridded of just "Examined" soundings representing submerged trees and other objects. These products were exported as ASCII point sets that were used in the development of the project data deliverables.

12.0 DELIVERABLES

12.1 Charts

Twenty-five navigational charts of the reservoir were created in AutoCAD 2013; 15 1:50,000 scale charts of the entire reservoir and 10 1:10,000 scale charts in select areas. All charts were plotted in PDF format at ANSI D scale. The chart scales and areas included are as follows:

1: 50,000		1:10,000	
1006-C11-01129	TSAY KEH DENE	1006-C11-01144	SHOVEL CREEK
1006-C11-01130	INGENIKA ARM	1006-C11-01145	COLLINS BAY
1006-C11-01131	COLLINS BAY	1006-C11-01146	CORLESS BAY NORTH
1006-C11-01132	LAFFERTY	1006-C11-01147	CORLESS BAY SOUTH
1006-C11-01133	OSPIKA ARM	1006-C11-01148	FINLAY BAY
1006-C11-01134	OMINECA ARM	1006-C11-01149	SIX MILE BAY
1006-C11-01135	FINLAY BAY	1006-C11-01150	CUT THUMB BAY
1006-C11-01136	MANSON ARM	1006-C11-01151	MACKENZIE LANDING
1006-C11-01137	SIX MILE CREEK	1006-C11-01152	DUNLEVY BAY
1006-C11-01138	NATION ARM	1006-C11-01153	WAC BENNETT DAM
1006-C11-01139	MACKENZIE		
1006-C11-01140	WICKED RIVER		
1006-C11-01141	CLEARWATER CREEK		
1006-C11-01142	SCHOOLER CREEK		
1006-C11-01143	WAC BENNETT DAM		

12.1.1 Location

The 1:50,000 charts cover the entire lake. Each chart has overlap of adjacent charts and is indicated as such on each chart. 1:10,000 chart outlines are also noted in a chart where applicable.

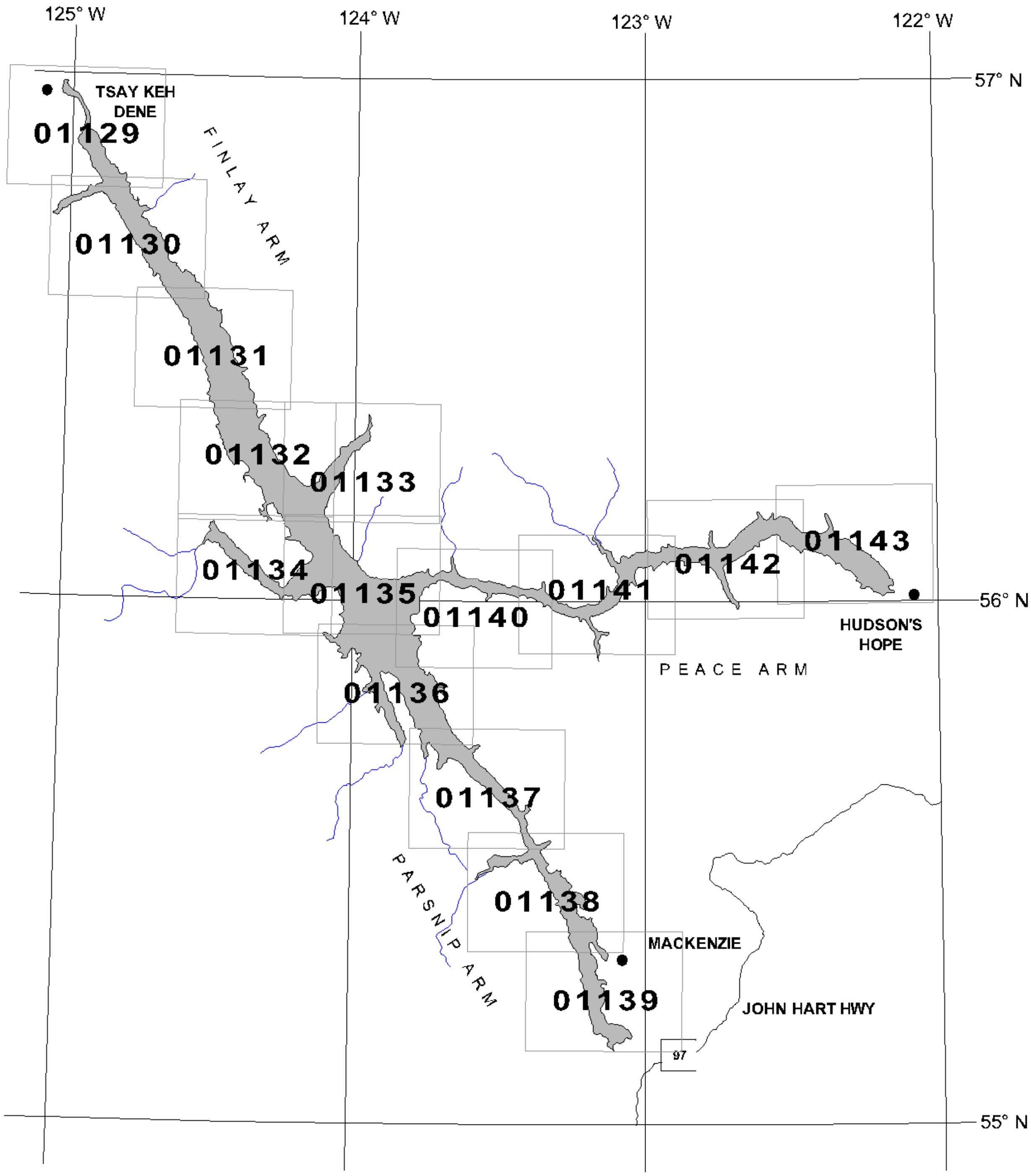


Figure 23 - 1:50,000 Scale Charts.

The 1:10,000 charts provide detail of specific areas around the lake; typically areas with boat launches or higher vessel activity.

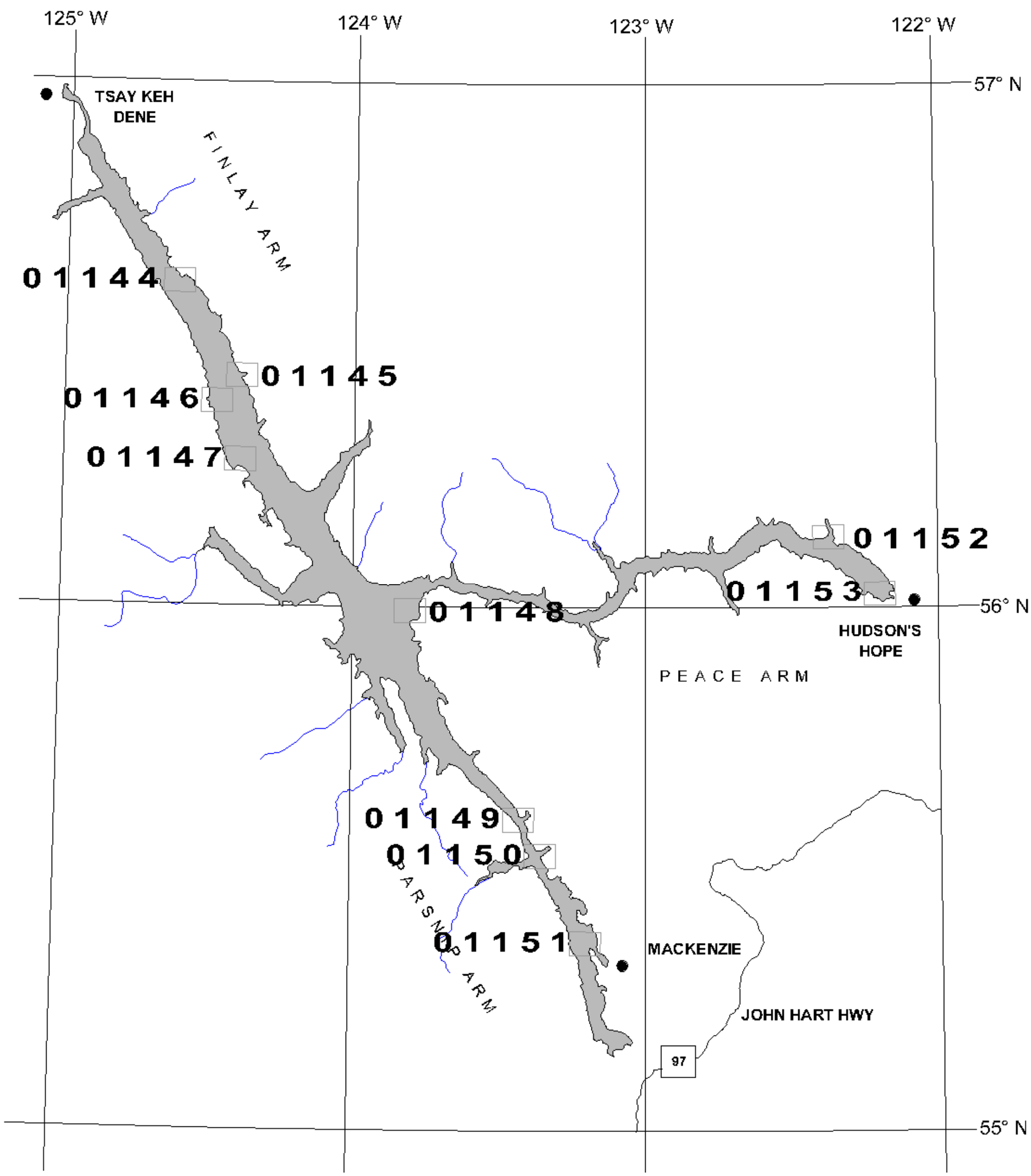


Figure 24 - 1:10:000 Scale Charts.

12.1.2 Background Data

All charts have background data in addition to the bathymetry/photogrammetry to provide context and additional information relevant to the chart.

Table 24 - Background data sources.

Type	Source
Topography	BC GIS
Roads	BC GIS
River Channel	BC Hydro
Hazard Areas	BC Hydro
Compass Rose	TerraSond
Average Water Level	BC Hydro

12.1.3 Bathymetry and Sounding Sources

The contours and soundings for the charts were created from 3 data sources:

1. 1-meter Multibeam bathymetry collected by TerraSond in 2010 and 2011. This data was provided by TerraSond and was divided into the 10 km^2 areas.
2. 5-meter Photogrammetry (with 2009 LiDAR) collected by BC Hydro in 2011. This data was merged by BC Hydro with the existing 2009 LiDAR. This data was provided by BC Hydro and was divided into each 1:50,000 chart area for the entire lake.
3. 5-meter Photogrammetry collected by BC Hydro in 2004. This data was provided by BC Hydro and was divided into each 1:50,000 chart area, primarily in the Finlay Arm.

A workflow was developed to combine the gridded points data for each chart and export them as points for contours or soundings:

1. QPS QINSy Sounding Grid Utility (SGU) was used to combine the data. The Sounding Grid Utility was set up to scale data at preset grid sizes. The data was gridded at 5, 10, 20, 40, and 80 meters. Mean or Shoal values could then be extracted from these gridded data sets.
2. The data was imported to the SGU in reverse order of priority, stacking and overwriting the overlapping areas with the newer data. The 2004 Photogrammetry, where available, was placed on the bottom layer, then the 2011 Photogrammetry, and finally the 2010-2011 bathymetry on the top layer. This ensured the newest and most accurate data was represented where available. The data was flagged in the SGU as to where it came from and was carried through upon export:

   1 = 2010-2011 Multibeam Bathymetry
   2 = 2009 LiDAR (unused)
   3 = 2011 Photogrammetry
   4 = 2004 Photogrammetry

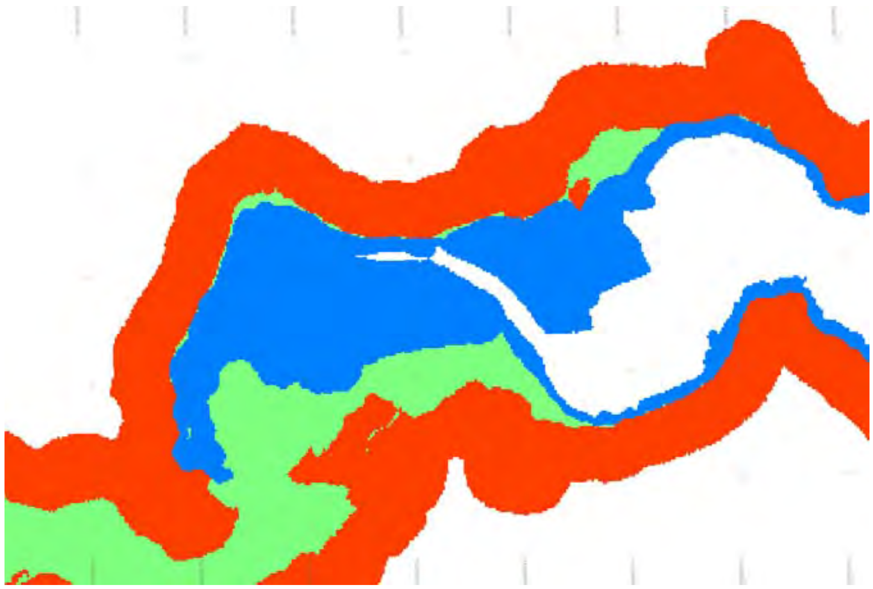


Figure 25 - Example of merged data sources in the Ingenika Arm. Colors: Blue=Bathymetry, Green=2004 Photogrammetry, Red=2011 Photogrammetry + 2009 LiDAR.

12.1.3.1 Creating points for chart contours

1. To create data for the contours, the points' ENH values were exported at the center of the gridded cell and the mean elevation of the entire cell. The lower vertical value was limited to 650-meters as part of the scope of this project.
2. In order to keep file sizes for AutoCAD 2012 manageable, The 1:50,000 scale charts used 20-meter gridded point sets and the 1:10,000 scale charts used 10-meter gridded point sets. These were exported from the same SGU files, using a border file to clip around the chart area.
3. The point sets were exported in AutoCAD-friendly ASCII with the following, comma-delimited format:

   <EASTING>,<NORTHING>,<ELEVATION>,<SOURCE FLAG>

   The file names have the following format example:

   1006-C11-01135_Chart07-FinlayBay_20m-Mean_UTM10N_CGVD28_xyz_BE_ALL.txt

   The naming includes the official chart number, the legacy chart number, the chart name, grid size and elevation type, datums, BE for bare earth (no trees for example) and all point sources included. Points files are included with the AutoCAD drawings and are also available in the Points directory as well

12.1.3.2 Depicting Bathymetry

The topography data from 650 meters to 672 meters was depicted on the chart using color banding to emphasize the shoreline areas of primary importance for navigation and attempt to provide simplicity for the user.

Table 25 - Chart Topography Colors.

Elevations (meters)	Color	Red, Green, Blue
668 – 672	Dark Green	154,177,124
664 – 668	Green	166,216,130
660 – 664	Light Green	187,255,185
656 – 660	Light Blue	146,245,252
652 – 656	Blue	97,183,245
650 – 652	Dark Blue	36,155,240

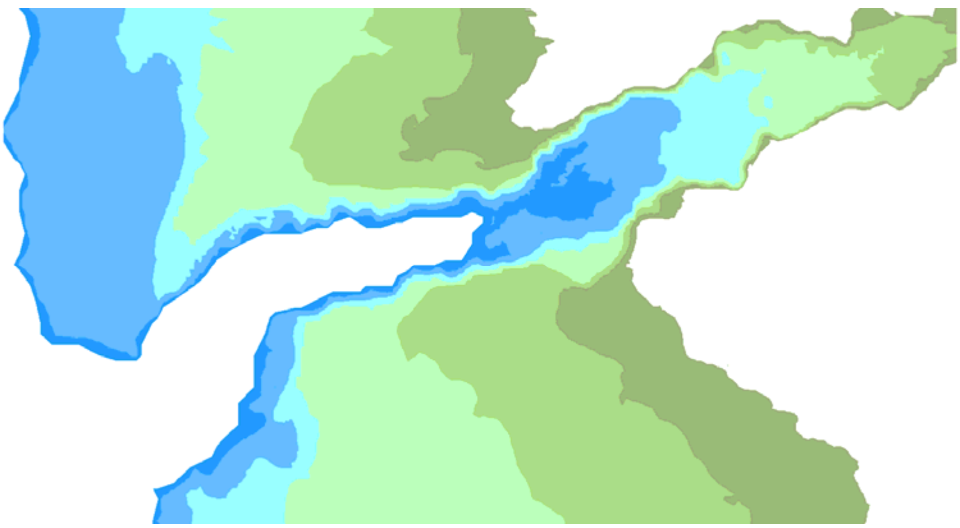


Figure 26 - Topography example at Collins Bay.

12.1.3.3 Creating points for chart shoal soundings

1. To create data for the soundings, further processing was required in the SGU and other software.
2. The data was first exported from SGU as an ASCII file at 5-meters with the easting and northing at the location within the cell at the shoalest point.
3. Hypack 2011 provides a sorting utility called Sounding Sort to weed out points in a shoal-biased sounding set in order to reduce it to a more manageable size for charting. The sorting routine starts with the highest elevation point value and then begins removing points within a given radius that are lower in elevation than the starting point. The Sounding Sort utility processes all given files and exports a new ASCII file with the shoalest value for that radius search pattern, reducing a points file size by several factors.

4. The 5-meter shoal points ASCII file was imported into the Sounding Sort utility. Additionally, points files provided by BC Hydro called Top of Isolations Soundings (Isolations) from the bathymetry were imported into Hypack to further improve the sorting routine to find the shoalest value in a given area.
5. The data was exported at 100-meter sorted files for each 1:50,000 chart location and 250-meter for the 1:10,000 chart locations.

12.1.3.4 Chart Soundings Selection

1. The sounding density for each chart was determined to be best suited at the following values:
   a. The 1:50,000 charts should have a radius of 500-meter sounding density.
   b. The 1:10,000 charts should have a radius of 250-meter sounding density.
2. The 1:10,000 charts were sorted at 250 meters. The points were cleaned out in AutoCAD as needed, typically along the shoreline. Further examination was applied to each chart to determine if further soundings were required in a given area to provide clarification.
3. A hand-selection method for the 1:50,000 charts was developed to reduce the likelihood that a shoal object on the chart would be skipped over in the Hypack Sounding Sort utility due to the large sort radius of 500 meters.
4. The 100-meter point files were imported into AutoCAD as COGO point objects. Then a surface was created from the mean surface to show contours of the lakebed and highlight objects and high points. This created a digital smooth sheet from which to work with.

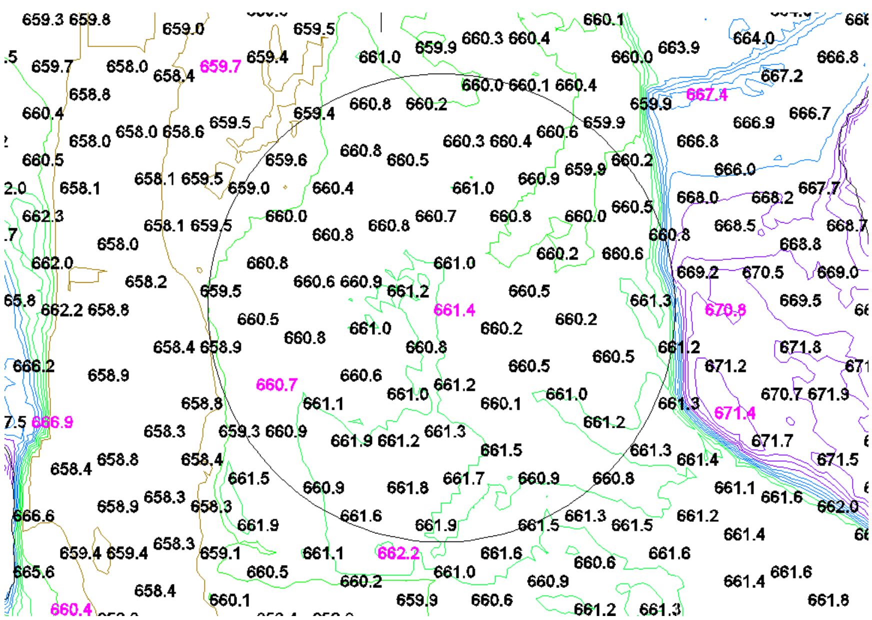


Figure 27 - Digital Smooth Sheet. The selected soundings are magenta, the remaining soundings were excluded. The circle represents a 500-meter radius search area.

5. The hydrographer then commenced the hand-sorting routine by selecting a high point in the lake bed within the chart area. A 500-meter circle was transcribed to provide a reference to the user. The following are general criteria considered when selecting soundings:
   a. Potential navigational hazard locations were given top priority.

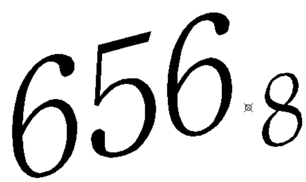
b. Sorted points on the shoreline were generally ignored in favor of other high points within the 500-meter radius.
c. Areas of steep grades, such as along the shoreline common to the Peace Arm, soundings were ignored altogether to reduce visual clutter and lack of necessity in these areas. In some cases where the slope of the grade has flattened, a representative sounding may have been selected.
d. In some cases soundings closer than 500 meters were kept when high points of significance were close to each other.

6. Upon completion, the soundings were exported as ASCII files in the following format:

<POINT>,<EASTING>,<NORTHING>,<ELEVATION>,<DESCRIPTION>

12.1.3.5 Chart Depiction

1. Soundings were imported as Civil 3D points to each chart.
2. The soundings were designed with the following characteristics:



a. The text is presented at a 15°angle with a 15° slant.
b. The primary value on the left is larger than the vertically offset decimal value on the right.
c. The elevations use standard rounding to the nearest tenth of a meter.
d. The position of the text representing the sounding is based at the small point between the numbers visible in the example above. The visual representation of the point itself is disabled in AutoCAD for the charts to reduce visual clutter.

12.2 Drawings

AutoCAD 2013 with Civil 3D was used to develop the charts. There are 25 separate charts that utilize referenced drawings that provide additional data. Each drawing has the following structure:

- "CHARTS" Folder
  - Chart – *"1006-C11-<No.>_<Name>.dwg"*
    - "XREF" Folder
      - Border file – *WILLISTON_BORDER_<scale>.dwg*
        - Vicinity Map – *1_WILLISTON_VICINITY_NTS.dwg*
      - Hazards - *WILLISTON POTENTIAL HAZARD AREAS <scale>.dwg*
      - River Channel - *WILLISTON_PRE-FLOOD_RIVER_CHANNEL_1966.dwg*
      - Water Level Chart - *WILLISTON_HISTORIC_WATER_LEVEL_CHART.dwg*
    - "CONTOURS" Folder

- 10 or 20 meter Gridded ASCII points file for creating surface. The creation method for the TIN surface points was described in Section 12.1.3.1 above.

12.3 Points

As discussed in Section 12.1.3, the point sets were created from a combination of sources into a seamless gridded point set for each chart site.

Bathymetry and LiDAR ASCII points were created in Caris HIPS and are named in the following format:

"<SW-Corner of 10km x 10km format>_<Tile #>_ <Grid Size>_<Horizontal System>_<Vertical System>_<Comma-delimited ormat>_<BareEarth or Objects>_<LiDAR or Bathymetry>.txt"

For example, a LiDAR point set was named the following:

41-624_22_2m_INT_UTM10N_CGVD28_xyz_BE_LiDAR.txt

The 2004 and 2011 Photogrammetry retains the same files as provided by BCHydro but have been corrected to the CGG2005 model of CGVD28.

12.3.1 2009 LiDAR

- 2-meter gridded point sets in 10 kilometer x 10 kilometer tiles

12.3.2 2010-2011 Bathymetry

- "Bare Earth" 1-meter gridded point sets in 10 kilometer x 10 kilometer tiles
- "Objects" 1-meter gridded point sets in 10 kilometer x 10 kilometer tiles representing flagged submerged objects.

12.3.3 2004 and 2011 Photogrammetry

- 5-meter point sets in the 1:50,000 scale charts as provided by BC Hydro

12.4 Fledermaus

12.4.1 Overview

Fledermaus 7.3 Professional is a product designed to assemble large amounts of data from various sources into "scene" files. Three-dimensional products are created to assist in viewing and understanding the collected data. This section outlines the composition of the scenes.

Eighty-seven scenes for each of the 10 kilometer x 10 kilometer tiles were created. See Figure 28 for an example of a typical Fledermaus scene. The scenes provided are composed of the following items:

1. The 10 kilometer tile drawing used for use as a reference (10km_Tiles_withLabels)

2. A 672 meter contour derived from the LiDAR data down-sampled at 20 meters, where available, for use as an approximate shoreline reference (Williston_672m_LiDAR_20m)
3. A DTM surface built from the LiDAR 2 meter Bare Earth gridded point set (EE_NNN_##_2m_INT_UTM10N_CGVD28_BE_LiDAR.sd)
4. A DTM surface built from the bathymetry 1 meter Bare Earth gridded point set (EE_NNN_##_1m_UTM10N_CGVD28_BE_Bathy.sd) <where available>
5. A DTM surface built from the 2004 and 2011 Photgrammetry 5-meter gridded point set (5m_UTM10N_CGVD28_xyz_BE_PHOTO20##.sd)
6. A points file representing tree locations built from the bathymetry 1 meter objects gridded point set (EE_NNN_##_2m_INT_UTM10N_CGVD28_BE_Trees.sd) <where available>

The DTM files were created in Fledermaus as .sd files. They use a single Color Range file to improve visualization by representing the DTMs as a unified surface. The color range utilizes color changes to help identify areas outside of the project scope. The data within the project scope of 652 meters-672 meters is represented by shades of blue. Data below 652 meters is grey and data above 672 meters starts with dark green and changes color with elevation.

The points .sd files representing trees is a simple single point representation derived from the bathymetry 1m points set. These points are a single shade of brown.

12.4.2 Deliverables

Fledermaus' free tool iView4D is used to view the scene files, which is available at http://www.qps.nl/display/fledermaus/iview

The scene files are named by the 10km x 10km area they represent, using a truncated Easting and Northing of the southwest corner of the tile for the first and second values. The third value is an assigned tile number for easier identification.

"EE_NNN_ID.scene" Example: *"43-619_36.scene"*

The scene files default to a vertical exaggeration of 2.00, though this can be changed within the viewer. Any of the objects making up the scene can be turned on or off using the check boxes. The "Esc" key can be pressed at any time to return to the default view. More information regarding using iView4D is available in the software "Help" directory by pressing the "F1" key.

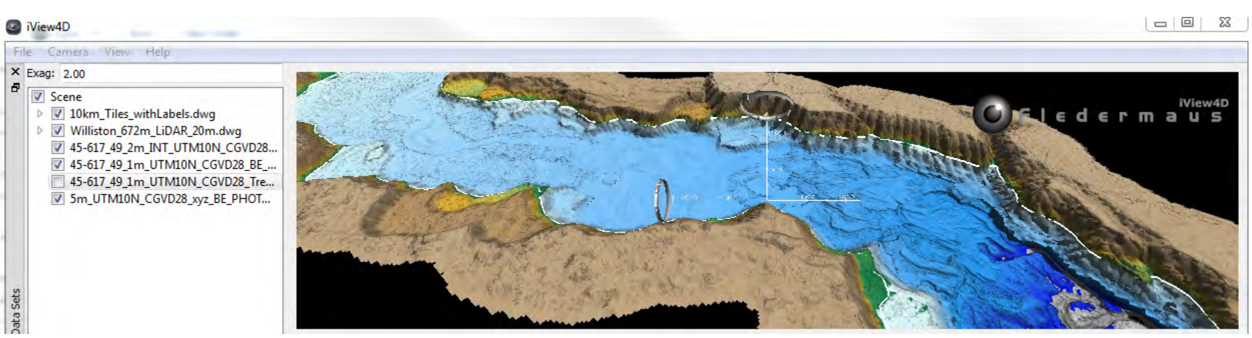


Figure 28 - Typical Fledermaus Scene.

Not Included in PDF Version of Report

Not Included in PDF version of the report

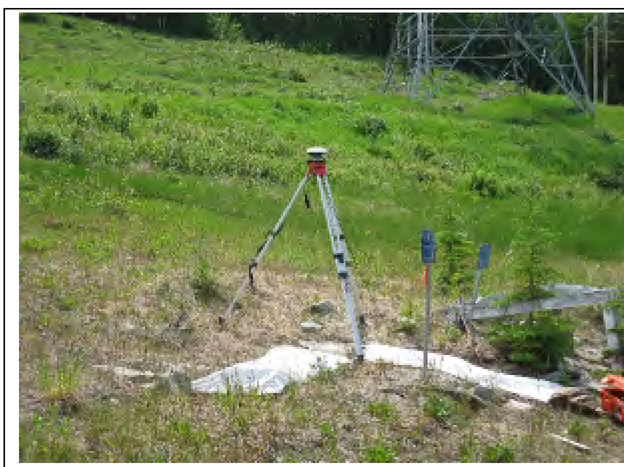
STATION DESCRIPTION/RECOVERY FORM

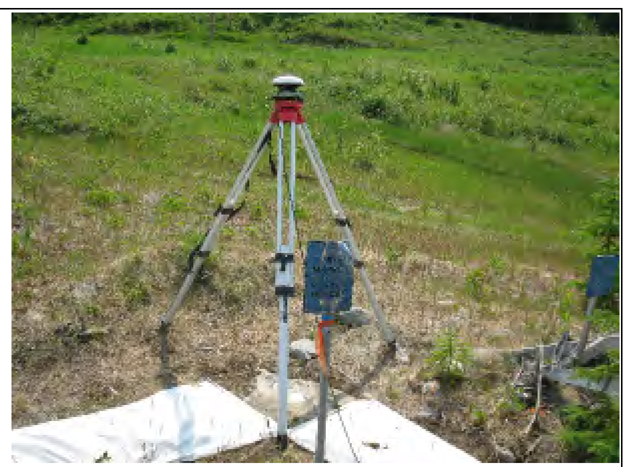
Station Designation	667007
Marker Type	Brass Disk in bedrock
Agency	BC Hydro/ Geodetic Survey Canada
Stamping	G.S.C. 667007
Recovery Condition	Good
General Location	W.A.C. Bennett Dam
Northing (NAD 83)	6207499.139
Easting (NAD 83)	550588.617
Ellipsoid Height (M)	709.477
Elevation (HT2)	722.000
Elevation (CGG05)	722.104
Recovered by	P. Rontu, C. Kemp
Recovery date (m/d/y)	06/16/2010

GCM No: 7377841

The monument is located at the SE end of the WAC Bennett dam. It is approximately 20 meters south of the main access road to the dam entrance and approx. 400 meters West of the dam entrance gate. It is located under the transmission lines. Monument is a brass disk set in rock.

Coordinates provided are as surveyed by TerraSond.





STATION DESCRIPTION / RECOVERY FORM

Station Designation	821
Marker Type	Rebar w/ Tag
Agency	BC Hydro
Stamping	BC Hydro 821
Recovery Condition	Good
General Location	Finlay Bay
Northing (NAD 83)	6204197.084
Easting (NAD 83)	449637.858
Ellipsoid Height (M)	675.681
Elevation (HT2)	685.390
Elevation (CGG05)	685.718
Recovered by	CK, TerraSond
Recovery date (m/d/y)	06/16/2010

Photo target east side of Parsnip West Forest Service Road. 1.5 KM north of junction with Finlay Bay forest service road and +/- 1KM west of south end of Finlay Bay. Rebar with plastic tag stamped "BC HYDRO 821".

Coordinates provided are as surveyed by TerraSond.

STATION DESCRIPTION/RECOVERY FORM

Station Designation	FR 1
Marker Type	Rebar w/ Brass Disk
Agency	BC Hydro
Stamping	BC Hydro GPS 1
Recovery Condition	Good
General Location	North end Williston Lake
Northing (NAD 83)	6305939.162
Easting (NAD 83)	383667.852
Ellipsoid Height (M)	691.938
Elevation (HT2)	699.285
Elevation (CGG06)	699.589
Recovered by	JM, CK, TerraSond
Recovery date (m/d/y)	06/18/2010

Approx. 200 meters east of Finlay-Davis FSR on old skid road. Monument is marked by a survey sign. Monument is approx. 3 km south from McIvor Creek bridge (km 8). Monument is a 3 ¼” brass disk atop a ½” rebar stamped “BC HYDRO GPS 1 2007”. Disk is approx. 0.16M above ground.

Coordinates provided are as surveyed by TerraSond.

STATION DESCRIPTION / RECOVERY FORM

Station Designation	WLT 48
Marker Type	Rebar w/ Punch
Agency	BC Hydro
Stamping	None
Recovery Condition	Good
General Location	South End Parsnip
Northing (NAD 83)	6114246.701
Easting (NAD 83)	490359.196
Ellipsoid Height (M)	712.263
Elevation (HT2)	724.021
Elevation (CGG05)	724.444
Recovered by	J.Muir, P.Rontu
Recovery date (m/d/y)	06/15/2010

From MacKenzie, head south to causeway over south end of Williston Lake (Parsnip Reach). Continue past causeway approx. 1.2 km to gravel pullout and monument on left. The monument is 3 meters from west edge of roadway and 52 meters west of road sign “17 KM”. The monument is a rebar with punch mark.

Coordinates provided are as surveyed by TerraSond.

APPENDIX D
Horizontal Position Checks

GMSWORKS#25: Williston Reservoir Bathymetric Survey
Horizontal Positioning Verification

STATION:	667007	AGENCY:	GSC		GCM No.	7378413

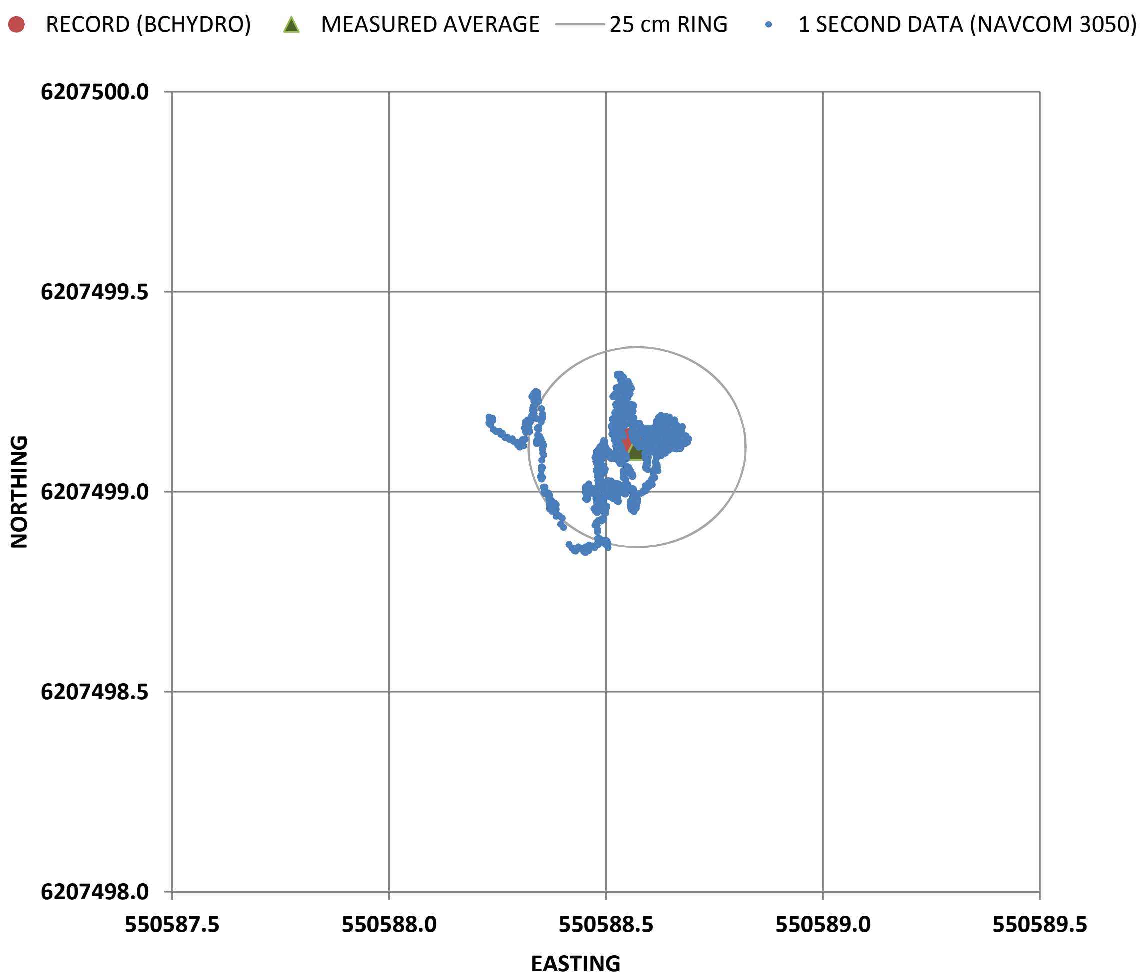
RECORD COORDINATES

NORTHING:	6207499.126	**EASTING:**	550588.557	(NAD83 CSRS, UTM 10 N, Meters)
LATITUDE:	56 00 36.309585	**LONGITUDE:**	122 11 19.125978	(NAD83 CSRS)

OBSERVATON COORDINATES

NORTHING:	6207499.11	**EASTING:**	550588.57	(NAD83 CSRS, UTM 10 N, Meters)
d NORTHING:	-0.01	**d EASTING:**	0.01	
STD DEV (95%):	0.16		0.16	

POSITIONING SYSTEM:	NAVCOM 3050 - RTG CORRECTION
OBSERVATION DATE/TIME (UTC):	6/21/10 20:00
OBSERVATION LENGTH:	00:59
OBSERVATIONS:	3591



GMSWORKS#25: Williston Reservoir Bathymetric Survey
Horizontal Positioning Verification

STATION:	**821**	**AGENCY:**	**BC Hydro**	**GCM No.**	**NA**

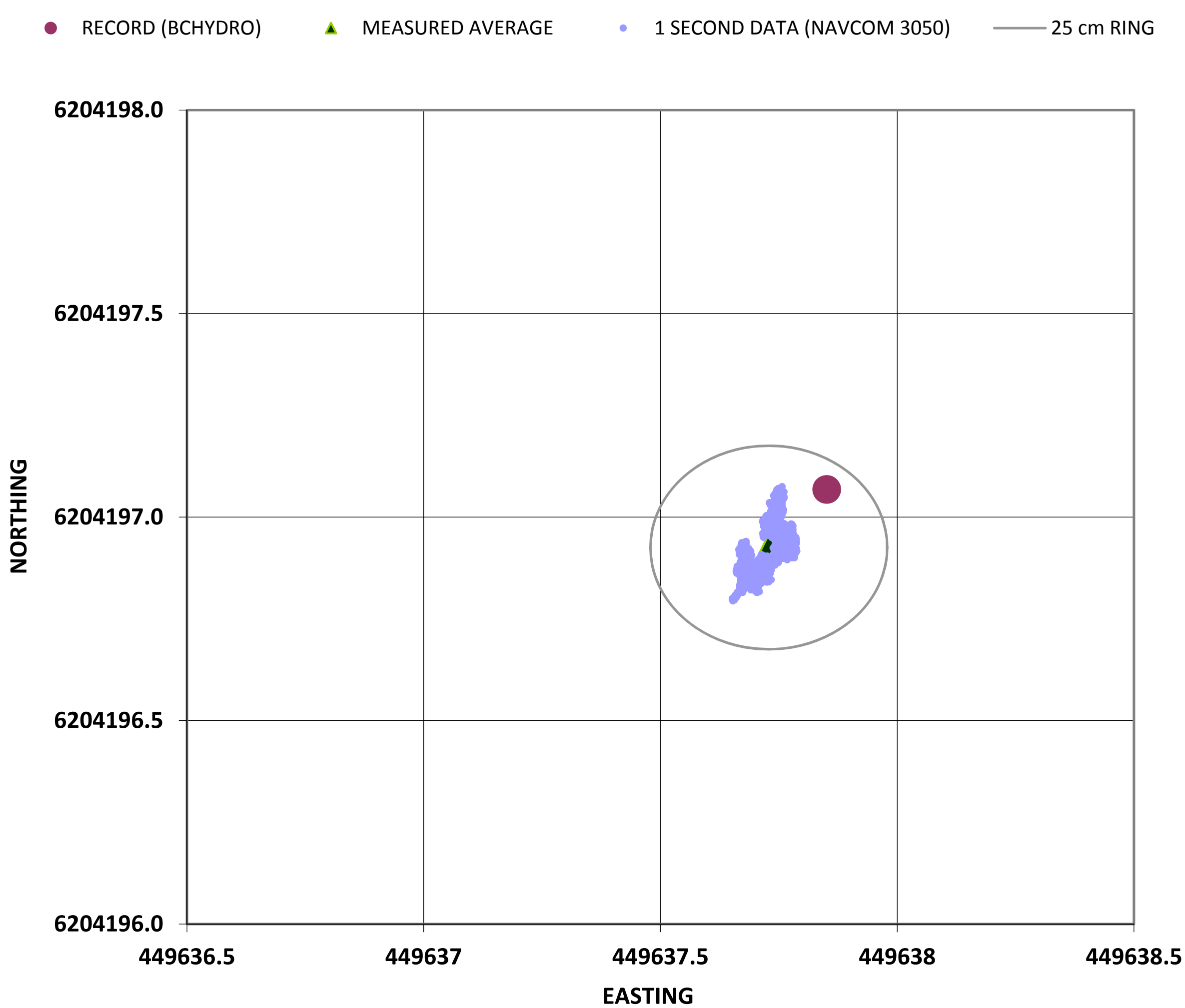
RECORD COORDINATES

NORTHING:	6204197.068	**EASTING:**	449637.851	(NAD83 CSRS, UTM 10 N, Meters)
LATITUDE:	55 58 49.59819	**LONGITUDE:**	123 48 25.57688	(NAD83 CSRS)

OBSERVATON COORDINATES

NORTHING:	6204196.93	**EASTING:**	449637.73	(NAD83 CSRS, UTM 10 N, Meters)
d NORTHING:	-0.14	**d EASTING:**	-0.12	
STD DEV (95%):	0.12		0.07	

POSITIONING SYSTEM:	NAVCOM 3050 - RTG CORRECTION
OBSERVATION DATE/TIME (UTC):	8/19/10 15:36
OBSERVATION LENGTH:	00:51
OBSERVATIONS:	3089



GMSWORKS#25: Williston Reservoir Bathymetric Survey
Horizontal Positioning Verification

STATION:	FR1	AGENCY:	BC Hydro	GCM No.	NA

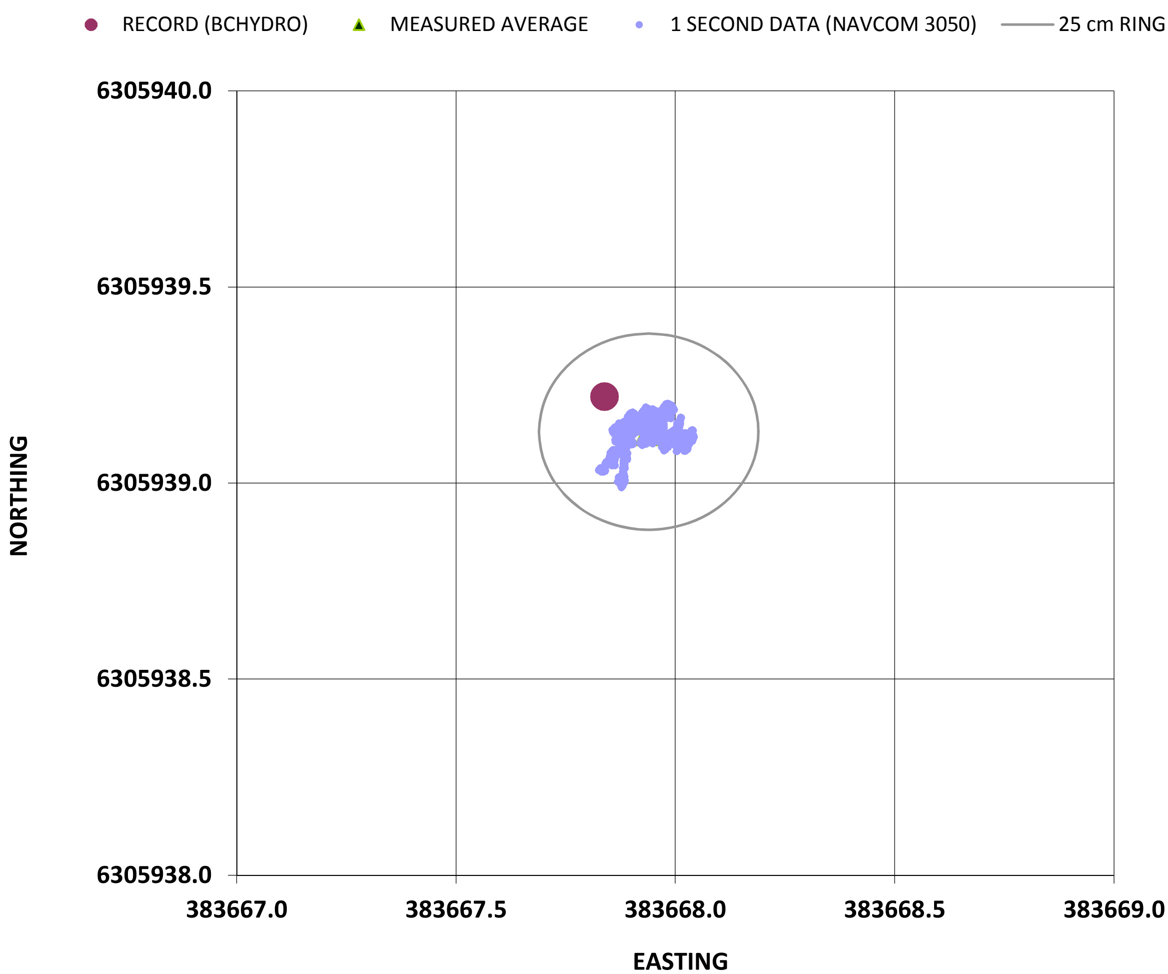
RECORD COORDINATES

NORTHING:	6305939.22	**EASTING:**	383667.839	(NAD83 CSRS, UTM 10 N, Meters)
LATITUDE:	56 52 57.29749	**LONGITUDE:**	124 54 32.88156	(NAD83 CSRS)

OBSERVATON COORDINATES

NORTHING:	6305939.13	**EASTING:**	383667.94	(NAD83 CSRS, UTM 10 N, Meters)
d NORTHING:	-0.09	**d EASTING:**	0.10	
STD DEV (95%):	0.07		0.10	

POSITIONING SYSTEM:	NAVCOM 3050 - RTG CORRECTION
OBSERVATION DATE/TIME (UTC):	6/19/10 20:19
OBSERVATION LENGTH:	00:55
OBSERVATIONS:	3353



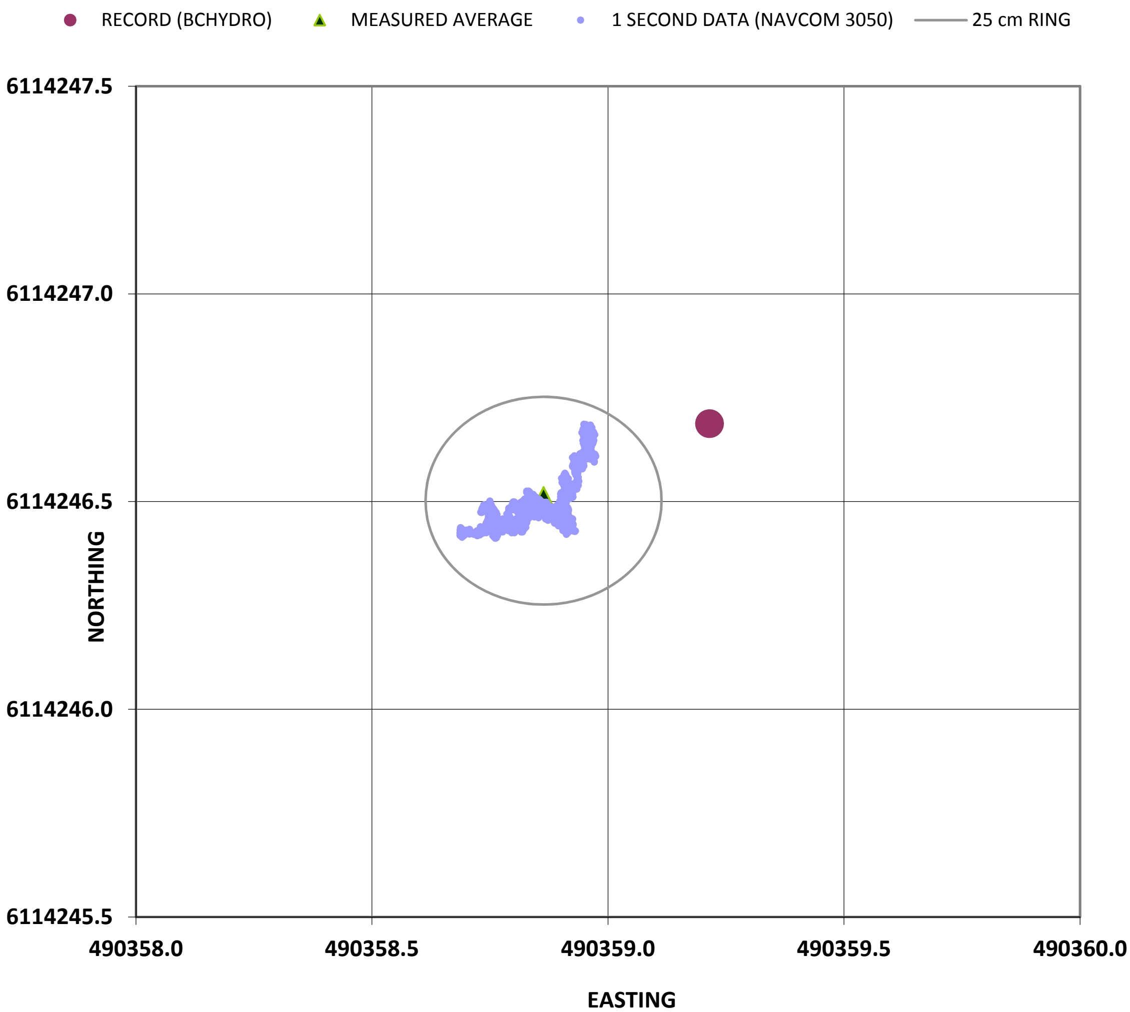
GMSWORKS#25: Williston Reservoir Bathymetric Survey
Horizontal Positioning Verification

STATION:	**WLT48**	**AGENCY:**	**BC Hydro**		**GCM No.**	**NA**

RECORD COORDINATES				
NORTHING:	6114246.688	**EASTING:**	490359.215	(NAD83 CSRS, UTM 10 N, Meters)
LATITUDE:	55 10 29.05234	**LONGITUDE:**	123 09 04.93189	(NAD83 CSRS)

OBSERVATON COORDINATES				
NORTHING:	6114246.50	**EASTING:**	490358.86	(NAD83 CSRS, UTM 10 N, Meters)
d NORTHING:	-0.19	**d EASTING:**	-0.35	
STD DEV (95%):	0.14		0.15	

POSITIONING SYSTEM:	NAVCOM 3050 - RTG CORRECTION
OBSERVATION DATE/TIME (UTC):	6/22/10 1:42
OBSERVATION LENGTH:	00:39
OBSERVATIONS:	2382



APPENDIX E
Benchmark Descriptions

Water Level Station: W.A.C. Bennett Dam (DAM)

Station Description

The benchmarks for the **Station DAM** are located in the vicinity of the BC Hydro Visitors Center approximately 21 KM from Hudson's Hope via Canyon Drive. The primary benchmark **"667007"** is approximately 250 m west of the Visitor Center driveway and the three secondary benchmarks are at the south end of the dam access road.

Figure 1 - Vicinity map for DAM benchmarks.

Benchmark Elevations

Benchmark elevations were established with closed differential level loops from "667007", holding the published elevation for "667007" of 722.050 m (CGVD28).

Benchmark	Elevation
667007	722.050
DAM A	680.412
DAM 3	680.492
DAM 4	680.118

Benchmark Descriptions

"667007" is located on the south side of the dam access road approximately 250 m southwest of the entrance road to the W.A.C. Bennett Visitors Center. The monument is a brass disk set in rock stamped "667007". Coordinates are provided in Horizontal Control section.

"DAM A" is located in the northerly corner of the asphalt pad supporting the BC Hydro monument/sculpture. The benchmark is a 3 ¼" brass disk stamped "DAM A"

"DAM 3" is located on the first light post on the west side of the dam access road at the south end of the dam. The benchmark is the "R" in "BARBER" in the base of the light post on the south side.

“DAM 4” is located at the base of the easterly of the two posts supporting the “No Parking On Top of Dam” sign on the east side road. The benchmark is the top of the southeasterly bolt.

Water Level Station: Finlay Bay (BAY)

Station Description

The benchmarks for the **Station BAY** are located in the vicinity of the Finlay Bay recreation area approximately 95 km northwest of Mackenzie. The benchmarks are located along the shoreline east of the picnic area.

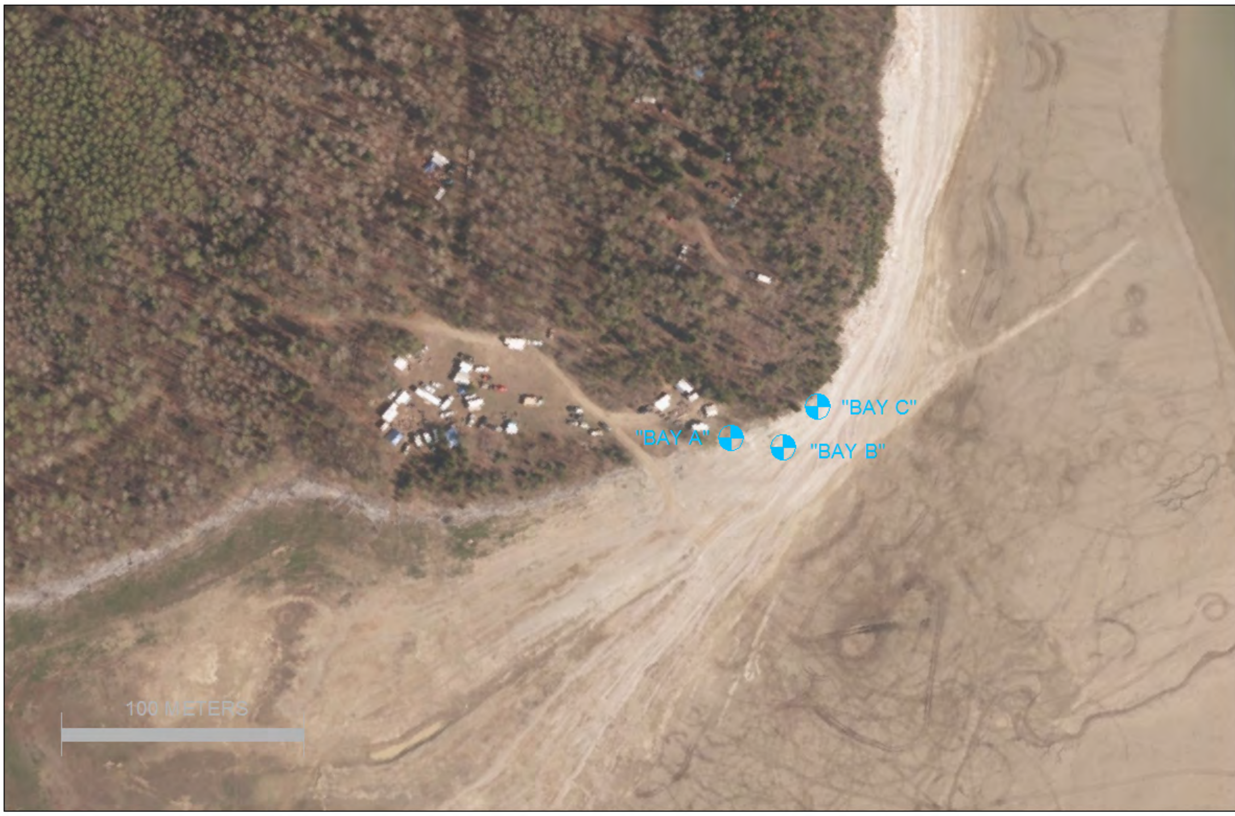


Figure 2 - Vicinity map for the BAY benchmarks.

Benchmark Elevations

Benchmark elevations were established by water level transfer from DAM (described in the Vertical Control Survey section of the report) and closed differential level loops between all benchmarks at the site. All elevations are relative to CGVD28.

Benchmark	Elevation
BAY A	673.322
BAY B	668.994
BAY C	669.162
BC HYDRO 821	685.737

Benchmark Descriptions

"BAY A" is located in a 1 x 1 meter boulder in the middle of a small access trail to the reservoir from the picnic area. The benchmark is a 3 ¼" brass disk.

"BAY B" is located approximately 20 meters east of BAY A and 4 m lower in elevation in a 2 x 2 meter boulder on the beach. The benchmark is a 3 ¼" brass disk drilled and cemented in the rock.

"BAY C" is approximately 20 meters east of BAY B near the base of the rock outcrop. The benchmark is a 3 ¼" brass disk drilled and cemented in the rock

“821” is located approximately 2.0 km from the picnic area in Finlay Bay, 10 meters northeast of the main road at the intersection of a secondary spur road towards Finlay Bay through the cut block. The benchmark is the top of the rebar in the center of two remaining panels of a photo target. Coordinates are provided in Horizontal Control section.

Water Level Station: Alexander Mackenzie's Landing (MAC)

Station Description

The benchmarks for the **Station MAC** are located at the Alexander Mackenzie's Landing approximately 8 km from Mackenzie off the Parsnip West Forest Service Road.

Figure 3 - Vicinity Map for the MAC benchmarks.

Benchmark Elevations

Benchmark elevations were established by water level transfer from DAM (described in the Vertical Control Survey section of the report) and closed differential level loops between all benchmarks at the site except WLT48 which was established with an independent water level transfer from DAM. All elevations are relative to CGVD28.

Benchmark	Elevation
MAC A	677.183
MAC B	672.953
MAC C	674.082
MAC D	674.094
WLT 48	724.383

Benchmark Descriptions

"MAC A" is located on the Alexander Mackenzie monument at the site. The benchmark is the top of the "A" at eh beginning of the phrase "**A** TRULY GREAT MAN".

"MAC B" is located in the concrete pedestal supporting the information kiosk. The benchmark is a 3 ¼" brass disk set in the concrete stamped "MAC B".

"MAC C" is located on the metal post base of the northwest post of the picnic shelter. The benchmark is the northwest corner of the base stamped "MAC C".

"MAC D" is located on the metal post base of the southwest post of the picnic shelter. The benchmark is the northwest corner of the base stamped "MAC D".

"WLT48" is located at the south end of the Parsnip Arm on the Finlay FSR, 800 m south of the causeway, approximately 52 m south of the "17 KM" sign in a gravel shoulder 3 m south of the of the edge of the road. The benchmark is the top of a driven rebar. Coordinates are provided in Horizontal Control section.

Water Level Station: Tsay Keh Dene (KEH)

Station Description

The benchmarks for the **Station KEH** are located at the north end of the Finlay Arm across the Finlay River from Tsay Keh Dene. There are three benchmarks, two at the Rubyred Creek Bridge near KM Post 8 on the Finlay-Davis FSR and the other approximately 3 km south of the bridge on the Finlay-Davis FSR.

Figure 4 - Vicinity map for KEH benchmarks.

Benchmark Elevations

Benchmark elevations were established by water level transfer from DAM (described in the Vertical Control Survey section of the report) and closed differential level loops between the three benchmarks. All elevations are relative to CGVD28.

Benchmark	Elevation
IVOR	679.751
KEH A	679.768
FR-1	699.588

Benchmark Descriptions

"IVOR" is located on the west side of the south abutment of the Rubyred Creek Bridge. The benchmark reference is the top of the concrete 8.5 cm from north edge and 7.0 cm from west edge.

No Photo

"KEH A" is located on the east side of the same abutment. The benchmark is a 3 ¼" brass cap. There are no photos of this benchmark.

No Photo

No Photo

"FR-1" is located approximately 3 km south of the Rubyred Creek bridge at KM 11 on a cut block access road that heads east from the Finlay-Davis FSR. The benchmark is approximately 200 m west of the Finlay-Davis FSR. The benchmark is a 3 ¼" brass cap on ½" rebar about 16cm above ground stamped "BC HYDRO GPS 1 2003". Coordinates are provided in Horizontal Control section.

Survey and Sounding Accuracy

The survey order defined for the survey is S-44 Special Order. The requirement for vertical accuracy is given by the following formula:

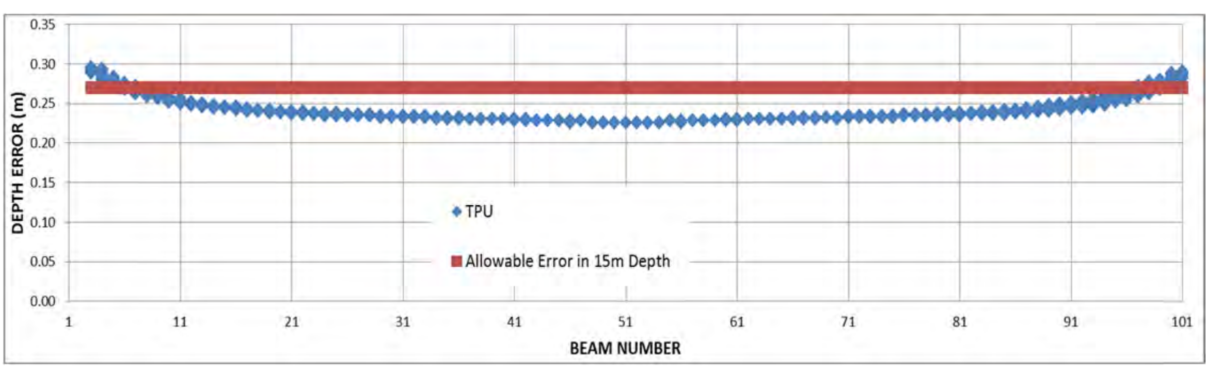
Maximum Allowable Depth Error = $\sqrt{a^2 + d * b^2}$
a= 0.25 (m) fixed allowable error
b=0.0075 depth dependent factor
d=depth (m)

The minimum survey depth was typically 5 meters and the max depth was no larger than 21 meters. A table of allowable error by depth is provided below.

Depth (m)	Error (m)
0	0.25
5	0.25
10	0.26
15	0.27
20	0.29

The maximum allowable depth error defines the survey equipment and procedures that must be implemented in order to meet the specifications. This encompasses everything from accuracy of the vessel offset survey, equipment selection (multibeam, gyro, motion sensor and sound velocity sensor), survey line spacing, vessel settlement and squat characteristics and water level monitoring.

A Total Propagated Uncertainty (TPU) model is created that computes the expected error for each beam of the multibeam. The beams furthest out in the array have the highest TPU as they are most susceptible to vertical error that develops as a function of vessel roll and refraction through the water column. The TPU is a theoretical error uncertainty based on the equipment and procedures but the actual error may differ, being greater or less than the TPU based on the accuracy of calibrations, conditions encountered in the field and the actual procedures used.



In order to quantify the actual accuracy of the survey, specific quality assurance checks are conducted to assess the accuracy of the survey and the survey systems. The checks that were conducted to verify the accuracy for this survey included:

1. Bar and Lead-Line Checks
2. Cross-line analysis
3. Independent verification.

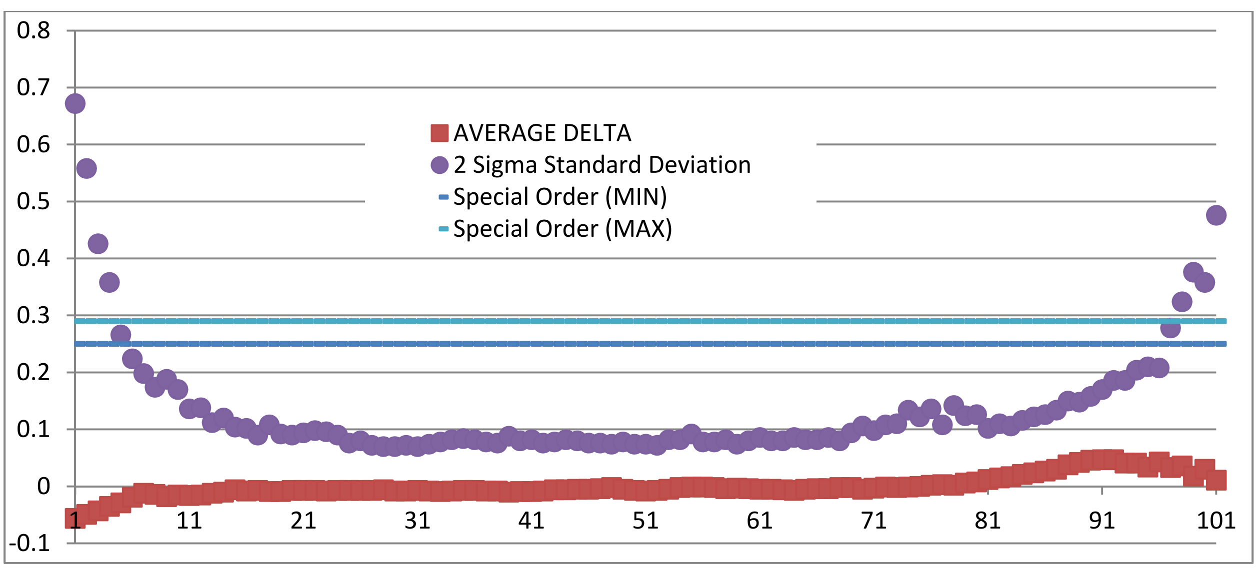
Bar Check and Leadline

Bar checks and lead-line checks were conducted for both vessels to verify the sounding accuracy and vessel offsets. They compare the corrected sounder depth with a known depth measured with a lead-line

Vessel	Latitude	Longitude	Corrected Depth	Lead Line	Delta
Carta	56-47-07.88N	124-53-49.09W	7.71	7.74	0.03
Carta	56-47-07.88N	124-53-49.32W	5.03	5.00	-0.03
McKellar	56-47-07.88N	124-53-49.09W	8.21	8.24	0.03
McKellar	56-47-07.88N	124-53-49.32W	4.97	5.00	0.03

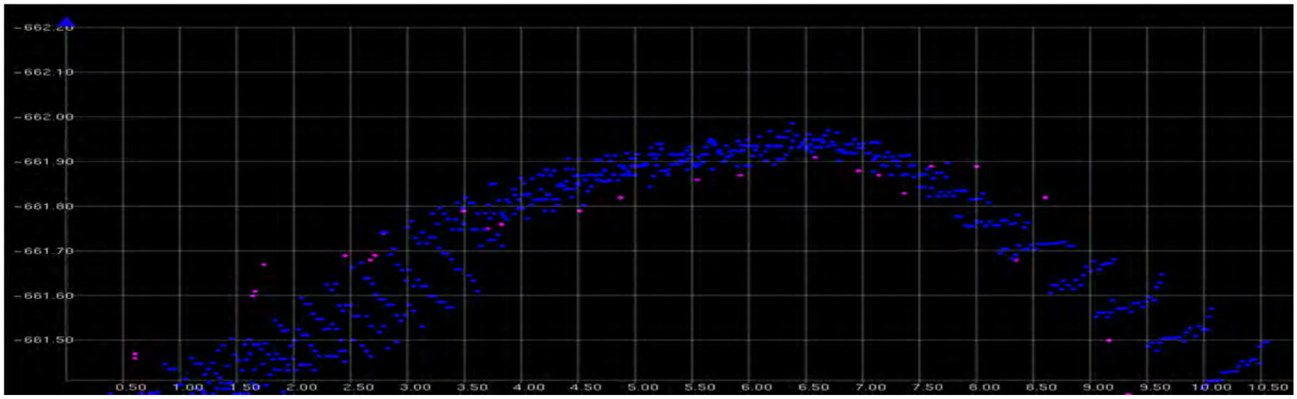
Cross-line Analysis

Cross-line analysis compares the accuracy of the beams across the full swath to a reference surface. It provides a measure of which beams are meeting sounding accuracy specifications. As described above, the beams on the outer portions of the swath are more susceptible to error and will at some point exceed the allowable error. These beams were rejected in the post processing of the data and not included in final data sets. The figure below shows an example of the one of the cross-lines analyzed.

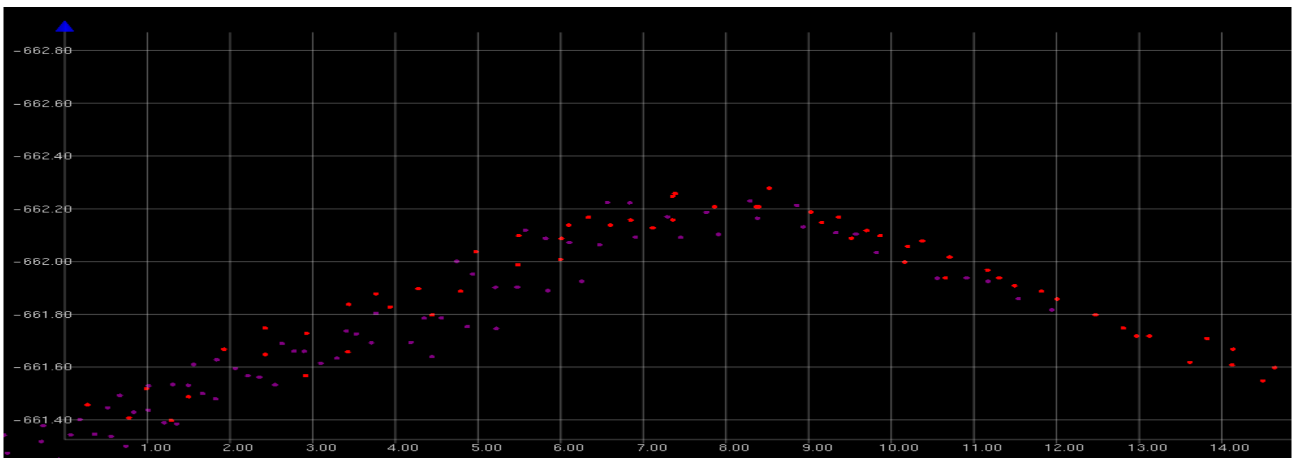


Independent Verifications

Spot checks were conducted throughout the reservoir comparing the multibeam bathymetry to the LiDAR data (adjusted with the CGG05 geoid model). Locations were chosen where erosion was not expected to be a factor. The two datasets agreed very well. Typical differences between the two datasets were +/- 5 cm. Examples near Mackenzie (Top) and Manson Arm (Below) are shown.



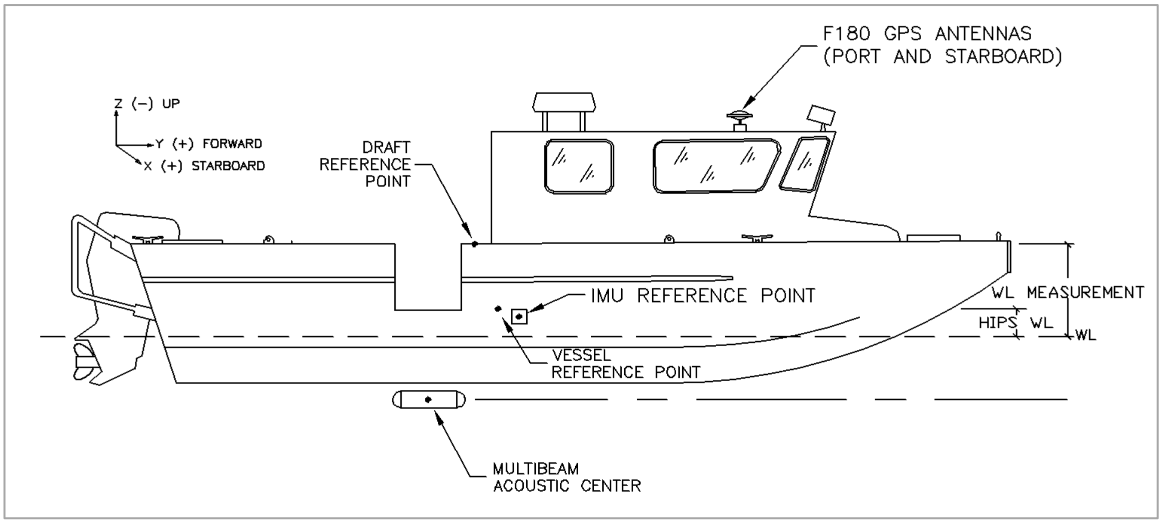
LiDAR points are magneta, multibeam points are blue. Vertical grid interval is 10 cm



LiDAR points are red, multibeam points are purple. Vertical grid interval is 20 cm

Vessel Offset Diagrams

R/V Carta



VESSEL OFFSETS

Location	**X**	**Y**	**Z**	**Xgps**	**Ygps**	**Zgps**
Reference Point (RP)	0.000	0.000	0.000	-	-	-
F180 RP	0.090	0.083	0.089	-	-	-
F180 Primary (Port)	-0.994	2.231	-1.864	-1.097	-2.113	-1.998
F180 Secondary (Starboard)	1.003	2.236	-1.861	-	-	-
Reson 8101	1.294	0.785	0.983	-	-	-
Draft Reference	(+/-)1.250	-0.210	-0.629	-	-	-

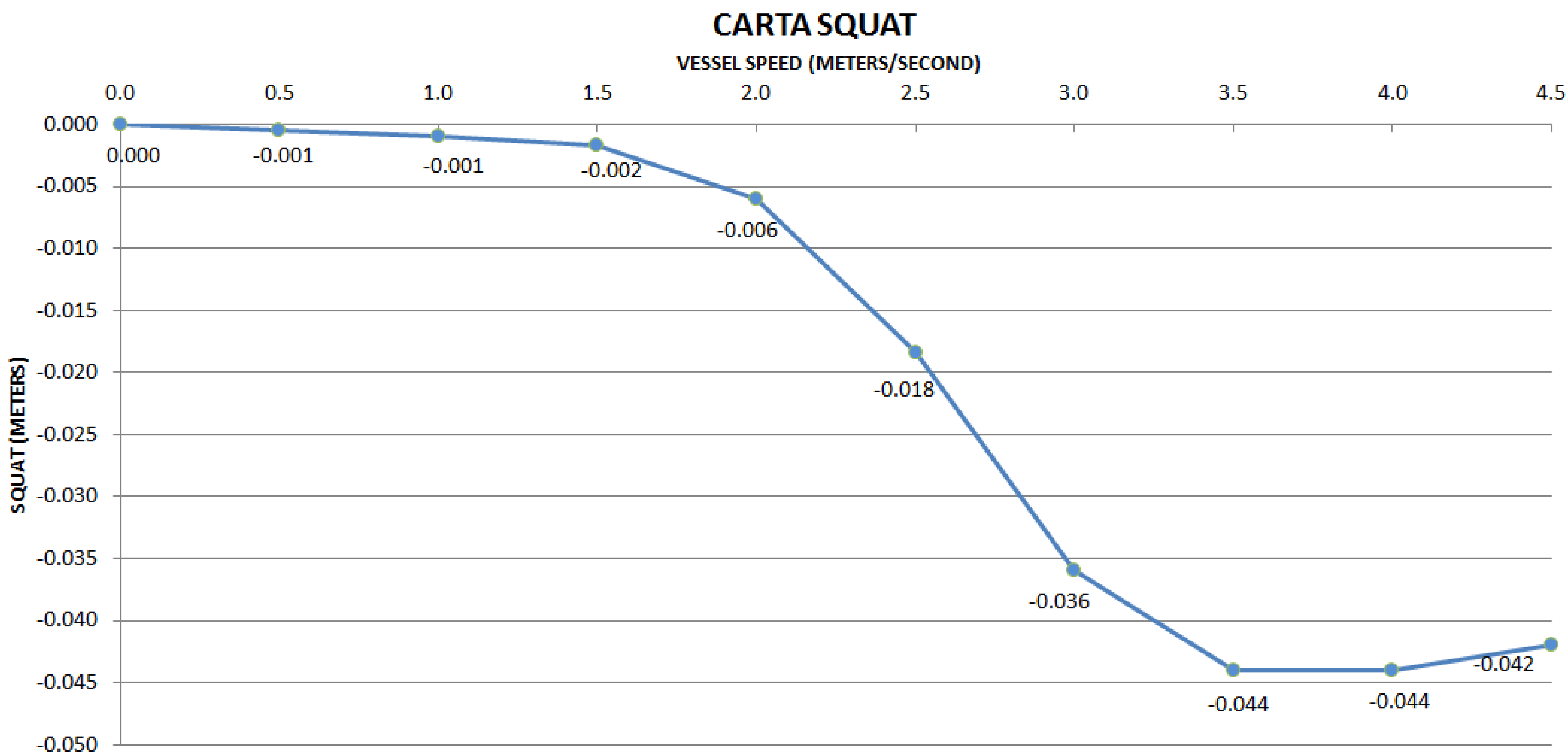
Vessel reference frame: *X (+) Starboard, Y (+) Forward, Z (+) Down. Values in Meters*

F180 CONFIGURATION

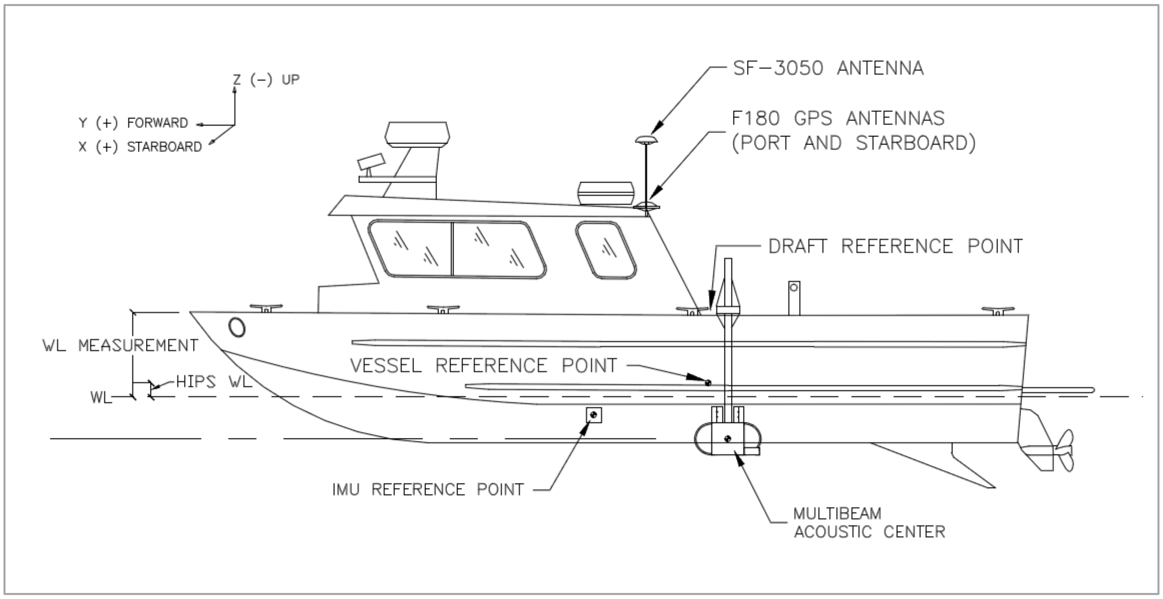
Date	**Xgps**	**Ygps**	**Zgps**	**ROTgps**	**ELgps**	**SEPgps**
2010	-0.980m	-2.211m	-1.864m	-0.21°	0.15°	1.997m
2011	-1.097m	-2.113m	-1.998m	-0.62°	0.22°	1.997m

Heading Offset= -90° Pitch Offset=0.00 Roll Offset=0.00

F180 reference frame: *X (+) Starboard, Y (+) Forward, Z (+) Down*


CARTA SQUAT
VESSEL SPEED (METERS/SECOND)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
SQUAT (METERS)
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
-0.045
-0.050
0.000
-0.001
-0.001
-0.002
-0.006
-0.018
-0.036
-0.044
-0.044
-0.042

M/V McKellar



VESSEL OFFSETS

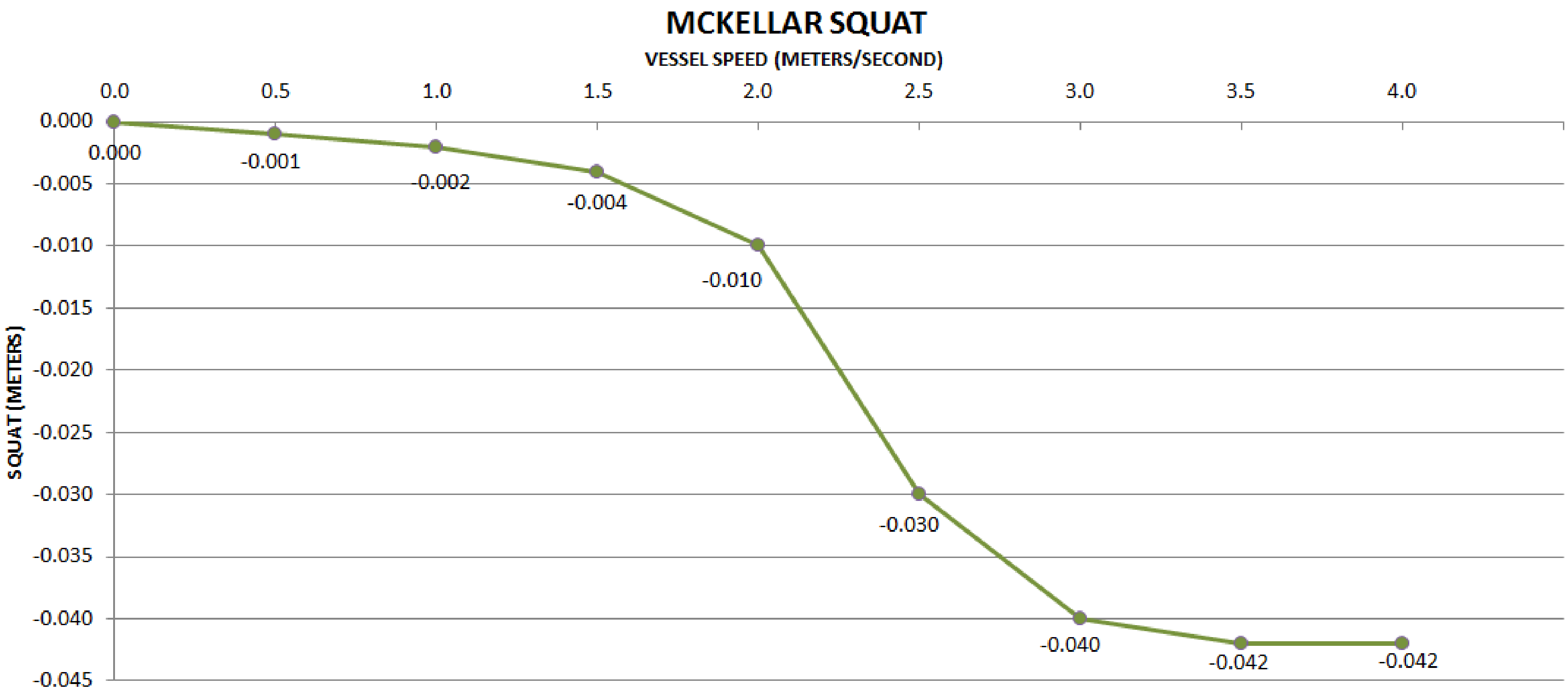
Location	**X**	**Y**	**Z**	**Xgps**	**Ygps**	**Zgps**
Reference Point (RP)	0.000	0.000	0.000	-	-	-
F180 RP	0.239	1.035	0.288	-	-	-
F180 Primary (Port)	-1.005	0.557	-1.593	-1.290	-1.892	-0.440
F180 Secondary (Starboard)	1.035	0.562	-1.593	-	-	-
Reson 8101	-1.519	-0.178	0.504	-	-	-
Draft Reference	(+/-)1.200	0.000	-0.615	-	-	-
Vessel reference frame:	*X (+) Starboard, Y (+) Forward, Z (+) Down. Values in Meters*					

F180 CONFIGURATION

Date	**Xgps**	**Ygps**	**Zgps**	**ROTgps**	**ELgps**	**SEPgps**
2010	-1.271m	-1.890m	-0.442m	1.04°	0.41°	2.020m
2011	-1.290m	-1.892m	-0.440m	1.74°	-0.38°	2.020m

Heading Offset=-90° Pitch Offset=-90° Roll Offset=0.00

F180 reference frame: *X (+) Starboard, Y (+) Forward, Z (+) Down*


MCKELLAR SQUAT
VESSEL SPEED (METERS/SECOND)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
SQUAT (METERS)
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
-0.045
0.000
-0.001
-0.002
-0.004
-0.010
-0.030
-0.040
-0.042
-0.042

Vessel Name: Carta.hvf
Vessel created: January 17, 2014

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2010-219 00:00

Comments:
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -2.800
Roll Offset: 0.230
Azimuth Offset: -0.700

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

Manufacturer:
Model: sb8101
Serial Number:

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2011-224 00:00

Comments:
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -3.000
Roll Offset: -0.470
Azimuth Offset: -1.700

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

Manufacturer:
Model: sb8101
Serial Number:

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2011-242 20:02

Comments: Apparent Change in roll after line 1233
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -3.000
Roll Offset: -0.190
Azimuth Offset: -1.700

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

Manufacturer:
Model: sb8101
Serial Number:

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2011-253 12:00

Comments:
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -3.000
Roll Offset: -0.250
Azimuth Offset: -1.700

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

Manufacturer:
Model: sb8101
Serial Number:

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2011-255 12:00

Comments:
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -3.000
Roll Offset: -0.180
Azimuth Offset: -1.700

DeltaX: 1.294

DeltaY: -0.785
DeltaZ: 0.983

Manufacturer:
Model: sb8101
Serial Number:

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2011-258 12:00

Comments:
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -3.000
Roll Offset: -0.250
Azimuth Offset: -1.700

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

Manufacturer:
Model: sb8101
Serial Number:

Navigation Sensor:

Time Stamp: 2010-219 00:00

Comments: (null)
Time Correction(s) 0.000
DeltaX: 0.000
DeltaY: 0.000
DeltaZ: -2.205

Manufacturer: (null)
Model: (null)
Serial Number: (null)

Gyro Sensor:

Time Stamp: 2010-219 00:00

Comments:
Time Correction(s) 0.000

Heave Sensor:

Time Stamp: 2010-219 00:00

Comments:
Apply Yes
Time Correction(s) 0.000
DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000
Offset: 0.000

Manufacturer: (null)
Model: (null)
Serial Number: (null)

Pitch Sensor:

Time Stamp: 2010-219 00:00

Comments:
Apply Yes
Time Correction(s) 0.000
Pitch offset: 0.000

Manufacturer: (null)
Model: (null)
Serial Number: (null)

Roll Sensor:

Time Stamp: 2010-219 00:00

Comments:
Apply Yes
Time Correction(s) 0.000
Roll offset: 0.000

Manufacturer: (null)
Model: (null)
Serial Number: (null)

Draft Sensor:

Time Stamp: 2010-219 00:00

Apply Yes
Comments:
Time Correction(s) 0.000

Entry 1) Draft: 0.000 Speed: 0.000
Entry 2) Draft: 0.001 Speed: 0.972

Entry 3) Draft: 0.002 Speed: 1.944
Entry 4) Draft: 0.002 Speed: 2.916
Entry 5) Draft: 0.006 Speed: 3.888
Entry 6) Draft: 0.018 Speed: 4.860
Entry 7) Draft: 0.036 Speed: 5.832
Entry 8) Draft: 0.044 Speed: 6.803
Entry 9) Draft: 0.044 Speed: 7.775
Entry 10) Draft: 0.042 Speed: 8.747
Entry 11) Draft: 0.042 Speed: 19.438

TPU

Time Stamp: 2010-219 00:00

Comments: see T:\SEATTLE\Equipment\1_Vessels\Carta_TPU\Determining TPU Values.doc
Offsets

Motion sensing unit to the transducer 1
X Head 1 1.204
Y Head 1 -0.868
Z Head 1 0.894
Motion sensing unit to the transducer 2
X Head 2 0.000
Y Head 2 0.000
Z Head 2 0.000
Navigation antenna to the transducer 1
X Head 1 0.000
Y Head 1 0.000
Z Head 1 -2.205
Navigation antenna to the transducer 2
X Head 2 0.000
Y Head 2 0.000
Z Head 2 0.000

Roll offset of transducer number 1 0.230
Roll offset of transducer number 2 0.000

Heave Error: 0.050 or 5.000" of heave amplitude.
Measurement errors: 0.010
Motion sensing unit alignment errors
Gyro:0.050 Pitch:0.050 Roll:0.050
Gyro measurement error: 0.050
Roll measurement error: 0.025
Pitch measurement error: 0.025
Navigation measurement error: 0.100
Transducer timing error: 0.005
Navigation timing error: 0.005
Gyro timing error: 0.005
Heave timing error: 0.005
PitchTimingStdDev: 0.005
Roll timing error: 0.005
Sound Velocity speed measurement error: 0.000
Surface sound speed measurement error: 0.000
Tide measurement error: 0.000

Tide zoning error: 0.000
Speed over ground measurement error: 1.286
Dynamic loading measurement error: 0.005
Static draft measurement error: 0.010
Delta draft measurement error: 0.010
StDev Comment: (null)

Svp Sensor:

Time Stamp: 2010-219 00:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

Time Stamp: 2011-224 00:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000

Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

Time Stamp: 2011-242 20:02

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

Time Stamp: 2011-243 12:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

Time Stamp: 2011-253 12:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

Time Stamp: 2011-255 12:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000

DeltaZ: 0.000

Time Stamp: 2011-258 12:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 1.294
DeltaY: -0.785
DeltaZ: 0.983

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

WaterLine:

Time Stamp: 2010-219 00:00

Comments: (null)
Apply Yes
WaterLine 0.250

Time Stamp: 2011-225 00:00

Comments: (null)
Apply Yes
WaterLine 0.250

Vessel Name: McKellar.hvf
Vessel created: January 17, 2014

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2010-219 00:00

Comments:
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: 0.550
Roll Offset: 3.220
Azimuth Offset: 1.700

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

Manufacturer:
Model: sb8101
Serial Number:

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2011-225 00:00

Comments:
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -1.200
Roll Offset: 2.620
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

Manufacturer:
Model: sb8101
Serial Number:

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2011-232 12:00

Comments: Making Roll Adjustments
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -1.200
Roll Offset: 2.770
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

Manufacturer:
Model: sb8101
Serial Number:

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2011-238 12:00

Comments:
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -1.200
Roll Offset: 2.820
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

Manufacturer:
Model: sb8101
Serial Number:

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2011-247 12:00

Comments:
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -1.200
Roll Offset: 2.920
Azimuth Offset: 0.000

DeltaX: -1.519

DeltaY: -0.178
DeltaZ: 0.504

Manufacturer:
Model: sb8101
Serial Number:

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2011-251 12:00

Comments:
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -1.200
Roll Offset: 2.820
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

Manufacturer:
Model: sb8101
Serial Number:

Depth Sensor:

Sensor Class: Swath
Time Stamp: 2011-256 12:00

Comments:
Time Correction(s) 0.000

Transduer #1:

Pitch Offset: -1.200
Roll Offset: 2.720
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

Manufacturer:
Model: sb8101
Serial Number:

Navigation Sensor:

Time Stamp: 2010-219 00:00

Comments: Starfire
Time Correction(s) 0.000
DeltaX: 0.000
DeltaY: 0.560
DeltaZ: -2.201

Manufacturer: (null)
Model: (null)
Serial Number: (null)

Gyro Sensor:

Time Stamp: 2010-219 00:00

Comments:
Time Correction(s) 0.000

Heave Sensor:

Time Stamp: 2010-219 00:00

Comments:
Apply Yes
Time Correction(s) 0.000
DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000
Offset: 0.000

Manufacturer: (null)
Model: (null)
Serial Number: (null)

Pitch Sensor:

Time Stamp: 2010-219 00:00

Comments:
Apply Yes
Time Correction(s) 0.000
Pitch offset: 0.000

Manufacturer: (null)
Model: (null)
Serial Number: (null)

Roll Sensor:

Time Stamp: 2010-219 00:00

Comments:
Apply Yes
Time Correction(s) 0.000
Roll offset: 0.000

Manufacturer: (null)
Model: (null)
Serial Number: (null)

Draft Sensor:

Time Stamp: 2010-219 00:00

Apply Yes
Comments:
Time Correction(s) 0.000

Entry 1) Draft: 0.000 Speed: 0.019
Entry 2) Draft: 0.001 Speed: 0.972
Entry 3) Draft: 0.002 Speed: 1.944
Entry 4) Draft: 0.004 Speed: 2.916
Entry 5) Draft: 0.010 Speed: 3.888
Entry 6) Draft: 0.030 Speed: 4.860
Entry 7) Draft: 0.040 Speed: 5.832
Entry 8) Draft: 0.042 Speed: 6.803
Entry 9) Draft: 0.042 Speed: 7.775
Entry 10) Draft: 0.042 Speed: 19.438

TPU

Time Stamp: 2010-019 00:00

Comments:
Offsets

Motion sensing unit to the transducer 1
X Head 1 -1.785
Y Head 1 -1.213
Z Head 1 0.216
Motion sensing unit to the transducer 2
X Head 2 0.000
Y Head 2 0.000
Z Head 2 0.000
Navigation antenna to the transducer 1
X Head 1 -1.519
Y Head 1 -0.738
Z Head 1 2.705
Navigation antenna to the transducer 2
X Head 2 0.000
Y Head 2 0.000
Z Head 2 0.000

Roll offset of transducer number 1 3.220
Roll offset of transducer number 2 0.000

Heave Error: 0.050 or 5.000" of heave amplitude.
Measurement errors: 0.010
Motion sensing unit alignment errors
Gyro:0.050 Pitch:0.050 Roll:0.050
Gyro measurement error: 0.050
Roll measurement error: 0.025
Pitch measurement error: 0.025
Navigation measurement error: 0.100
Transducer timing error: 0.005
Navigation timing error: 0.005
Gyro timing error: 0.005
Heave timing error: 0.005
PitchTimingStdDev: 0.005
Roll timing error: 0.005
Sound Velocity speed measurement error: 0.000
Surface sound speed measurement error: 0.000
Tide measurement error: 0.000
Tide zoning error: 0.000
Speed over ground measurement error: 1.286
Dynamic loading measurement error: 0.005
Static draft measurement error: 0.010
Delta draft measurement error: 0.010
StDev Comment: (null)

Svp Sensor:

Time Stamp: 2010-219 00:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

Time Stamp: 2011-225 00:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

Time Stamp: 2011-232 12:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

Time Stamp: 2011-238 12:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

Time Stamp: 2011-247 12:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

Time Stamp: 2011-251 12:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

Time Stamp: 2011-256 12:00

Comments:
Time Correction(s) 0.000

Svp #1:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: -1.519
DeltaY: -0.178
DeltaZ: 0.504

SVP #2:

Pitch Offset: 0.000
Roll Offset: 0.000
Azimuth Offset: 0.000

DeltaX: 0.000
DeltaY: 0.000
DeltaZ: 0.000

WaterLine:

Time Stamp: 2011-225 00:00

Comments:
Apply Yes
WaterLine 0.087

APPENDIX 1-2 TERMS OF REFERENCE

Peace Project Water Use Plan

Physical Works Terms of Reference

- **Williston Reservoir Bathymetry GMSWORKS #25**

1.0 INTRODUCTION

This Terms of Reference describes a project to develop an accurate bathymetric map for the Finlay, Peace and Parsnip arms of the Williston Reservoir. This project was approved by the WUP Committee for the Peace Project Water Use Plan (WUP). The Peace Water Use Plan water use planning process was initiated in February 2001 and completed in May 2003.

These Terms of Reference are submitted in response to the Order (Files No. 76975-35/Peace) issued by the Comptroller of Water Rights on 09 August 2007. Schedule A of the Order states that:

3. The licensee shall submit, within 9 months of the date of this Order, for approval by the Comptroller, terms of reference to:

    d. map the reservoir between full pool and 652.27 metres (2140 feet) GSC.

These Terms of Reference provide a preliminary work plan for the bathymetric map, as well as a cost estimate and a tentative schedule for completing the work.

2.0 DESCRIPTION OF PROJECT

2.1 Location

The headwaters of the Peace, a tributary of the Mackenzie River, are located in north-eastern British Columbia (Figure 2-1). The Peace is formed by the confluence of the Finlay and Parsnip rivers flowing in opposite directions in the Rocky Mountain Trench. At the confluence the Peace flows east and is the only river to cut through the Rocky Mountains. Once out of the Peace Canyon the river maintains an easterly direction, crossing the B.C./Alberta border. The Peace drains into Great Slave Lake and joins the Mackenzie River before it enters the Arctic Ocean.

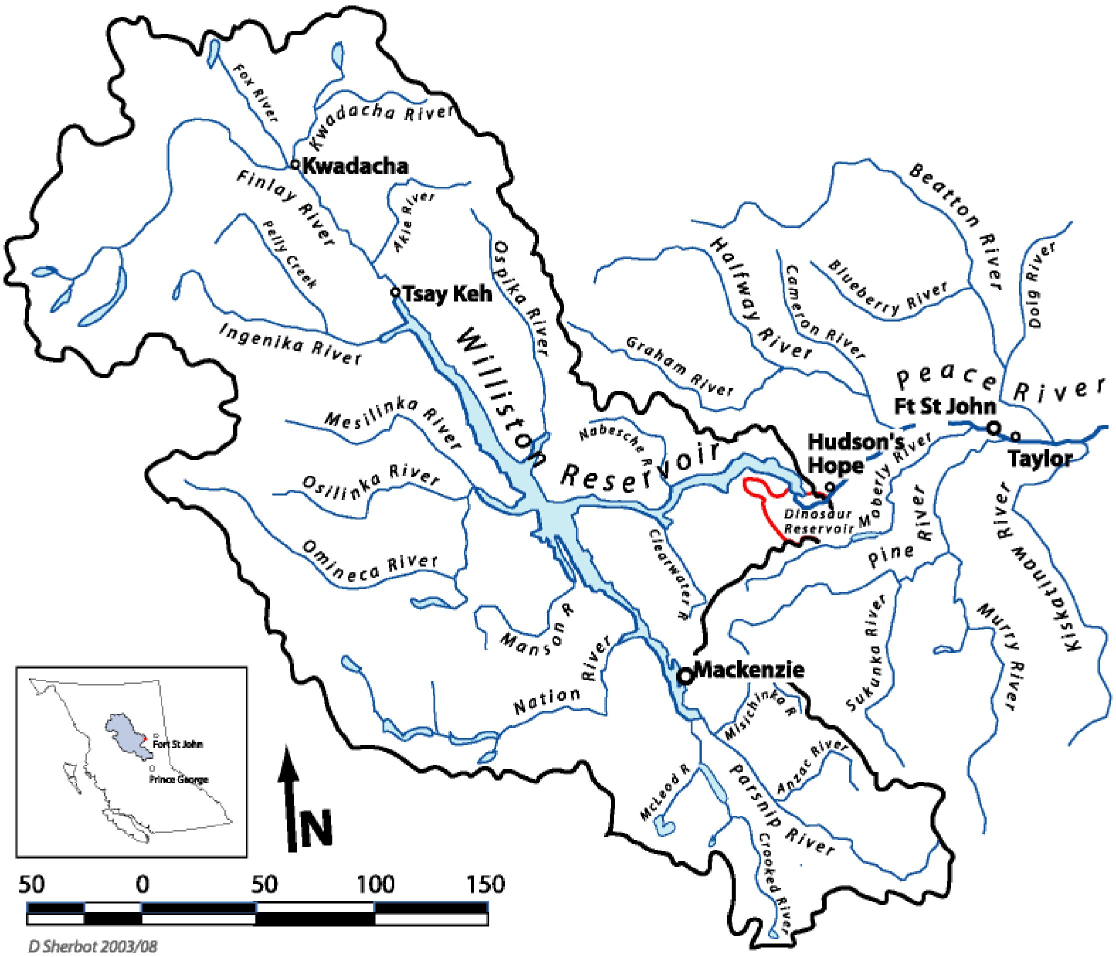


Figure 2-1: Place Names in Peace Water Use Plan

2.2 Existing Works

The existing works comprising the Peace project include:

W.A.C. Bennett Dam:

- This dam, commissioned in 1967, is located at head of the Peace Canyon forming Williston Reservoir. The earthfill dam is 2040 m (6692.8 ft) in length at the crest and 183 m (600.4 ft) high with a crest elevation of 679.7 m (2230.0 ft) above sea level.
- Williston Reservoir covers approximately 1773 square kilometres (km^2) (684.6 square miles ($miles^2$)) at full pool and has an active storage of 393 Million cubic metres (Mm^3) (32 Million acre feet (MAF)). The operating range of the reservoir for power generation is between 672.08 m (2205.0 ft) and 642.00 m (2106.3 ft).
- The spillway has three radial gates and nine sluice gates. The sill elevation for the radial gates is 653.53 m (2144.1 ft) and the sluice gates 641.60 m (2105 ft). The maximum discharge is 9200 m^3/s (325 000 ft^3/s) using the radial and sluice gates.
- Power Intakes: There is one power intake for each unit. They are located on the left side of the dam. Intakes are 3.96 x 5.94 m (13 x 19.5 ft). The sill elevation for intakes 1 to 3 is 594.36 m (1950.0 ft). The sill elevation of intakes 4 to 10 is 627.89 m (2060.0 ft).

G.M. Shrum Generating Station:

- The underground G.M. Shrum Generating Station has 10 units with a total installed capacity of 2730 MW. Once through the turbines, the water is discharged through two manifolds, one for units G1 to G5 and one for G6 to G10, into the upper end of Dinosaur Reservoir.

Peace Canyon Dam:

- This dam is located at the foot of the Peace Canyon forming Dinosaur Reservoir. The Peace Canyon Dam consists of a concrete gravity dam and earthfill saddle dam on the right abutment. The main dam is 325 m (1066.3 ft) long and 61 m (200.1 ft) high with a crest elevation of 507.5 m (1665.0 ft) above sea level. The saddle dam is 200 m (656.2 ft) long and 20 m (65.6 ft) high.
- Dinosaur Reservoir covers approximately 9 km^2 (3.5 $miles^2$) at full pool. It has limited active storage. The shoreline length is 54.4 km (33.8 miles). The normal operating range is between 502.92 m (1650.0 ft) and 500.00 m (1640.4 ft).
- The spillway has six radial gates. The sill elevation for the radial gates is 491.3 m (1611.9 ft). The maximum discharge is 10 280 m^3/s (363 000 ft^3/s).
- Power Intake: There is one power intake for each unit. The intakes are 6.7 x 12.4 m (22.0 x 40.7 ft). The sill elevation is 426.3 m (1516.5 ft).

Peace Canyon Generating Station:

- The Peace Canyon Generating Station has four units with a total installed capacity of 700 MW. The water is discharged into the Peace.

3.0 BACKGROUND

The Peace Water Use Plan Committee (WUP Committee) sought to manage the impacts of operations on Williston Reservoir through non-operating alternatives. In developing a Water Use Plan for the Williston Reservoir, the WUP Committee adopted an integrated approach as most impacts were linked to the same causes and their potential solutions would also be related. Further, since the WUP planning process did not have the benefits of time and resources to develop a full technical understanding of many of the issues, it becomes necessary to incorporate some research and information gathering into the management plans to further scope some of these issues.

The Williston Reservoir Bathymetry is one such project. Information from this project will serve as a primary or secondary information source for developing and managing approaches to issues such as Reservoir Transportation and Safety, Erosion Control, Dust Control, Tributary Access and Wetland Habitats. As well, there will be direct synergies between this Bathymetry project and the Aerial Photos and DEM projects.

The normal operating draft of the Williston Reservoir is approximately 12 metres (40 feet) over the course of a year. This drafting is the root cause of a number of water use issues on the reservoir. The reservoir is at its annual minimum level at the end of April before it begins filling with the high inflows and lower electricity demands. By October 1, the beginning of the “water year” it is at its annual maximum level and begins to draw down aging over the winter period of low inflows and high electricity demand. As a result of this drawdown parts of the reservoir bottom can become exposed a nearly exposed at times during the year. Knowing how much reservoir bed will be dewatered in any given year can assist in work planning for erosion control, debris management and work around tributaries and wetlands. Knowing how much of the reservoir bed will be just subsurface (and where), will improve safety for boating and barging on the reservoir.

Very little information exists on the bathymetry of Williston Reservoir. Some acoustic soundings were undertaken in the late 1980's. In the mid -1990's a bathymetry was developed using old topographic maps from the pre-inundation period. As such this bathymetry likely represents 50-year old data. These maps were digitized and matched to area trim mapping to create a DEM of the reservoir and the basin up to the 2500 foot level. The topographic maps used were converted to metric units from the original imperial units. The original topographic lines had significant margins of error and since that time the reservoir has degraded in places and aggraded in other areas. In addition to the above some more recent information exists for the upper Parsnip Reach as a result of work around the water intakes and effluent outfalls for the industries at Mackenzie. The management of water use issues in and around the Williston Reservoir would benefit from an accurate and up-to-date bathymetric map of the reservoir.

In December, 2005, Canadian Hydrographic Services of Fisheries and Oceans Canada published their updated Standards for Hydrographic Surveys. These new standards identify survey precision and quality requirements for hydrographic surveys. The bathymetric survey of the Williston Reservoir will follow the standards set out by the CHS Special Order. This order and the accuracy levels are consistent with the accuracy needs for the reservoir given the focus on the shallow near-shore area and the fluctuating nature of Williston levels.

4.0 BENEFITS OF A BATHYMETRIC MAP

A bathymetric map of the Williston Reservoir is an integral part of the integrated approach to the management of the many diverse water management issues in the basin. Using this data base and map the amount and location of exposed reservoir bed can be identified in advance based on predicted reservoir levels. This advance information will allow more proactive and detailed planning for many of the projects identified for reservoir including; debris, dust, erosion, wetlands and tributaries. Once this bathymetry is complete a boating and transportation map can be produced identifying water depths known over navigation hazards and shallows for specific reservoir elevations. In conjunction with the communication and boat access projects expected reservoir levels can be posted and otherwise communicated to reservoir users so that shallows and hazards can be avoided. These bathymetric data can also be used to develop accurate hydrographic charts of the shallower near-shore areas of the Williston Reservoir for use by the deeper draft barges and tugs that use the reservoir periodically.

5.0 WORK PLAN

The objective is to develop a bathymetric map of the Williston Reservoir down to 652.27 metres (2140 feet) GSC. At full pool, or near full pool, there are extensive shallow shoals at various locations around the perimeter of the reservoir. These shoals make it difficult for a MBES-equipped boat to access the near shore areas. A boat capable of undertaking a MBES survey of the reservoir will be large enough to safely navigate in rough water and will need to have a deep draft. The plan, then, is to undertake this project in two stages. The first stage would involve airborne LiDAR to capture the topography of the de-watered foreshore area in spring when the reservoir is at minimum levels. Performing the LiDAR in the spring, when the reservoir levels are lowest will provide an accurate topography of the near shore area as well as portions of the upland area around the reservoir. LiDAR data will be collected and post-processed prior to the beginning of the MBES work. This sequencing will allow detailed planning of the water-based survey to be based on the data that was collected in the first stage ensuring that there are no gaps in the survey between the LiDAR and the MBES.

The second stage would be later in summer when the reservoir is closer to full pool and the remainder of the necessary area can be surveyed by boat using multi-beam echo sounding. Depending on the coverage of the spring LiDAR survey, the MBES survey may be able to cover the remaining bathymetry to the required 652 metre mark with one pass around the perimeter of the reservoir.

Topographic coverage of the near-shore and upland interface areas around the delta should be at or better than 2m x 2m point densities. Much of this near shore area is featureless shoal area that will be well-described at a 2x2 grid. This standard would approximate the resolution achieved by the MBES portion of the survey as describe in the Special Order. The MBES survey will comply with standards outlined in the Special Order of the Standards for Hydrographic Surveys (CHS 2005). These standards include horizontal accuracy of 2 metres and a depth accuracy of 25 cm (constant depth error) and 7.5 millimetres (depth dependent error). The Special Order also specifies a detection capability of features greater than 1 metre cubed. These accuracies are necessary in the Williston because water depths over shoals around the reservoir may look navigable when in fact they are not due to changing water levels. As well, there remains considerable standing timber on the bottom of the reservoir that can become a navigation hazard at the lower extremes of the reservoir drawdown.

For this survey horizontal positions shall be determined by GPS capable of tracking at least 5 satellites simultaneously. Position error will be at the 95% confidence level and referenced to either World Geodetic System 84 (WGS 84) or North American Datum 83 (NAD 83). Primary shore control points, established using GPS, shall have an error that does not exceed 10 cm at 95% confidence level wit respect to the above references.

The Canadian Hydrographic Standard requires that all depths must be reduced to a low water datum. The Williston Reservoir fluctuates through an annual range of approximately 12 metres and has a licenced range of 30 metres. During the primary boating season the reservoir will be at or near full pool so the sounding datum should be referenced to the full pool water level elevation (672.05 metres). Any hydrographic charts that area printed for distribution could reference soundings to both full pool and 652 metres.

To allow a comprehensive assessment of the quality of the survey data it is necessary to record or document certain information together with the survey data. Metadata documents this information on data quality and should comprise, at a minimum;

- The survey in general as e.g. date, area, equipment used, name of survey platform
- The geodetic reference system used
- Calibration procedures and results
- Sound velocity
- Water level during survey
- Accuracy achieved and the respective confidence levels.

The use of non-vertical beams introduces additional errors caused by incorrect knowledge of the ship's orientation at the time of transmission and reception of sonar echoes. The MBES vessel must have peripheral system for corrections for; Vessel Heading, Roll, Heave, Pitch, Speed, Squat and Settlement, Draught, Positioning and Offsets in order to minimize these errors.

6.0 DELIVERABLES

This project includes the following deliverables:

- A spring LiDAR survey, at annual low pool, of the shoreline around Williston Reservoir to elevation 678.3 metres (~2225 feet) including the dewatered near shore reservoir bottomlands.
- A late summer Multi-beam Echo Sounding survey of the near shore area, with an appropriate overlap of the LiDAR coverage, to an elevation of 652 metres (2140 feet).
- Hydrographic charts, bathymetric contour maps, 3-D projections and bathymetric profiles of Williston Reservoir.
- Post-processed data
- Post-processed data in a readable format that facilitates BC Hydro's ability to reproduce charts, maps profiles and projections.

7.0 SCHEDULE

The following are the milestone dates for the work:

- Submit TOR to Comptroller for leave to commence. – May 2008
- Develop Request for Proposals – January 2010
- Contract – April 2010
- Low water/Foreshore Survey – May 2010
- High water survey – August 2010
- Draft Report – October 2010
- Final Report – December 2010

8.0 COST OBJECTIVES

The following tables show the cost estimates associated with this project.

Total	**$990,000.00**

9.0 REFERENCES

Standards for Hydrographic Surveys. Prepared by Canadian Hydrographic Service, Fisheries and Oceans Canada. First Edition. December 2005.