U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

Horizontal and Vertical Control Report

Type of Survey Hydrographic Lidar

Project No. OPR-I169-KRL-10

Time frame January – February 2011

LOCALITY

State U.S. Virgin Islands

General Locality U.S. Virgin Islands

2011

HYDROGRAPHER
MARK SINCLAIR

CHIEF OF PARTY
SCOTT RAMSAY

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NOAA FORM 77-28
(11-72)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

HYDROGRAPHIC TITLE SHEET

REGISTRY No.

H12271 – H12273

State U.S. Virgin Islands

General Locality U.S. Virgin Islands

Scale 1:10,000 **Date of Survey** January 29 to February 28, 2011

Instructions dated October 2010 **Project No.** OPR-I169-KRL-10

Vessel Fugro LADS Aircraft, call sign VH-EWP

Hydrographer M.J. Sinclair **Chief of Party** S.R. Ramsay

Surveyed by R.J. Bertucci, M.H. Blackbourn, J.G. Guilford, M.S. Hawkins, N.J. Stricklin, B.A. Weidman

Soundings by Laser Airborne Depth Sounder

Graphic record scaled by B.A. Weidman

Graphic record checked by S.R. Ramsay, J.G. Guilford **Automated Plot** N/A

Verification by

Soundings in Meters at MLLW

REMARKS

Requisition / Purchase Req. # NCNJ3000-10-18924

Contractor Fugro LADS, Inc., 2113 Government St., Suite I, Ocean Springs, MS 39564

Sub-Contractor John Oswald and Associates, 12001 Audubon Dr., Anchorage, AK 99516

Times All times are recorded in UTC.

Datum and Projection NAD83, UTM (N) Zone 20

Purpose The purpose of this survey is to provide NOAA with modern, accurate hydrographic survey data with which to update the nautical charts of the assigned area.

Acronyms A complete list of all acronyms used throughout this report is provided at Appendix I of the Separates Report.

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A. VERTICAL CONTROL

Vertical control for this survey was based on MLLW at the National Water Level Observation Network (NWLON) stations at San Juan, PR (9755371), Lameshur Bay, St. John (9751381) and Charlotte Amalie, St. Thomas (9751639), as well as subordinate stations at Ruy Point, St. Thomas (9751768), Water Bay, St. Thomas (9751583), and Leinster Point, St. John (9751309). Tide zoning and sounding reduction was based on data relative to and collected by these tide stations. Refer to Appendix I for the NWLON and subordinate station descriptions.

A.1 TIDE STATIONS

A.1.1 San Juan

The San Juan station (9755371) served as datum control for this project. Data collected at the San Juan station was used to conduct a MLLW datum transfer to the three subordinate gauges installed by JOA at Ruy Point, Water Bay and Leinster Point. This tide gauge recorded continuously during data collection periods.

		NAD83	
Gauge	**Location**	**Latitude (N)**	**Longitude (W)**
9755371	San Juan	18° 27.5'	066° 06.9'

A.1.2 Lameshur Bay

The Lameshur Bay station (9751381) was used for the duration of the survey for preliminary and final reduction of depth soundings and was used to derive preliminary and final tidal zoning for the project area. This tide gauge recorded continuously during data collection periods.

		NAD83	
Gauge	**Location**	**Latitude (N)**	**Longitude (W)**
9751381	Lameshur Bay	18° 19.0'	064° 43.4'

A.1.3 Charlotte Amalie

The Charlotte Amalie station (9751639) was used during the data acquisition phase of the survey for preliminary reduction of depth soundings. This gauge recorded continuously during data collection periods.

		NAD83	
Gauge	**Location**	**Latitude (N)**	**Longitude (W)**
9751639	Charlotte Amalie	18° 20.1'	064° 55.2'

A.1.4 Ruy Point

The Ruy Point station (9751768) established by JOA on November 2, 2010 was used for the duration of the survey for preliminary and final reduction of depth soundings and was used to derive preliminary and final tidal zoning for the project area. This tide gauge recorded continuously during data collection periods.

		NAD83	
Gauge	**Location**	**Latitude (N)**	**Longitude (W)**
9751768	Ruy Point	18° 22.3'	064° 57.8'

A.1.5 Water Bay

The Water Bay station (9751583) established by JOA on October 30 was used for the duration of the survey for preliminary and final reduction of depth soundings and was used to derive preliminary and final tidal zoning for the project area. This tide gauge recorded continuously during data collection periods.

		NAD83	
Gauge	**Location**	**Latitude (N)**	**Longitude (W)**
9751583	Water Bay	18° 20.9'	064° 51.8'


A.1.6 Leinster Point

The Leinster Point station (9751309) established by JOA on November 6 was used for the duration of the survey for preliminary and final reduction of depth soundings and was used to derive preliminary and final tidal zoning for the project area. This tide gauge recorded continuously during data collection periods.

		NAD83	
Gauge	**Location**	**Latitude (N)**	**Longitude (W)**
9751309	Leinster Point	18° 22.1'	064° 43.2'


A.2 TIDE ZONES

Final tide zones covering the extent of the survey area were derived from tide zone coordinates supplied by NOAA CO-OPS. The tide zones were modified to extend approximately 20 miles offshore and to leave no gaps over land, ensuring that all lidar coverage would be covered by zones. The zoning cell geometry was simplified, while attempting to preserve original shape, in order to meet the LADS GS requirement that each zoning cell have 10 or fewer vertices.

Each of these final tide zones used time and range correctors, as determined by JOA, relative to the Lameshur Bay NWLON tide station and three subordinate tide stations at Ruy Point, Water Bay and Leinster Point. These are as follows:

Tide Zone	GS Identifier	Time Corrector	Range Corrector	Reference Station
VIR80	TA10	-6 minutes	x1.05	9751381
VIR69	TA11	0 minutes	x0.96	9751583
VIR71B	TA12	0 minutes	x1.04	9751583
VIR71A	TA13	0 minutes	x1.04	9751583
VIR75	TA14	0 minutes	x0.96	9751768
VIR74	TA15	0 minutes	x1.00	9751768
VIR1A	TA16	0 minutes	x0.92	9751768
VIR72	TA17	-6 minutes	x1.04	9751583
VIR71	TA18	0 minutes	x1.04	9751583
VIR1B	TA19	-24 minutes	x1.13	9751381
VIR33	TA20	12 minutes	x0.99	9751309
VIR32	TA21	18 minutes	x0.98	9751309
VIR31	TA22	-6 minutes	x1.11	9751381
VIR30	TA23	-6 minutes	x0.99	9751381
VIR35	TA24	0 minutes	x1.00	9751309
VIR34	TA25	6 minutes	x1.00	9751309
VIR35A	TA26	0 minutes	x1.03	9751309
VIR73	TA27	0 minutes	x0.98	9751768
VIR31A	TA28	6 minutes	x1.11	9751381
VIR68	TA29	0 minutes	x1.00	9751583
VIR25	TA30	-12 minutes	x0.99	9751381
VIR27	TA31	-6 minutes	x1.11	9751381
VIR31B	TA32	24 minutes	x1.11	9751381
VIR70	TA33	0 minutes	x1.00	9751583
VIR28	TA34	-12 minutes	x1.11	9751381

Tide Zone	GS Identifier	Time Corrector	Range Corrector	Reference Station
VIR29	TA35	-6 minutes	x0.99	9751381
VIR66	TA36	-18 minutes	x1.23	9751381
VIR67	TA37	0 minutes	x1.04	9751583
LAND1	TA38	0 minutes	x1.00	9751381
LAND2	TA39	0 minutes	x1.00	9751381

Coordinates of the turning points (TP's) for the tide zones are as follows:

VIR80 (TA 10)	Latitude (N)	Longitude (W)
TP	18.27316°	64.68285°
TS10	18.30447°	64.67629°
TP	18.29706°	64.62558°
TP	18.24469°	64.22456°
TP	18.07615°	64.21964°
TP	18.07152°	64.67829°

VIR69 (TA 11)	Latitude (N)	Longitude (W)
TP	18.35428°	64.78983°
TP	18.35273°	64.78563°
TP	18.34835°	64.78647°
TP	18.33609°	64.78215°
TP	18.32647°	64.79960°
TP	18.32491°	64.80735°
TP	18.33084°	64.84660°
TP	18.32864°	64.87068°
TS11	18.35614°	64.79636°

VIR71B (TA 12)	Latitude (N)	Longitude (W)
TP	18.38834°	64.88027°
TP	18.36041°	64.87406°
TP	18.36341°	64.88718°
TS12	18.36467°	64.90175°
TP	18.36447°	64.90879°
TP	18.39962°	64.91045°

VIR71A (TA 13)	Latitude (N)	Longitude (W)
TP	18.39521°	64.78745°
TP	18.37741°	64.82194°
TP	18.35818°	64.84865°
TP	18.35790°	64.85542°
TS13	18.36041°	64.86776°
TP	18.36041°	64.87406°
TP	18.38834°	64.88027°
TP	18.39430°	64.88161°
TP	18.61842°	64.97893°
TP	18.62252°	64.64350°

VIR75 (TA 14)	Latitude (N)	Longitude (W)
TP	18.34492°	65.14737°
TP	18.26888°	65.44148°
TP	18.35971°	65.44025°
TP	18.38471°	65.03655°
TS14	18.35528°	65.01312°
TP	18.35428°	65.02554°
TP	18.36877°	65.04175°

VIR74 (TA 15)	Latitude (N)	Longitude (W)
TP	18.35971°	65.44025°
TP	18.39314°	65.44197°
TP	18.40641°	65.01928°
TP	18.38573°	64.97612°
TP	18.37647°	64.96727°
TP	18.37526°	64.95294°
TS15	18.35438°	64.93252°
TP	18.35686°	64.99348°
TP	18.35528°	65.01312°
TP	18.38471°	65.03655°

VIR1A (TA 16)	Latitude (N)	Longitude (W)
TP	18.34492°	65.14737°
TP	18.36877°	65.04175°
TS16	18.35428°	65.02554°
TP	18.31669°	65.12600°
TP	18.15423°	65.43738°
TP	18.26888°	65.44148°

VIR72 (TA 17)	Latitude (N)	Longitude (W)
TP	18.61842°	64.97893°
TP	18.39430°	64.88161°
TP	18.38834°	64.88027°
TS17	18.39962°	64.91045°
TP	18.61448°	65.22455°

VIR71 (TA 18)	Latitude (N)	Longitude (W)
TP	18.37741°	64.82194°
TP	18.39521°	64.78745°
TP	18.38345°	64.76436°
TP	18.37060°	64.75034°
TP	18.35428°	64.78983°
TP	18.35614°	64.79636°
TP	18.35997°	64.81007°
TS18	18.35818°	64.84865°

VIR1B (TA 19)	Latitude (N)	Longitude (W)
TP	18.35428°	65.02554°
TP	18.35528°	65.01312°
TS19	18.35686°	64.99348°
TP	18.35438°	64.93252°
TP	18.31958°	64.93162°
TP	18.07160°	64.92523°
TP	18.05745°	65.43729°
TP	18.15423°	65.43738°
TP	18.31669°	65.12600°

VIR33 (TA 20)	**Latitude (N)**	**Longitude (W)**
TP	18.38290°	64.66005°
TP	18.62603°	64.22601°
TP	18.35587°	64.22409°
TP	18.35442°	64.62525°
TP	18.35295°	64.66283°
TP	18.34990°	64.68380°
TS20	18.35642°	64.69047°
TP	18.35686°	64.69657°

VIR32 (TA 21)	**Latitude (N)**	**Longitude (W)**
TP	18.35442°	64.62525°
TP	18.35587°	64.22409°
TP	18.29131°	64.22489°
TP	18.32699°	64.60707°
TP	18.33718°	64.66769°
TP	18.34043°	64.66852°
TS21	18.34419°	64.67573°
TP	18.34990°	64.68380°
TP	18.35295°	64.66283°

VIR31 (TA 22)	**Latitude (N)**	**Longitude (W)**
TP	18.33718°	64.66769°
TP	18.32699°	64.60707°
TP	18.29131°	64.22489°
TP	18.24469°	64.22456°
TP	18.29706°	64.62558°
TP	18.30447°	64.67629°
TP	18.31114°	64.70737°
TP	18.31879°	64.70385°
TS22	18.32947°	64.67036°

VIR30 (TA 23)	Latitude (N)	Longitude (W)
TP	18.31523°	64.71369°
TP	18.32170°	64.71564°
TP	18.31879°	64.70385°
TS23	18.31114°	64.70737°
TP	18.30447°	64.67629°
TP	18.27316°	64.68285°
TP	18.07152°	64.67829°
TP	18.07258°	64.76016°
TP	18.28886°	64.77035°
TP	18.29390°	64.75363°

VIR35 (TA 24)	Latitude (N)	Longitude (W)
TP	18.39199°	64.69316°
TP	18.37619°	64.69949°
TP	18.36016°	64.71279°
TS24	18.35975°	64.72930°
TP	18.37498°	64.72486°
TP	18.38709°	64.72309°
TP	18.62252°	64.64350°
TP	18.62393°	64.51513°

VIR34 (TA 25)	Latitude (N)	Longitude (W)
TP	18.39199°	64.69316°
TP	18.62393°	64.51513°
TP	18.62603°	64.22601°
TP	18.38290°	64.66005°
TP	18.35686°	64.69657°
TS25	18.36016°	64.71279°
TP	18.37619°	64.69949°

VIR35A (TA 26)	Latitude (N)	Longitude (W)
TP	18.38709°	64.72309°
TP	18.37498°	64.72486°
TP	18.35975°	64.72930°
TP	18.36005°	64.73782°
TS26	18.36818°	64.74101°
TP	18.37060°	64.75034°
TP	18.38345°	64.76436°
TP	18.39521°	64.78745°
TP	18.62252°	64.64350°

VIR73 (TA 27)	Latitude (N)	Longitude (W)
TP	18.39314°	65.44197°
TP	18.61296°	65.44384°
TP	18.61448°	65.22455°
TP	18.39962°	64.91045°
TS27	18.36447°	64.90879°
TP	18.35438°	64.93252°
TP	18.37526°	64.95294°
TP	18.37647°	64.96727°
TP	18.38573°	64.97612°
TP	18.40641°	65.01928°

VIR31A (TA 28)	Latitude (N)	Longitude (W)
TP	18.34419°	64.67573°
TP	18.34043°	64.66852°
TP	18.33718°	64.66769°
TP	18.32947°	64.67036°
TP	18.31879°	64.70385°
TP	18.32170°	64.71564°
TS28	18.33004°	64.70999°

VIR68 (TA 29)	Latitude (N)	Longitude (W)
TP	18.36041°	64.87406°
TP	18.36041°	64.86776°
TP	18.35790°	64.85542°
TP	18.35818°	64.84865°
TP	18.35997°	64.81007°
TP	18.35614°	64.79636°
TP	18.32864°	64.87068°
TS29	18.33545°	64.87604°

VIR25 (TA 30)	Latitude (N)	Longitude (W)
TP	18.31735°	64.88870°
TP	18.30696°	64.87961°
TP	18.30270°	64.87791°
TP	18.29893°	64.84487°
TP	18.29110°	64.81725°
TP	18.29064°	64.79736°
TP	18.28886°	64.77035°
TP	18.07258°	64.76016°
TP	18.07160°	64.92523°
TS30	18.31958°	64.93162°

VIR27 (TA 31)	Latitude (N)	Longitude (W)
TP	18.29893°	64.84487°
TP	18.30270°	64.87791°
TP	18.30696°	64.87961°
TP	18.31735°	64.88870°
TS31	18.32864°	64.87068°

VIR31B (TA 32)	Latitude (N)	Longitude (W)
TP	18.33004°	64.70999°
TS32	18.34673°	64.72111°
TP	18.35686°	64.69657°
TP	18.35642°	64.69047°
TP	18.34990°	64.68380°
TP	18.34419°	64.67573°

VIR70 (TA 33)	Latitude (N)	Longitude (W)
TP	18.35428°	64.78983°
TP	18.37060°	64.75034°
TP	18.36818°	64.74101°
TP	18.36005°	64.73782°
TP	18.34580°	64.74634°
TP	18.33609°	64.78215°
TP	18.34835°	64.78647°
TS33	18.35273°	64.78563°

VIR28 (TA 34)	Latitude (N)	Longitude (W)
TP	18.32864°	64.87068°
TP	18.30925°	64.82985°
TP	18.30754°	64.80339°
TP	18.31213°	64.78162°
TS34	18.33609°	64.78215°
TP	18.32568°	64.74037°
TP	18.30195°	64.75307°
TP	18.29064°	64.79736°
TP	18.29110°	64.81725°
TP	18.29893°	64.84487°

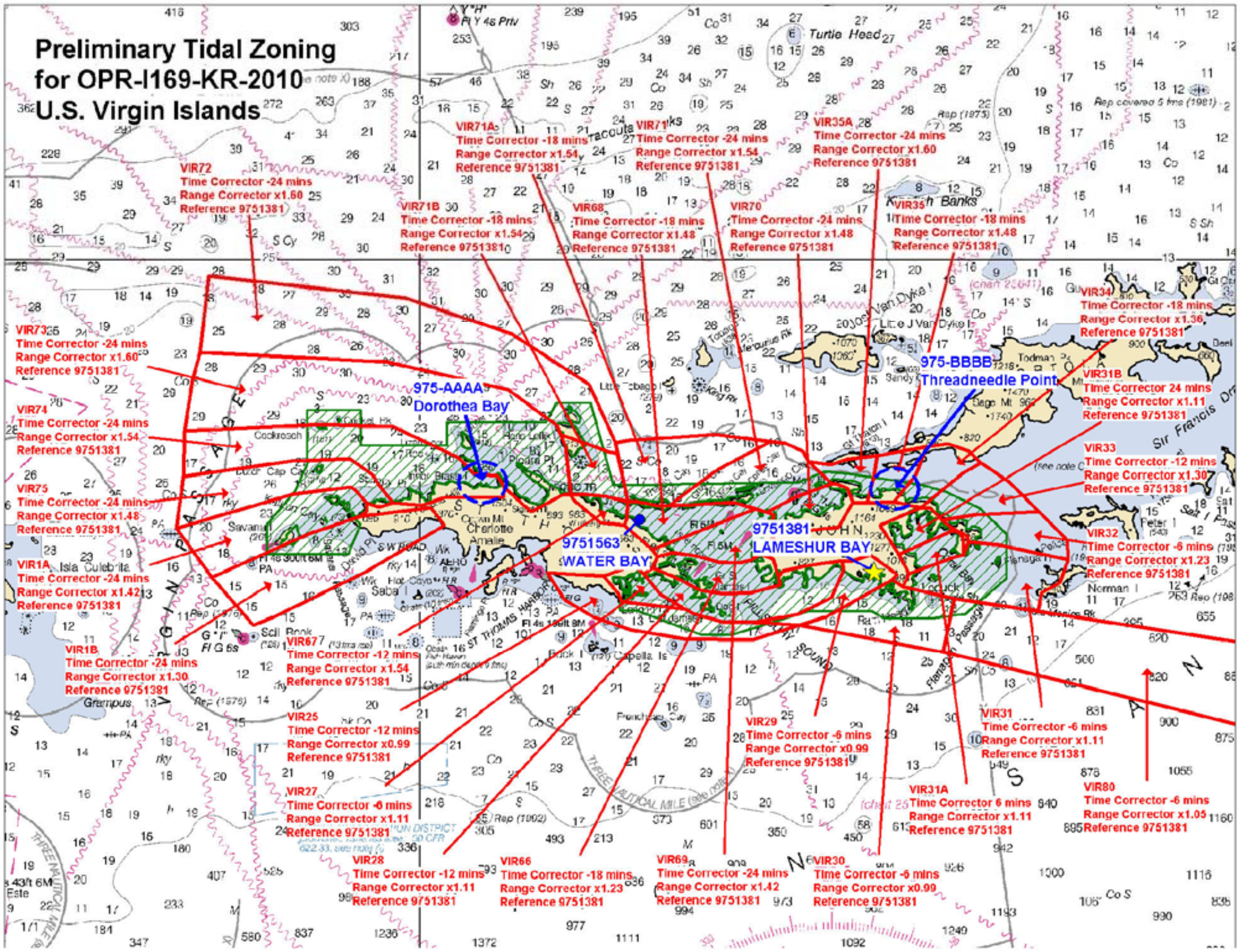
VIR29 (TA 35)	Latitude (N)	Longitude (W)
TP	18.29064°	64.79736°
TP	18.30195°	64.75307°
TS35	18.32568°	64.74037°
TP	18.32170°	64.71564°
TP	18.31523°	64.71369°
TP	18.29390°	64.75363°
TP	18.28886°	64.77035°

VIR66 (TA 36)	Latitude (N)	Longitude (W)
TP	18.33084°	64.84660°
TP	18.32491°	64.80735°
TS36	18.32647°	64.79960°
TP	18.33609°	64.78215°
TP	18.31213°	64.78162°
TP	18.30754°	64.80339°
TP	18.30925°	64.82985°
TP	18.32864°	64.87068°

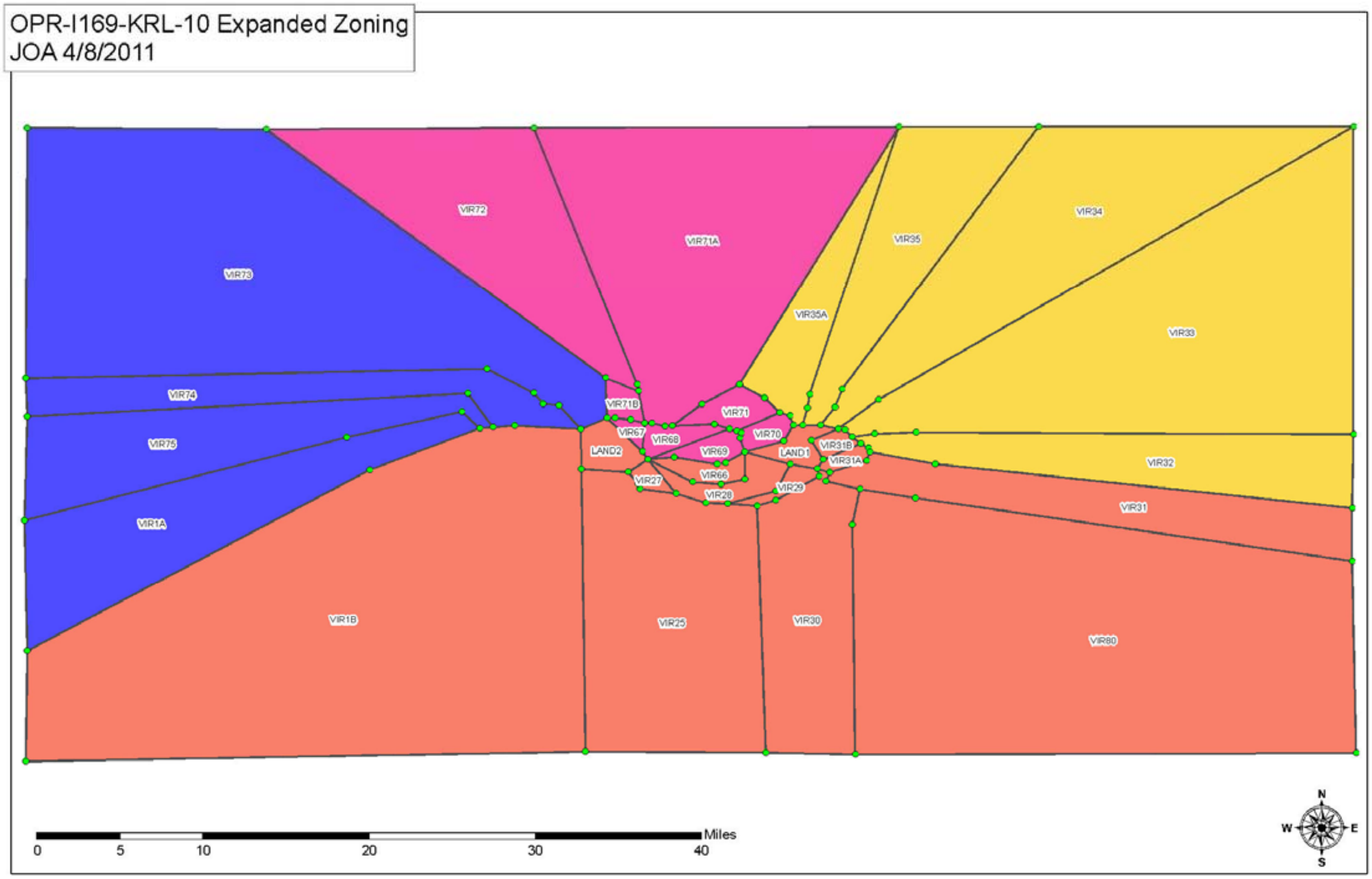
VIR67 (TA 37)	Latitude (N)	Longitude (W)
TP	18.36447°	64.90879°
TP	18.36467°	64.90175°
TP	18.36341°	64.88718°
TS37	18.36041°	64.87406°
TP	18.33545°	64.87604°

LAND1 (TA 38)	Latitude (N)	Longitude (W)
TP	18.33609°	64.78215°
TS38	18.34580°	64.74634°
TP	18.36005°	64.73782°
TP	18.35975°	64.72930°
TP	18.36016°	64.71279°
TP	18.35686°	64.69657°
TP	18.34673°	64.72111°
TP	18.33004°	64.70999°
TP	18.32170°	64.71564°
TP	18.32568°	64.74037°

LAND2 (TA 39)	Latitude (N)	Longitude (W)
TP	18.35438°	64.93252°
TP	18.36447°	64.90879°
TP	18.33545°	64.87604°
TP	18.32864°	64.87068°
TS39	18.31735°	64.88870°
TP	18.31958°	64.93162°



Preliminary tide zones



Final tide zones used in the LADS GS

A.3 TIDAL REDUCTION

In each tide zone within the Ground System (GS), there is only one reference tide station (TS). Soundings have been reduced by that station using the relevant JOA established time and range correctors for each zone.

A.3.1 Sounding Datum

All depth soundings were reduced to Mean Lower Low Water (MLLW). Island, islet and drying rock heights are also related to MLLW.

A.3.2 Tides and Water Levels

After each survey flight preliminary tide observations at NWLON and subordinate stations were downloaded from their respective online sources for the interim reduction of soundings. The format of this data was in UTC and meters.

John Oswald and Associates (JOA) was subcontracted to smooth NOAA verified tides for all tide stations after survey operations concluded. These verified tide readings are raw 6-minute readings reduced to MLLW, smoothed using a fifth order polynomial of five hours. The final smoothed tide data was subsequently reapplied to all soundings following field operations.
Tidal information used in establishing final zoning correctors and reducing soundings is forwarded in digital format on the USB flash drive. Below is a description of the digital files:

Subordinate Tide Gauge Installation and Demobilization	Transmittal Letters, Calibration Reports, Site Reports, Chartlets and USGS Maps, Sensor Elevation Drawings, Benchmark Sketches, To Reach Statements, Benchmark Descriptions, Photos, Level Records, Datum Offset Computation Reports, Staff to Gauge Observation Summaries and Reports, Benchmark History Reports, Field Notes, Submittal Checklists, Water Density and Slope Constant Reports, GPS Data in RINEX format, OPUS Solution Reports, and Water Level Data in .dat format.
Tidal Zoning	Final tidal zoning from JOA, including Caris .zdf files, zoning cell coordinates in .xls format, and final zoning report.
Preliminary Tides	Raw, unsmoothed tide data for each sortie relative to MLLW in .xls and .txt formats.
Verified Tides	Final, JOA smoothed tide data for each sortie relative to MLLW in .xls and .txt formats.
Tide Application Reports	LADS GS reports on tide zone used in tidal application of each line of survey in .csv format.

A.4 ACCURACY OF SOUNDINGS – DEPTH

A.4.1 LADS Mk II Vertical System Accuracy

A vertical system accuracy of ± 0.3m (95% confidence) is considered appropriate from historical system performance and trials.

A.4.2 Tidal Accuracy

The error budget for tides can be assessed from three sources: Measurement Error, Datum Computation Error and Tidal Zoning Error.

Source	**Estimate**	**Error Type**
Measurement Error		
Calibration	0.01m	Random
Dynamic Effects	0.05m	Random
Processing to Datum		
Staff / Gauge	0.03m	Random
Leveling	0.01m	Random
Interpolation	0.03m	Random
Datum Computation Error	0.10m	Systematic
Tidal Zoning Error	0.10m	Systematic
Total systematic errors	0.200m	
Total random errors	0.067m	
TOTAL TIDE ERROR = 0.20 + 1.96 X 0.067 = 0.33m		

A.4.3 Swell

Swell had little effect on survey operations. An allowance of ± 0.1m (95% confidence) has been incorporated into the depth accuracy assessment for the effects of swell.

A.4.4 Accuracy of Soundings

An assessment of the final sounding accuracy can be determined by combining the errors due to the LADS Mk II system, tidal model and swell. These are combined using a Gaussian model as follows:

$$\sigma^2 \text{ survey} = \sigma^2 \text{ LADS Mk II} + \sigma^2 \text{ Tide Model} + \sigma^2 \text{ swell}$$

95% confidence limit = 1.96σ

[For a single dimensional distribution]

$$\text{Survey Accuracy} = \sqrt{(0.3^2 + 0.33^2 + 0.1^2)} = 0.46\text{m}$$

From the assessment above, it is considered depth accuracy meets IHO Order-1 standard throughout the survey area. The agreement observed between adjacent survey lines in overlap areas and the depth benchmark and crossline comparison results are also consistent with IHO Order-1 depth accuracy.

B. HORIZONTAL CONTROL

Data collection and processing were conducted on the Airborne and Ground Systems in World Geodetic System 1984 (WGS84) on Universal Transverse Mercator (Northern Hemisphere) projection UTM (N) in Zone 20, Central Meridian 063° West. This data was post-processed and all soundings are positioned relative to the North American Datum 1983 (NAD83). All units are in meters.

B.1 GEODETIC CONTROL STATIONS

B.1.1 LADS Local GPS Base Station – San Juan

A local GPS base station was established by FLI personnel on the roof of the Courtyard Marriott Hotel, San Juan on February 3, 2011. The coordination was undertaken using an Ashtech Z12 GPS L1/L2 receiver. The position was coordinated relative to three NGS CORS Stations. The base station position was determined from a NGS OPUS solution, using a rapid ephemeris, relative to the following NGS CORS stations:

CORS Site	ID	NAD83 Latitude (N)	NAD83 Longitude (W)	Ellipsoidal Height (m)	Baseline Distance (km)
4N INC	PRN4	18° 04' 42.9158”	066° 22’ 08.7083”	131.059	52
San Juan WAAS 1	ZSU1	18° 25' 52.8032”	065° 59’ 36.5180”	-27.189	10
Las Piedras	PRLP	18° 11’ 41.6282”	065° 52’ 05.7544”	58.889	37

The NGS CORS descriptions are provided at Appendix II.

The derived NAD83 coordinates for the LADS local GPS base station are:

NAD83		UTM (N) Zone 20		
Latitude (N)	Longitude (W)	Easting (m)	Northing (m)	Ellipsoidal Height (m)
18° 27’ 20.2748”	066° 04’ 56.2682”	174421.834	2043370.320	13.252

The ellipsoidal height is relative to the bottom of the threads of the antenna pole. The NGS OPUS solution report for the coordination of the local GPS base station is provided at Appendix III.

B.1.2 Local GPS Base Station Site Confirmation

The local GPS base station site was checked for obstructions and multipath over a 24-hour period on February 12 and 13, 2011. A second ‘rover’ GPS antenna was established 3.200m from the local GPS base station site. GPS data was logged at one-second epochs at the base and rover position simultaneously over a single session. This enabled statistical analysis for the computed position of the rover in a spreadsheet utility. The GPS data was processed with GrafNav software for KGPS (L1 + L2 carrier phase, fixed ambiguities and forward / backward processing) position solutions.

The results of the site confirmation are detailed below:

Solution	Taped Distance (m)	Observed Distance (m)	St. Dev. 1σ Eastings (m)	St. Dev. 1σ Northings (m)	St. Dev. 1σ Positions (m)
KGPS	3.200	3.201	0.009	0.006	0.011

Scatter plots for the computed position of the rover are presented in the Separates Report. The results presented above and scatter plots produced reveal that the local GPS base site is free from site specific problems such as multipath and obstructions.

B.1.3 CORS Sites Utilized For Post Processed KGPS

The first five sorties for this project were conducted from Martinique and the final flight from Guadeloupe. In order to avoid long GPS baseline distances from these two operating sites to the survey area, data from 3 CORS sites were used to accurately solve for the position of the aircraft GPS antenna during post-processing. The following 3 CORS sites provided GPS base station data for all flights conducted, including those from the main base of operations in San Juan:

CORS Site	ID	NAD83 Latitude (N)	NAD83 Longitude (W)	Ellipsoidal Height (m)
San Juan WAAS 1	ZSU1	18° 25' 52.8032"	065° 59' 36.5180"	-27.189
St. Thomas	VITH	18° 20' 35.9771"	064° 58' 09.1765"	6.366
Kingshill, St. Croix	VIKH	17° 42' 58.2438"	064° 47' 53.2599"	-4.424

B.1.4 Static Position Check – Control Point Coordination

In order to conduct the Static Position Check of the LADS positioning systems, it was necessary to establish and coordinate a control point directly below the laser source position on the main scanning mirror. The position of the laser source was plumbed from the laser bay window to the tarmac and clearly marked with fluorescent paint. The aircraft was then moved in order to occupy and independently coordinate the control point.

The coordination of the control point was conducted by FLI personnel on February 17, 2011 using Ashtech Z12 GPS L1/L2 receivers in static mode. The position of the control point was derived using GrafNav GPS post-processing software relative to the LADS GPS Base

Station, and confirmed by applying a free adjustment with GrafNet network adjustment software, relative to three NGS CORS Stations and the LADS GPS Base Station. The derived control point position was held fixed in the GrafNet adjustment. The stations and their baselines are listed below.

Site	ID	NAD83 Latitude (N)	NAD83 Longitude (W)	Ellipsoidal Height (m)	Baseline Distance (km)
4N INC CORS ARP	PRN4	18° 04' 42.9158”	066° 22’ 08.7083”	131.059	56
Bayamon CORS ARP	PRHL	18° 22' 48.0915”	066° 09’ 12.8159”	-22.546	18
Las Piedras CORS ARP	PRLP	18° 11’ 41.6282”	065° 52’ 05.7544”	58.889	30
LADS Base Station	LADS BS	18° 27’ 20.2748”	066° 04’ 56.2682”	13.252	9

The NAD83 coordinates for the control point (laser source position) is listed below:

NAD83		UTM (N) Zone 20	
Latitude (N)	Longitude (W)	Easting (m)	Northing (m)
18°26’30.5654”	065°59’55.1685”	183237.700	2041692.213

The network adjustment for the coordination of the control point, for the static position check, is provided at Appendix IV.

It was also necessary to compute the WGS84 coordinates for the control point in order to compare a static position check session in WADGPS mode. The derived WGS84 coordinates for the control point are:

WGS84		UTM (N) Zone 20	
Latitude (N)	Longitude (W)	Easting (m)	Northing (m)
18°26’30.5794”	065°59’55.1666”	183237.764	2041692.643

B.1.5 Static Position Check – GPS Antenna Position

On February 16, 2011 the LADS Mk II aircraft was positioned at San Juan International Airport and an aircraft grid heading of 251° was determined from a Ground Compass Alignment using the LADS Mk II Attitude and Heading Reference System (AHRS). The GPS antenna absolute position was calculated by applying the antenna x and y offsets from the laser source position (refer to Appendix V). The GPS antenna offset distances are described in the DA&P Report. The NAD83 coordinates for the absolute position of the GPS antenna are:

NAD83		UTM (N) Zone 20	
Latitude (N)	**Longitude (W)**	**Easting (m)**	**Northing (m)**
18° 26’ 30.5626”	065° 59’ 55.1666”	183237.757	2041692.125

It was also necessary to compute the WGS84 coordinates for the GPS antenna position in order to compare a static position check session in WADGPS mode. The derived WGS84 coordinates for the GPS antenna position during the static position check are:

WGS84		UTM (N) Zone 20	
Latitude (N)	**Longitude (W)**	**Easting (m)**	**Northing (m)**
18° 26’ 30.5766”	065° 59’ 55.1646”	183237.821	2041692.555

The difference between NAD83 and WGS84 at the San Juan airport is:

	Easting	Northing
NAD83 to WGS84	+0.064	+0.430

B.2 POSITIONING FIXING SYSTEMS

Throughout the survey the real-time position of the LADS Mk II system was derived from an Ashtech GG24 receiver aided by Wide Area Differential GPS (WADGPS).

For sorties conducted from San Juan the KGPS (L1 + L2 carrier phase) position was obtained by simultaneous GrafNav data logging with two Ashtech Z12 GPS L1/L2 receivers; the roving receiver onboard the aircraft and the reference receiver at the coordinated local GPS base station on the roof of the Courtyard Marriott Hotel in San Juan. The final KGPS solution was improved by utilizing GPS base station data from 3 NGS CORS sites, within the GrafNav multi-base station processing utility.

For the sorties conducted from Martinique and Guadeloupe the LADS local GPS base station was inactive, so GPS reference station data was retrieved from the 3 NGS CORS sites only. These data were processed against the roving receiver data using GrafNav multi-base station processing to produce an accurate KGPS solution for the aircraft.

Following each flight the post-processed GrafNav data was imported into the GS where the dynamic position check function was used to calculate statistics on the accuracy of the real-time positioning system. The KGPS post-processed position solution was then applied to all soundings.

B.3 GPS STATIC POSITION CHECK

On February 16, 2011, static position checks of the LADS Mk II positioning systems were undertaken relative to the aircraft GPS antenna position. A single observation session took place using Wide Area Differential GPS (WADGPS) for real-time positioning. Additionally, during this period the roving receiver at the aircraft logged data simultaneously with the local

GPS base station on the roof of the Courtyard Marriott Hotel. Post-processing of this data provided KGPS (L1 + L2 carrier phase) positions for the aircraft GPS antenna. The WADGPS is relative to the WGS84 reference framework and the post-processed positions are referenced to the NAD83 horizontal datum.

Logging commenced on the local GPS base station at the Courtyard Marriott Hotel and the roving receiver prior to the commencement of logging on the Airborne System (AS). The AS was set to receive real-time differential corrections and this resulted in Wide Area Differential GPS positioning. Position data was recorded on Digital Linear Tape (DLT) using the manual logging function on the AS. The recording period was approximately two hours.

B.3.1 Observations

The observation period was as follows:

	Start Time (UTC)	**Stop Time (UTC)**	**Logging Duration**	**Average Number of GPS Satellites**
Session 1	19:25	21:25	2 hrs 00 min	10

The AS GPS observables were recorded manually every ten minutes. The number of GPS satellites used, Positional Dilution of Precision (PDOP), Estimate of Horizontal Error (EHE), Easting and Northing were noted and were within normal acceptable limits.

B.3.2 Processing

The KGPS positions were produced by processing the base station file and the aircraft file with Waypoint GrafNav software. The KGPS position was produced by solving for the carrier phase ambiguity and using double differencing and forward and backward processing techniques. The WADGPS file was produced in real-time on the AS and the solution was logged directly to tape. The files were then processed using Position Analysis Software on the GS.

B.3.3 Results

The final positions were exported to a commercial spreadsheet / graphical based software package where calculations of means and standard deviations of positions were conducted and scatter plots produced. The scatter plots can be found in the Separates Report.

The following tables show the comparison between the position of the GPS antenna, as determined by the LADS AS positioning systems during the Static Position Check, and the independent positioning of the control point after the aircraft was moved.

Note: Absolute Accuracy (95% Confidence) = $2.45\ (\sigma_E^2 + \sigma_N^2)^{½} + (\Delta\ East^2 + \Delta\ North^2)^{½}$
AS WADGPS positions are relative to WGS84 and post-processed GrafNav KGPS positions are relative to NAD83.

Positioning System	**Easting WGS84**	**Northing WGS84**			
Absolute Position of GPS Antenna	183237.821	2041692.555			
Session 1	**Mean Easting +/- 1σ (m)**	**Mean Northing +/- 1σ (m)**	**Δ East C – O (m)**	**Δ North C – O (m)**	**Absolute Accuracy 95% Confidence (m)**
AS WADGPS	183237.965 +/- 0.698	2041692.107 +/- 0.548	-0.144	0.448	2.645

Positioning System	**Easting NAD83**	**Northing NAD83**			
Absolute Position of GPS Antenna	183237.757	2041692.125			
Session 1	**Mean Easting +/- 1σ (m)**	**Mean Northing +/- 1σ (m)**	**Δ East C – O (m)**	**Δ North C – O (m)**	**Absolute Accuracy 95% Confidence (m)**
KGPS	183237.703 +/- 0.011	2041692.113 +/- 0.018	0.054	0.012	0.107

The stated theoretical accuracy of each of the positioning systems has been compared against the absolute accuracy achieved during the static position check in the following table:

Positioning System	**Baseline Distance (km)**	**Theoretical GPS Accuracy 95% Confidence (m)**	**Absolute Accuracy 95% Confidence (m)**	**Notes**
WADGPS	-	13.0	2.645	
KGPS	9	0.309	0.107	1, 2

Notes

1. This solution may be affected slightly by the aircraft not being totally static during the data logging due to wind and personnel movements onboard the aircraft.
2. The KGPS solution was the most accurate and within the theoretical accuracy.

A compilation of graphs, illustrating the spread of solved positions for the static position check session and the report, is included within the Separates Report. These graphs show the mean point of recorded positions and the position of the actual antenna, as determined by the static position control point coordination and antenna offset application.

B.3.4 Conclusion

The accuracy of the logged WADGPS position was well within the theoretical accuracy and was sufficient for the real-time positioning of the aircraft.

The KGPS position yielded a more accurate result, and this positioning solution was subsequently applied to all survey data. The position check shows that there are no gross errors.

B.4 DYNAMIC POSITION CHECK

During each sortie, GPS data was logged both on the aircraft and at the base station, which enabled a KGPS position solution to be determined. These position fixes were then compared to the coordinates as determined by the real-time positioning system. For each survey line the mean difference and standard deviation of position fix differences have been calculated. The following table shows the mean and standard deviation of the difference in position between the real-time positioning system and the post-processed KGPS for each sortie during which data was collected in support of the survey.

Sortie No.	Lines Flown	Max. Difference AS - KGPS (m)	Mean Difference AS - KGPS (m)	Overall Average Standard Deviation (m)
8	18	2.247	0.762	0.202
9	15	1.876	0.792	0.151
10	19	2.181	1.021	0.131
11	14	2.277	0.817	0.187
12	19	2.285	0.954	0.157
13	41	2.350	0.908	0.143
14	36	2.383	0.981	0.148
16	31	2.280	0.989	0.151
18	29	2.201	0.820	0.146
19	13	1.277	0.540	0.142
20	38	2.317	1.079	0.136
22	21	1.730	0.714	0.146
		Mean	**0.865**	**0.153**

These results show good agreement between the real-time positioning and the post-processed KGPS positioning. An extract from the Sortie 16 Dynamic GPS Position Check Report is provided in the Separates Report.

B.5 NAVIGATION POSITION CHECK

Navigation position checks were conducted over the Isla Culebrita Lighthouse on Culebrita Island, PR. Positions were obtained from the USCG District 7 Light List, 2010, and details are provided at Appendix VI. The aircraft was flown over this coordinated point at the commencement, or on completion of sorties when suitable weather conditions prevailed. Following the sortie, the logged aircraft position was processed against the downward-looking camera image to determine the difference in position at the time of overflight. This provided a gross error check of the real-time aircraft positioning. A total of four passes over the navigation position checkpoint were conducted and used in the statistical analysis (refer to the Separates Report for all results).

Initial corrections (both port / starboard and aft / forward) for the platform position in relation to the coordinated mark were manually extracted from the digital imagery. The precision of the navigation position check can be limited by the difficulty in accurately determining the center of the target, and the image pixel size. The initial corrections were entered into the GS, which combined them with the platform pitch and roll, aircraft position, aircraft heading and time over the mark to compute the actual offsets in Eastings and Northings in meters.

All accepted offsets computed were assigned a confidence of 1 by the GS and given a hydrographic confidence of 1 by the System Operator responsible for the navigation position check.

B.5.1 Summary of Results

		Δ East (m)		Δ North (m)	
Navigation Check Point	**No. of Passes Analyzed**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
1	4	-2.13	2.60	-1.63	0.49

These results are consistent with correct system operation.

B.6 ACCURACY OF SOUNDINGS – HORIZONTAL POSITION

B.6.1 Theoretical Accuracy

The theoretical accuracy of the post-processed positioning is related to the distance of the aircraft GPS receiver from the base station. The relationship between baseline distance and theoretical accuracy was provided by Waypoint and is based on empirical data.

B.6.1.1 Waypoint GrafNav

The theoretical accuracy of the post-processed GrafNav positional data has been determined from the Waypoint GrafNav Software User's Manual and through consultation with Waypoint. For a PDOP of less than 4, the following GrafNav data processing accuracy has been quoted:

- L1/L2 carrier phase, float ambiguities,
  fwd / backwd processing (KGPS) = 0.3m + 1ppm (worse case)

For the survey area the maximum baseline distance between the local GPS base station (San Juan) and the aircraft was approximately 160km. Therefore, the expected accuracy of the post-processed solutions is:

- L1/L2 carrier phase = ±0.46m @ 95% confidence

B.6.2 Practical Accuracy

The actual performance of the positioning solutions was checked by:

a. Static position check

b. Dynamic position check

B.6.2.1 Static Position Check

Static position checks were conducted for the following GPS solutions:

a. KGPS – Forward and backward processed L1+L2 carrier phase, float ambiguities (offline)

b. Wide Area Differential GPS – One GPS receiver only

The static position check results are provided in Section B.3.3 and in the Separates Report.

B.6.2.2 Dynamic Position Monitoring

During the survey, GPS data was logged on the aircraft and at the local base station, which enabled post-processing to produce KGPS result files. These result files were then compared to the position as determined by the autonomous GPS on the AS. For each survey line, the mean difference and standard deviation have been calculated. The dynamic position check results for each sortie are enclosed in Section B.4.

B.6.3 LADS Mk II Positioning Accuracy

The total expected error of the LADS Mk II positioning is a combination of the following errors:

a. GPS errors (Egps), as previously stated, have a theoretical maximum of ± 0.46m (95% confidence - KGPS).

b. Errors in assigning frame center reference positions from GPS fixes (Eframe ref) have been assessed as ± 0.66m (95%).

c. Platform and laser positioning errors (Eplat, this includes such errors as gimbal angles, optical alignment, AHRS angles, AHRS mount, Optical Coupler mount, Scanner mount, Laser output, Laser mount, mirrors, timing and aircraft height). The resultant error in position has been assessed as ± 1.30m (95%).

d. Position errors of detecting objects due to the distance between laser spots (Espot). With a 4m laser spot spacing, it is considered the maximum position error is half of the sample interval distance, or $\pm$ 2.0m.

e. Sea surface errors (Esurface) due to swell. These are variable and dependant on the angle of incidence of the laser beam at the air / sea boundary, the depth of water and sea state. They have been assessed and are tabled below:

Depth (m)	**Sea State 1**	**Sea State 2**	**Sea State 3**	**Sea State 4**
5	0	0.03	0.31	0.55
10	0.01	0.06	0.62	1.10
15	0.01	0.09	0.93	1.65
20	0.02	0.12	1.24	2.20

Seas were typically slight to moderate during survey flights and swell was generally less than 2m. A maximum sea state of 2 was observed during survey operations, and the general maximum depth achieved by lidar was 20m.

- Total Expected Error $= ((Egps)^2 + (Eframe\ Ref)^2 + (Eplat)^2 + (Espot)^2 + (Esurface)^2)^{½}$

The maximum error expected, at 160km from the local GPS base station at San Juan, in a depth of 20m, with sea state 2 is:

- Total Expected Error $= ((0.46)^2 + (0.66)^2 + (1.30)^2 + (2.00)^2 + (0.12)^2)^{½}$
  $= 2.52$m at the 95% confidence level

Analyzing the positional data obtained from both the static and dynamic position checks, it has been concluded that during the survey, IHO Order-1 precision for position was achieved.

B.6.4 GPS Positional Accuracy – Summary

B.6.4.1 San Juan Airport

- Absolute accuracy of GrafNav post-processed KGPS (9km baseline) = 0.107m

B.6.4.2 Dynamic Position Check

- Mean value of range distances over all lines of survey between autonomous GPS and post-processed KGPS = 0.865m

- Maximum value of range distance, over all lines of survey between autonomous GPS and post-processed KGPS = 2.383m

B.6.5 Horizontal Accuracy of Final Soundings

- Theoretical Accuracy (Depth = 20m, Sea State 2, Baseline 160km) = 2.52m

- IHO Order-1 Horizontal Accuracy (95% confidence) = 5m + 5% of the depth

- **Survey Horizontal Accuracy (95% confidence) = better than 3m**

C. APPROVAL SHEET

LETTER OF APPROVAL – OPR-I169-KRL-10

This report and the accompanying digital data are respectfully submitted.

Field operations contributing to the accomplishment of this survey were conducted under my direct supervision with frequent personal checks of progress and adequacy. This report and the accompanying digital data have been closely reviewed and are considered complete and adequate as per the Statement of Work.

Report	Submission Date
Horizontal and Vertical Control Report	August 3, 2011

Mark Sinclair
Hydrographer
Fugro LADS, Inc.

Date: August 3, 2011