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

HORIZONTAL & VERTICAL CONTROL REPORT

Type of Survey: Navigable Area

Project Number: OPR-Z394-KR-21

Time Frame: July – August 2021

LOCALITY

State(s): Michigan

General Locality: Vicinity of Whitefish Point

2021

CHIEF OF PARTY

John R. Bean

LIBRARY & ARCHIVES

Date:

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A. TIME BASIS

Coordinated Universal Time (UTC) was used to annotate the tide records and all other data obtained for this project.

B. VERTICAL CONTROL

All soundings are referenced to Low Water Datum, International Great Lakes Datum of 1985 (LWD IGLD-85) using Ellipsoidally Referenced Survey (ERS) methods per the Project Instructions.

B.1 ERS Tide Source Data

Inertially Aided Post Processed Kinematic (IAPPK) ellipsoid heights were computed using POSPac MMS, Applanix SmartBase (ASB) processing. The ellipsoid heights in the resulting Smoothed Best Estimate Trajectory (SBET) data were used as the basis for the development of ERS Tide.

ASB processing was organized into POSPac projects by vessel and day. Figure 1 illustrates the location of Continuously Operating Reference Stations (CORS) stations (including OSI's locally installed base station OSWP) which contributed to ASB processing. The total number of stations occasionally varied from one POSPac project to the next (i.e. vessel-day) based on CORS data availability and solution quality. Table 2 shows the POSPac IAPPK project count for each station. The final coordinates of OSWP were determined using the NGS' Online Positioning User Service (OPUS).

ERS water levels ("GPS Tide") were derived from SBET altitude with minimal intervention. When apparent invalid altitude was present in the daily SBET, additional CORS stations were added to the ASB network. For the few remaining daily SBETs that contained invalid altitude data, NOAA's POSPacAutoQC application was used to interpolate through and replace the invalid data.

B.2 VDatum Separation Model (SEP)

A VDatum Separation Model (SEP) was provided by NOAA with the original project files and described in the Project Instructions (Table 1). An updated SEP model to increase coverage area was requested and supplied during final data processing.

Table 1
VDATUM Model

VDATUM Version	Geoid	Area	Area Version	Separation Uncertainty
4.1.2	2018	Eastern Lake Superior	2021.2	4.5 centimeters

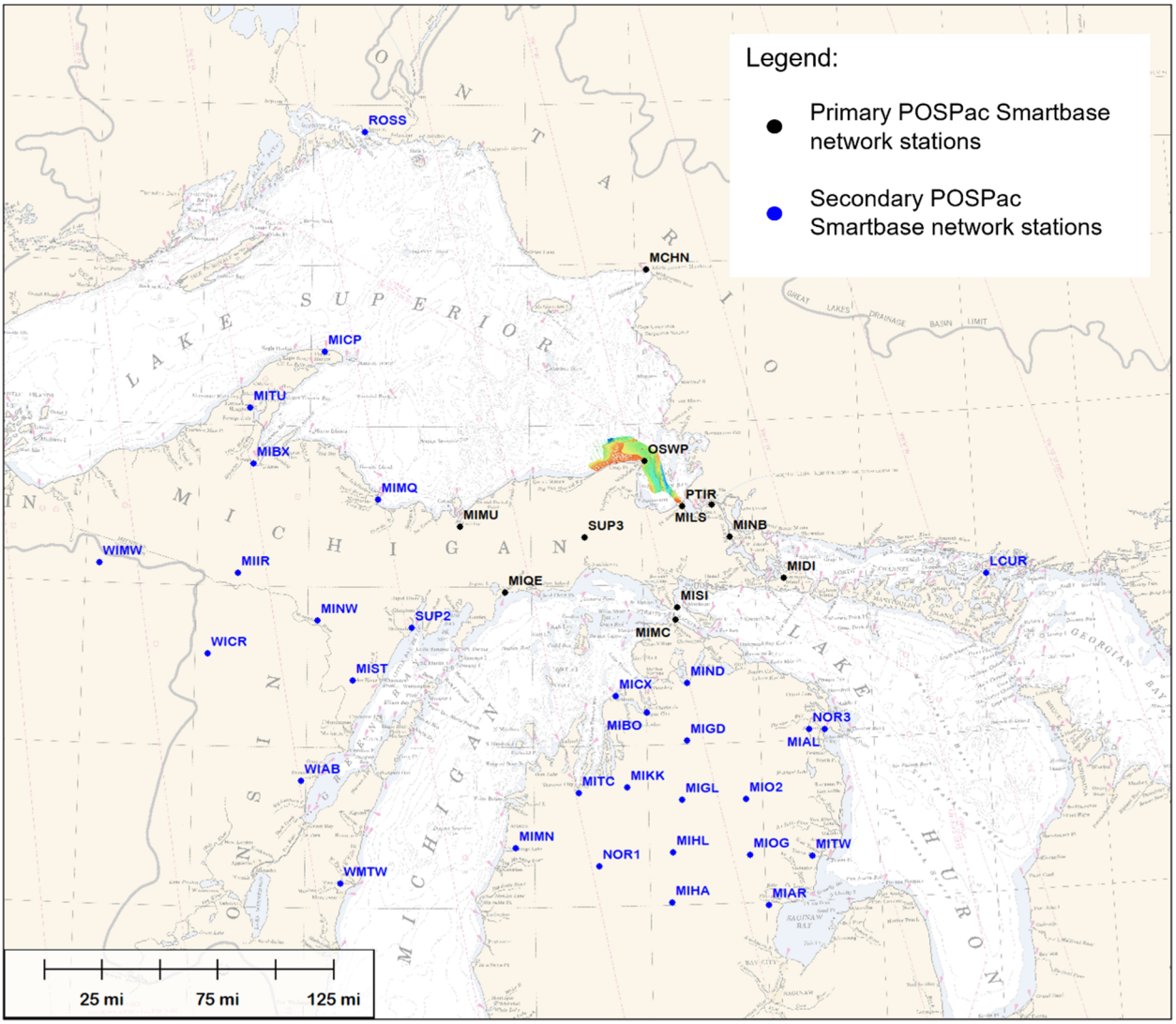

Figure 1. Local CORS network and "OSWP" in relation to the project site.

Table 2
CORS Station POSPac Project Counts

Station	POSPac Project Count
OSWP	86
PTIR	80
SUP3	78
MILS	72
MCHN	66
MINB	58
MISI	43
MIMU	35
MIQE	23
MIMC	19
MIDI	15
WIAB	12
WICR	12
LCUR	11
MIMQ	8
ROSS	8
SUP2	7
MICX	7
MIBX	6
MICP	6
MIGD	6

Station	POSPac Project Count
MIGL	6
MIIR	6
MIKK	6
MIND	6
MINW	6
MIO2	6
MIST	6
MITC	6
NOR3	6
MIHL	5
MIMN	5
MIOG	5
MITW	5
NOR1	5
MIAR	4
MITU	4
WMTW	4
MIAL	3
MIBO	3
MIHA	2
WIMW	1

B.3 Final Application of ERS Tides

For the final application of ERS tides, the final processed SBET ellipsoid record was imported to CARIS. The CARIS "Compute GPS Tides" function was used in conjunction with the NOAA-provided SEP to apply LWD tide correctors to the soundings:

OPR-Z394-KR-21_Whitefish_Bay_VDatumBuffer1282021_100m_NAD83_2011-LWD_IGLD85_Geoid18.csar.

Qualitative and quantitative crossline analysis as well as junction analysis indicated that the final ERS correctors applied to reduce soundings to LWD were adequate for the purpose. The results of crossline and junction analysis are presented in the Descriptive Report (DR) for each survey.

B.4 GNSS Base Station "OSWP"

To supplement IAPPK SBET processing, OSI installed a temporary GNSS base station on a structure roof at the Great Lakes Shipwreck Museum in Paradise, Michigan (Figure 2). The installed station was designated "OSWP" (Ocean Surveys Whitefish Point) and consisted of a Trimble NetR9 GNSS receiver equipped with a Zephyr 3 Geodetic antenna (Model: TRM115000.00 None).

Figure 2. Ortho imagery and setup images of OSI's user-installed base station "OSWP" on top of a building at the Great Lakes Shipwreck Museum in Paradise, MI. At the request of the museum, the GNSS antenna was camouflaged to preserve the historic character of the structure (far right panel).

The configuration of the NetR9 was based on UNAVCO standard configuration settings for this device. The NetR9 was configured to record GNSS observables continuously throughout the period of the survey and parse data observables into daily files for each 24-hour period. Data were delivered to OSI's home office processing center via regular automated FTP and e-mail "pushes." Pushes were transmitted over a network connection that was established on site for this purpose. Data were also saved to the receiver's internal storage as a backup.

The HSSD requires that "*The reference position of non-CORS antenna installations shall be verified at least once per week while the site is utilized for survey operations."* OSI submitted all individual days of dual frequency GNSS observables (Rinex files) from OSWP to OPUS. Data were submitted with an ARP height of 0m. OSI used OPUS Projects (https://www.ngs.noaa.gov/OPUS-Projects/OpusProjects.shtml) for OPUS solution management, quality control, and to compute the final network-adjusted coordinates which were then incorporated into ASB processing (Table 3). Processing steps and parameter selection were in accordance with the NGS-provided OPUS Projects Managers Training (required in order to obtain access to OPUS projects).

Table 3
OPUS Projects Network Adjusted Positions of OSWP

Time period	Latitude (NAD83-2011)	Longitude (NAD83-2011)	Ellipsoid Height (GRS80)
DN 199-236	46° 16' 16.39334'' N	084° 57' 26.37916'' W	160.864 m

Figure 3 shows a summary of the residuals for each of the daily OPUS solutions, and the improved residuals obtained with OPUS Projects session processing. The residuals are relative to the final network-adjusted position computed by OPUS Projects using all of the solutions. The error bars on each point indicate the 1-sigma peak-to-peak root mean square (RMS) error estimate of the 3D position components, namely east, north, and ellipsoid height. The apparent offset in the mean position of the daily residuals and the final network-adjusted position is due to plate velocities as handled in OPUS Projects for the time span of the project. All processing was done in ITRF 2014; however, final network-adjusted coordinates are also provided by OPUS Projects in NAD 83 (2011) @ 2010.00 (i.e. Table 3).

Individual OSWP OPUS Project results (OPUS solutions, sessions, and final network adjustment) are included in the HVCR digital deliverables.

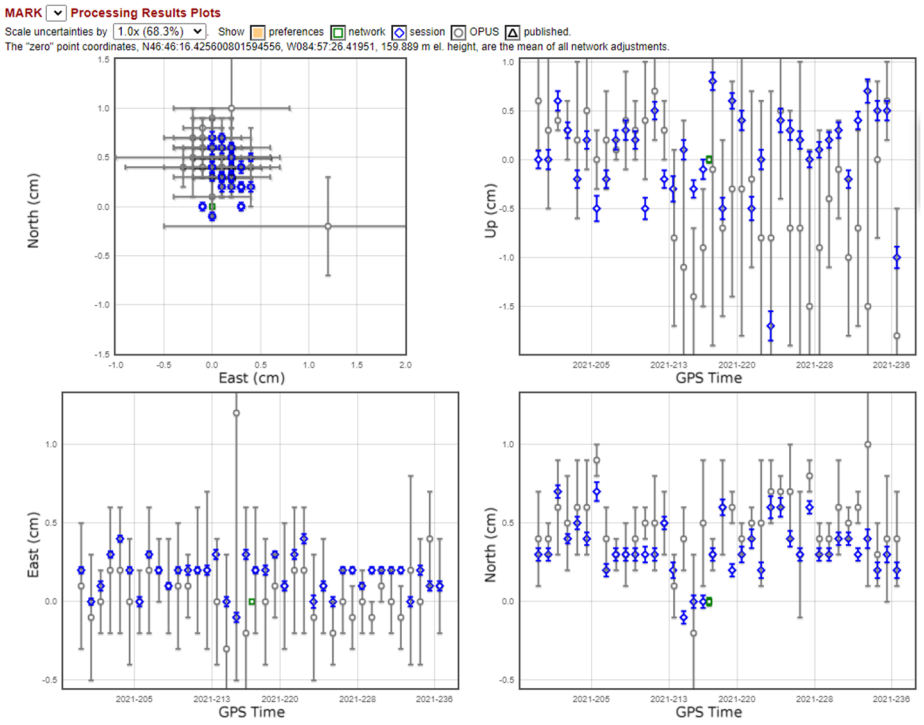

Figure 3. OPUS project coordinate residuals for GNSS observables at OSWP. OPUS solutions are in grey, improved OPUS Project session solutions are in blue. Error bars represent 1-sigma. Residuals are relative to the final network-adjusted and velocity corrected position (green) from OPUS Projects.

C. HORIZONTAL CONTROL

C.1 Horizontal Datum

The horizontal datum for this project is the North American Datum of 1983 (NAD83). Horizontal coordinates are referenced to Latitude/Longitude and Universal Transverse Mercator (UTM) Zone 16N, in meters. The assigned project boundary falls entirely within UTM Zone 16N.

C.2 Horizontal Control

Real-time vessel navigation was replaced during post processing with ASB-derived SBET positioning and attitude. Final SBET positioning is referenced to NAD83 (2011).

During the survey, each POSMV on the *RV H.F. Stout, RV North Cove,* and the *MV Northstar Challenger* was configured to receive SBAS (FAA WAAS) correctors for realtime positioning.

Positioning system confidence checks for each vessel were accomplished at the start of survey and periodically thereafter. In practice, the distance between the vessel's reference point (RP) and the dockside horizontal control point as computed by the navigation system was compared to the tape-measured distance between the vessel RP and the horizontal control point.

Temporary navigation confidence check points were installed near each vessel's dock. The horizontal positions of the temporary points were established using a single OPUS observation per location, with a duration of approximately 2 hours each (Figure 4 and Figure 5). The X,Y coordinates for each point are presented in Table 4. OPUS reports for each installation are included in the HVCR digital deliverables.

In all cases, dockside navigation system accuracy checks demonstrated an accuracy that was substantially better than 1.0 meter.

Table 4
Temporary Navigation Confidence Check Points

Designation	RTK Derived Easting UTM 16N, NAD83 (meters)	RTK Derived Northing UTM 16N, NAD83 (meters)	Locale	For Survey Vessel
WP Basin 2021	655473.05	5180553.49	Paradise, MI	RV H.F. Stout RV North Cove
MCM 2021	705633.66	5152335.50	Sault Ste. Marie, MI	MV Northstar Challenger

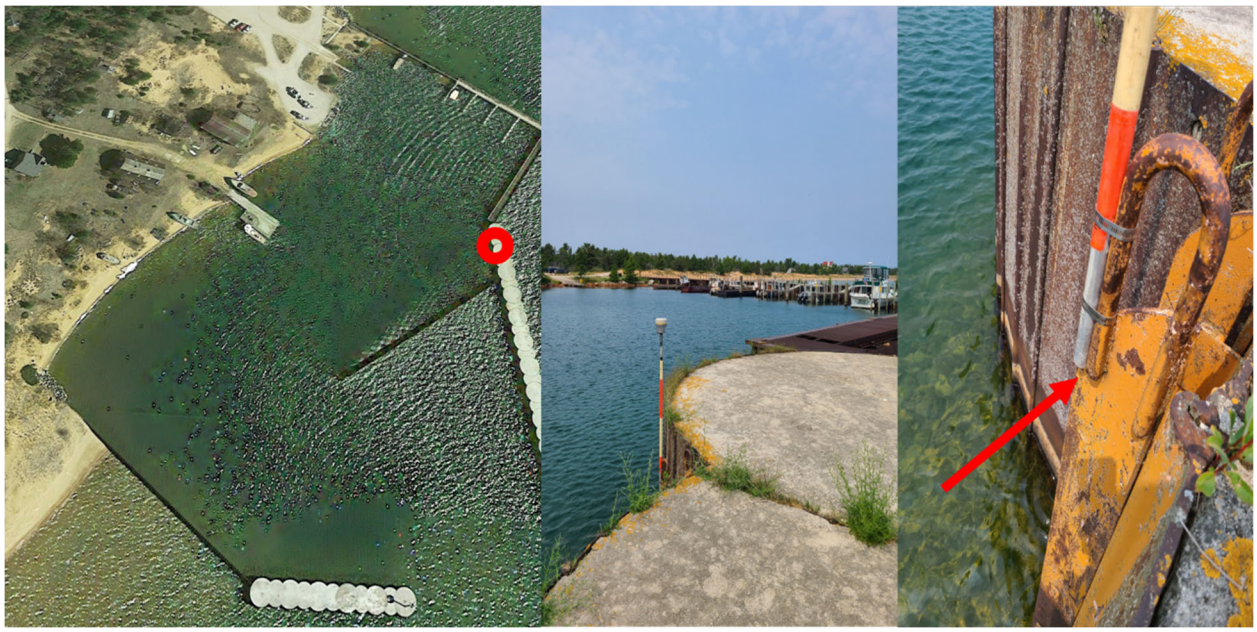

Figure 4. "WP Basin 2021" lies at the base of a handrail on a ladder at Whitefish Point State Dock in Paradise, MI.

Figure 5. "MCM 2021" sits atop a docking bollard at MCM Marine in Sault Ste. Marie, MI.

Navigation system confidence checks for each vessel are included below in Table 5 through Table 7.

Table 5
***RV H.F. Stout* Tabulation of Navigation System Confidence Checks**

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 16N, NAD83 (meters)	Observed Northing UTM 16N, NAD83 (meters)	Calculated Distance RP to Nav. Checkpoint (meters)	Tape Measure RP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
07/19/21 (DN200)	14:00	WP Basin 2021	WAAS	655,467.27	5,180,557.65	7.12	6.56	0.56
07/19/21 (DN200)	14:05	WP Basin 2021	WAAS	655,467.35	5,180,557.72	7.10	6.56	0.54
07/23/21 (DN204)	12:10	WP Basin 2021	WAAS	655,467.26	5,180,556.96	6.75	6.72	0.03
07/23/21 (DN204)	12:15	WP Basin 2021	WAAS	655,467.28	5,180,556.91	6.71	6.71	0.00

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 16N, NAD83 (meters)	Observed Northing UTM 16N, NAD83 (meters)	Calculated Distance RP to Nav. Checkpoint (meters)	Tape Measure RP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
07/23/21 (DN204)	12:20	WP Basin 2021	WAAS	655,467.26	5,180,556.93	6.73	6.71	0.02
07/24/21 (DN205)	11:40	WP Basin 2021	WAAS	655,467.24	5,180,556.74	6.66	6.66	0.00
07/24/21 (DN205)	11:45	WP Basin 2021	WAAS	655,466.46	5,180,554.67	6.69	6.56	0.13
07/24/21 (DN205)	21:33	WP Basin 2021	WAAS	655,466.28	5,180,553.85	6.78	6.56	0.22
07/25/21 (DN206)	12:43	WP Basin 2021	WAAS	655,466.03	5,180,554.35	7.07	6.56	0.51
07/25/21 (DN206)	12:45	WP Basin 2021	WAAS	655,466.01	5,180,554.56	7.12	6.56	0.56
07/25/21 (DN206)	21:37	WP Basin 2021	WAAS	655,466.46	5,180,553.96	6.61	6.56	0.05
07/26/21 (DN207)	10:57	WP Basin 2021	WAAS	655,466.18	5,180,554.22	6.91	6.56	0.35
07/26/21 (DN207)	22:29	WP Basin 2021	WAAS	655,466.16	5,180,553.37	6.89	6.63	0.26
07/27/21 (DN208)	11:23	WP Basin 2021	WAAS	655,466.22	5,180,554.17	6.86	6.57	0.29
07/27/21 (DN208)	21:38	WP Basin 2021	WAAS	655,466.80	5,180,554.66	6.36	6.39	0.03
07/28/21 (DN209)	11:07	WP Basin 2021	WAAS	655,466.14	5,180,553.21	6.92	6.62	0.30
07/28/21 (DN209)	21:25	WP Basin 2021	WAAS	655,466.18	5,180,553.12	6.88	6.64	0.24
07/29/21 (DN210)	10:34	WP Basin 2021	WAAS	655,466.12	5,180,554.37	6.99	6.56	0.43
07/29/21 (DN210)	10:35	WP Basin 2021	WAAS	655,465.94	5,180,554.00	7.13	6.56	0.57

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 16N, NAD83 (meters)	Observed Northing UTM 16N, NAD83 (meters)	Calculated Distance RP to Nav. Checkpoint (meters)	Tape Measure RP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
07/29/21 (DN210)	10:39	WP Basin 2021	WAAS	655,466.07	5,180,554.24	7.02	6.56	0.46
07/29/21 (DN210)	21:56	WP Basin 2021	WAAS	655,466.14	5,180,553.74	6.91	6.61	0.30
07/30/21 (DN211)	11:09	WP Basin 2021	WAAS	655,466.07	5,180,554.27	7.02	6.71	0.31
07/30/21 (DN211)	18:19	WP Basin 2021	WAAS	655,466.51	5,180,555.08	6.73	6.40	0.33
07/31/21 (DN212)	15:57	WP Basin 2021	WAAS	655,465.94	5,180,553.72	7.11	6.57	0.54
07/31/21 (DN212)	22:01	WP Basin 2021	WAAS	655,465.82	5,180,552.71	7.27	6.72	0.55
08/01/21 (DN213)	10:56	WP Basin 2021	WAAS	655,466.13	5,180,553.65	6.92	6.66	0.26
08/03/21 (DN215)	11:17	WP Basin 2021	WAAS	655,466.19	5,180,553.93	6.87	6.59	0.28
08/02/21 (DN214)	11:52	WP Basin 2021	WAAS	655,466.15	5,180,554.07	6.92	6.58	0.34
08/02/21 (DN214)	23:14	WP Basin 2021	WAAS	655,466.06	5,180,554.97	7.14	6.57	0.57
08/03/21 (DN215)	10:58	WP Basin 2021	WAAS	655,466.40	5,180,553.87	6.66	6.57	0.09
08/03/21 (DN215)	20:45	WP Basin 2021	WAAS	655,466.28	5,180,553.74	6.77	6.57	0.20
08/04/21 (DN216)	10:54	WP Basin 2021	WAAS	655,470.56	5,180,547.54	6.45	5.87	0.58
08/04/21 (DN216)	10:56	WP Basin 2021	WAAS	655,470.51	5,180,547.49	6.52	5.83	0.69
08/04/21 (DN216)	20:02	WP Basin 2021	WAAS	655,466.66	5,180,553.18	6.40	6.57	0.17

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 16N, NAD83 (meters)	Observed Northing UTM 16N, NAD83 (meters)	Calculated Distance RP to Nav. Checkpoint (meters)	Tape Measure RP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
08/05/21 (DN217)	11:25	WP Basin 2021	WAAS	655,470.38	5,180,548.30	5.84	5.18	0.66
08/05/21 (DN217)	11:27	WP Basin 2021	WAAS	655,470.38	5,180,548.30	5.84	5.22	0.62
08/07/21 (DN219)	10:30	WP Basin 2021	WAAS	655,470.14	5,180,547.62	6.55	5.83	0.72
08/07/21 (DN219)	10:33	WP Basin 2021	WAAS	655,470.16	5,180,547.98	6.22	5.83	0.39
08/09/21 (DN221)	15:21	WP Basin 2021	WAAS	655,465.80	5,180,553.62	7.25	6.57	0.68
08/10/21 (DN222)	10:45	WP Basin 2021	WAAS	655,466.35	5,180,554.28	6.75	6.57	0.18
08/11/21 (DN223)	11:01	WP Basin 2021	WAAS	655,466.13	5,180,554.06	6.94	6.79	0.15
08/12/21 (DN224)	10:56	WP Basin 2021	WAAS	655,466.20	5,180,554.20	6.89	6.76	0.13
08/13/21 (DN225)	10:22	WP Basin 2021	WAAS	655,466.06	5,180,553.44	6.99	6.65	0.34
08/14/21 (DN226)	11:19	WP Basin 2021	WAAS	655,465.78	5,180,553.40	7.27	6.67	0.60
08/15/21 (DN227)	10:59	WP Basin 2021	WAAS	655,466.02	5,180,552.87	7.06	6.70	0.36
08/16/21 (DN228)	10:30	WP Basin 2021	WAAS	655,470.40	5,180,548.27	5.86	5.02	0.84
08/17/21 (DN229)	11:38	WP Basin 2021	WAAS	655,465.72	5,180,553.47	7.33	6.65	0.68
08/18/21 (DN230)	22:52	WP Basin 2021	WAAS	655,466.00	5,180,554.05	7.07	6.57	0.50
08/19/21 (DN231)	11:23	WP Basin 2021	WAAS	655,466.17	5,180,553.97	6.90	6.61	0.29

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 16N, NAD83 (meters)	Observed Northing UTM 16N, NAD83 (meters)	Calculated Distance RP to Nav. Checkpoint (meters)	Tape Measure RP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
08/20/21 (DN232)	10:54	WP Basin 2021	WAAS	655,467.28	5,180,562.28	10.51	10.30	0.21
08/23/21 (DN235)	10:22	WP Basin 2021	WAAS	655,466.15	5,180,554.26	6.94	6.57	0.37
08/24/21 (DN236)	10:56	WP Basin 2021	WAAS	655,466.16	5,180,554.90	7.03	6.60	0.43
08/24/21 (DN236)	18:54	WP Basin 2021	WAAS	655,466.28	5,180,552.90	6.80	6.66	0.14

Table 6
***RV North Cove* Tabulation of Navigation System Confidence Checks**

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 16N, NAD83 (meters)	Observed Northing UTM 16N, NAD83 (meters)	Calculated Distance RP to Nav. Checkpoint (meters)	Tape Measure RP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
08/01/21 (DN213)	17:18	WP Basin 2021	WAAS	655,470.41	5,180,550.23	4.20	4.20	0.00
08/02/21 (DN214)	11:19	WP Basin 2021	WAAS	655,470.55	5,180,549.55	4.67	4.75	0.08
08/03/21 (DN215)	11:06	WP Basin 2021	WAAS	655,470.63	5,180,551.11	3.40	3.36	0.04
08/04/21 (DN216)	11:11	WP Basin 2021	WAAS	655,470.45	5,180,549.16	5.05	4.67	0.38
08/05/21 (DN217)	12:20	WP Basin 2021	WAAS	655,470.67	5,180,551.62	3.03	3.10	0.07
08/07/21 (DN219)	10:45	WP Basin 2021	WAAS	655,470.26	5,180,550.83	3.86	3.90	0.04
08/09/21 (DN221)	13:23	WP Basin 2021	WAAS	655,468.12	5,180,552.29	5.07	4.80	0.27

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 16N, NAD83 (meters)	Observed Northing UTM 16N, NAD83 (meters)	Calculated Distance RP to Nav. Checkpoint (meters)	Tape Measure RP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
08/10/21 (DN222)	10:40	WP Basin 2021	WAAS	655,469.31	5,180,551.16	4.41	4.20	0.21
08/11/21 (DN223)	11:19	WP Basin 2021	WAAS	655,470.26	5,180,554.26	2.89	2.37	0.52
08/12/21 (DN224)	10:39	WP Basin 2021	WAAS	655,470.65	5,180,551.60	3.06	3.35	0.29
08/13/21 (DN225)	10:12	WP Basin 2021	WAAS	655,470.36	5,180,550.22	4.24	4.30	0.06
08/14/21 (DN226)	11:10	WP Basin 2021	WAAS	655,470.51	5,180,549.69	4.57	4.69	0.12
08/15/21 (DN227)	11:34	WP Basin 2021	WAAS	655,470.57	5,180,549.81	4.44	4.48	0.04
08/16/21 (DN228)	10:51	WP Basin 2021	WAAS	655,470.52	5,180,549.75	4.52	4.60	0.08
08/17/21 (DN229)	11:00	WP Basin 2021	WAAS	655,470.52	5,180,549.31	4.89	5.0	0.11
08/18/21 (DN230)	10:28	WP Basin 2021	WAAS	655,470.77	5,180,548.67	5.33	4.80	0.53
08/19/21 (DN231)	10:39	WP Basin 2021	WAAS	655,470.37	5,180,549.18	5.08	4.80	0.28
08/20/21 (DN232)	10:52	WP Basin 2021	WAAS	655,470.43	5,180,549.20	5.03	4.76	0.27
08/23/21 (DN235)	10:08	WP Basin 2021	WAAS	655,470.63	5,180,549.78	4.43	4.30	0.13
08/24/21 (DN236)	10:27	WP Basin 2021	WAAS	655,469.39	5,180,550.09	5.00	4.55	0.45
08/24/21 (DN236)	21:00	WP Basin 2021	WAAS	655,470.60	5,180,549.16	4.98	4.68	0.30

Table 7
***MV Northstar Challenger* Tabulation of Navigation System Confidence Checks**

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 16N, NAD83 (meters)	Observed Northing UTM 16N, NAD83 (meters)	Calculated Distance TP to Nav. Checkpoint (meters)	Tape Measure TP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
07/23/21 (DN204)	10:39	MCM 2021	WAAS	705,649.93	5,152,352.00	23.18	23.5	0.32
08/11/21 (DN223)	18:01	MCM 2021	WAAS	705,649.27	5,152,350.11	21.38	21.7	0.32
08/22/21 (DN234)	11:00	MCM 2021	WAAS	705,648.15	5,152,346.68	18.30	18.8	0.50

D. APPROVAL SHEET

This report and the accompanying data are respectfully submitted.

Field operations contributing to the accomplishment of Surveys H13522, H13523, H13524, and H13525 were conducted under my direct supervision with frequent personal checks of progress and adequacy. This report and associated data have been closely reviewed and are considered complete and adequate as per the Statement of Work.

Approver Name	Approver Title	Approval Date	Signature
John R. Bean	Chief of Party	12/16/2021	John R. Bean 2021.12.16 14:37:37 -05'00'
David T. Somers	Data Processing Manager	12/16/2021	David T. Somers 2021.12.16 14:38:09 -05'00'