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MARYLAND GEOLOGICAL SURVEY
Richard A. Ortt, Jr., Director

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LAND SUBSIDENCE MONITORING TO ASSESS POTENTIAL EFFECTS OF GROUNDWATER WITHDRAWALS FROM COASTAL PLAIN AQUIFERS IN MARYLAND:

FALL, 2017 SURVEY

by

David C. Andreasen

Prepared in cooperation with
Anne Arundel County Department of Public Works
and
Dominion Cove Point LNG, LP

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KEY RESULTS

A GPS campaign was conducted October 16-20, 2017 to determine the heights of seven 3d marks to assess the potential effects of groundwater withdrawals from Maryland's coastal plain aquifers. The marks are located at major well fields in Anne Arundel County, Maryland, at Arnold (mark ARNO-1), Broad Creek (mark BROA-1), and Crofton Meadows (mark CROF-1), and at or near major well fields in southern Maryland at Cove Point (mark COV-1), Lexington Park (mark LEX-1), and Waldorf (mark WAL-1). One mark at Rosaryville State Park (mark ROS-1) in southern Maryland is located in an area of relatively low groundwater use. The GPS data were processed using the National Geodetic Survey's Online Positioning User Service (OPUS) Projects utility. The ellipsoid heights determined through OPUS Projects were 3.644 meters at ARNO-1, -6.182 meters at BROA-1, 7.085 meters at CROF-1, -1.508 meters at COV-1, -2.088 meters at LEX-1, 33.834 meters at ROS-1, and 28.797 meters at WAL-1. Height uncertainty for the measurements as reported by OPUS Projects is approximately +/- 0.1 centimeter for all marks with the exception of WAL-1 which had a reported uncertainty of +/- 0.2 centimeters. The greater uncertainty for that mark is possibly attributed to a shorter occupation time. Ellipsoid heights at ARNO-1, BROA-1 and CROF-1 show a slight decline over the period of record, however, the error associated with the heights (reported at +/- 0.1 cm by OPUS Projects for the 2017 values) and fairly significant scatter in the data makes identifying a clear trend difficult. No trends are discernable for the marks in southern Maryland since GPS readings only started in 2016.

INTRODUCTION

Decades of groundwater withdrawals from unconsolidated, confined (artesian) coastal plain aquifers in Anne Arundel County, Maryland have resulted in significant drawdown of groundwater levels. Water levels have declined in some aquifers by as much as 130 ft from pre-pumping (Andreasen, 2007; Staley and others, 2016). Projected increases in withdrawals to supply a growing population will result in additional drawdown (Andreasen, 2007). Withdrawing water from a confined aquifer reduces the hydrostatic pressure head in the pumped aquifer and in the adjacent confining layers (clay and silt). Reduction of hydrostatic pressure in the aquifer system resulting from the drawdown increases the load on the sediment which may lead to compaction and land subsidence. In the mid-Atlantic region, land subsidence ranging from 1.5 to 3.7 millimeters per year has occurred in the Franklin and Suffolk area of Virginia (lower Chesapeake Bay region) and is attributed to groundwater withdrawals from the Potomac Group aquifer system in Virginia (Patapsco and Patuxent aquifer systems in Maryland) (Davis, 1987; Eggleston and Pope, 2013). While not likely to cause major engineering problems land subsidence related to groundwater withdrawals could exacerbate the problem of tidal flooding in low-lying areas caused by future sea-level rise. Permanent reduction in reservoir capacity by irreversible compaction of sediments may also occur.

HISTORICAL GPS DATA

Starting in 1994, GPS elevation measurements at 3d marks at Arnold, Broad Creek, and Crofton Meadows well fields have been made at approximately yearly intervals (fig. 1). GPS measurements from 1994 to 2015 were made by the Maryland State Highway Administration (Division of Plats and Surveys). Starting in 1995, three GPS occupations were made for each yearly observation period with each occupation lasting at least 5.5 hours. The 1994 survey used fewer and shorter sessions. Starting in 1998 all measurements were made using a dual frequency (L1/L2) GPS receiver.

The earlier GPS data were originally processed by Donald M. Mulcare (State Advisor to Maryland, National Geodetic Survey) and later by the Maryland State Highway Administration (Division of Plats and Surveys). In 2016, the Maryland Geological Survey took over the function of both collecting and processing the GPS data. To maintain consistency in data processing and to take advantage of the most current National Geodetic Survey (NGS) Continuously Operating Reference Stations (CORS) information, the historical record was re-processed for the years with available raw GPS data. Raw GPS data available for re-processing began in 1999.

GPS SURVEY

A GPS occupation of the Arnold (ARNO-1), Broad Creek (BROA-1), and Crofton Meadows (CROF-1) 3d survey marks, along with the four marks in southern Maryland (COV-1, LEX-1, ROS-1, and WAL-1), was conducted October 16-20, 2017 (tab. 1). Occupations at ARNO-1, BROA-1, CROF-1, and LEX-1 ended October 19, 2017 after about 71 hours of observations. A battery malfunction at WAL-1 terminated that occupation after 29 hours. COV-1 and ROS-1 were occupied for 95 and 98 hours, respectively. The survey of ARNO-1, BROA-1, and CRFO-1, LEX-1 and WAL-1 marks was performed by staff of the NGS using dual frequency (L1/L2) GPS receivers (CHC X90D-OPUS) oriented north. The survey of COV-1 and ROS-1 marks was performed by staff of the Maryland Geological Survey also using dual frequency (L1/L2) GPS receivers (CHC X90D-OPUS) oriented north. All receivers were attached to fixed-height range poles with level vials. GPS readings were recorded at a 15 -second sampling rate. Weather conditions were clear to cloudy with fair to good visibility, moderate winds, and temperatures averaging about 70 degrees Fahrenheit. A small amount of rainfall occurred on the first day of measurements.

The data were processed using the NGS's OPUS Projects online utility to determine ellipsoid heights of the 3d marks. Ellipsoid heights were used as opposed to orthometric heights to avoid potential loss of accuracy associated with geoid models. OPUS Projects provides geodetic network solutions by baseline processing of simultaneous GPS observations. A detailed technical discussion of the concepts and processing used in OPUS Projects is provided in Armstrong (2015). The occupation period was divided into three sessions (tab. 1). Data-processing parameters specified in OPUS Projects used in this study included a piecewise linear tropospheric model with an interval of 7,200 seconds, an elevation cutoff of 15.0 degrees and normal constraint weights. CORS stations used to process session network baselines and in network adjustment are shown in Table 2. Ellipsoid heights determined by OPUS Projects network adjustment are given in Table 3.

CHANGE IN ELLIPSOID HEIGHT OVER TIME

The change in ellipsoid heights relative to the 1999 measurement at the 3d marks at Arnold, Broad Creek, and Crofton Meadows well fields is shown in Figure 2. Over the 18-year period, ellipsoid height varied by about 0.048 m at ARNO-1, 0.037 m at BROA-1, and 0.046 m at CROF-1. Of the two years of record at COV-1, LEX-1, ROS-1, and WAL-1 ellipsoid heights varied less than 0.015 m. Ellipsoid heights at ARNO-1, BROA-1 and CROF-1 show a slight decline over the period of record, however, given the error associated with the heights (reported at +/- 0.1 cm by OPUS Projects for the 2017 values) and fairly significant scatter in the data, identifying a clear trend is difficult (figs. 2 and 3). No trends are discernable at the southern Maryland marks since GPS reading only started in 2016.

ACKNOWLEDGEMENTS

Funding support for this project was provided by Anne Arundel County Department of Public Works and Dominion Cove Point LNG, LP. Special thanks is extended to Edward Cope of Anne Arundel County Department of Public Works, Gary Reynolds of St. Mary's Metropolitan Commission, and Sam Seymonovsky of Charles County Department of Public Works. Philippe Hensel of the National Geodetic Survey assisted in GPS measurements.

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Armstrong, M.L., 2015, OPUS Projects, Online positioning user service baseline processing and adjustment software, User instructions and technical guide (ver. 2.5): National Geodetic Survey, NOAA, Silver Spring, Maryland, 116 p. [http://www.ngs.noaa.gov/OPUS-Projects/OpusProjects.shtml, accessed 7/20/2016]

Davis, G.H., 1987, Land subsidence and sea level rise on the Atlantic Coastal Plain of the United States: Environ. Geol. Water Science, vol. 10, no.2, p. 67-80.

Eggleston, Jack and Pope, Jason, 2013, Land subsidence and relative sea-level rise in the southern Chesapeake Bay region: U.S. Geological Survey Circular 1392, 30 p.

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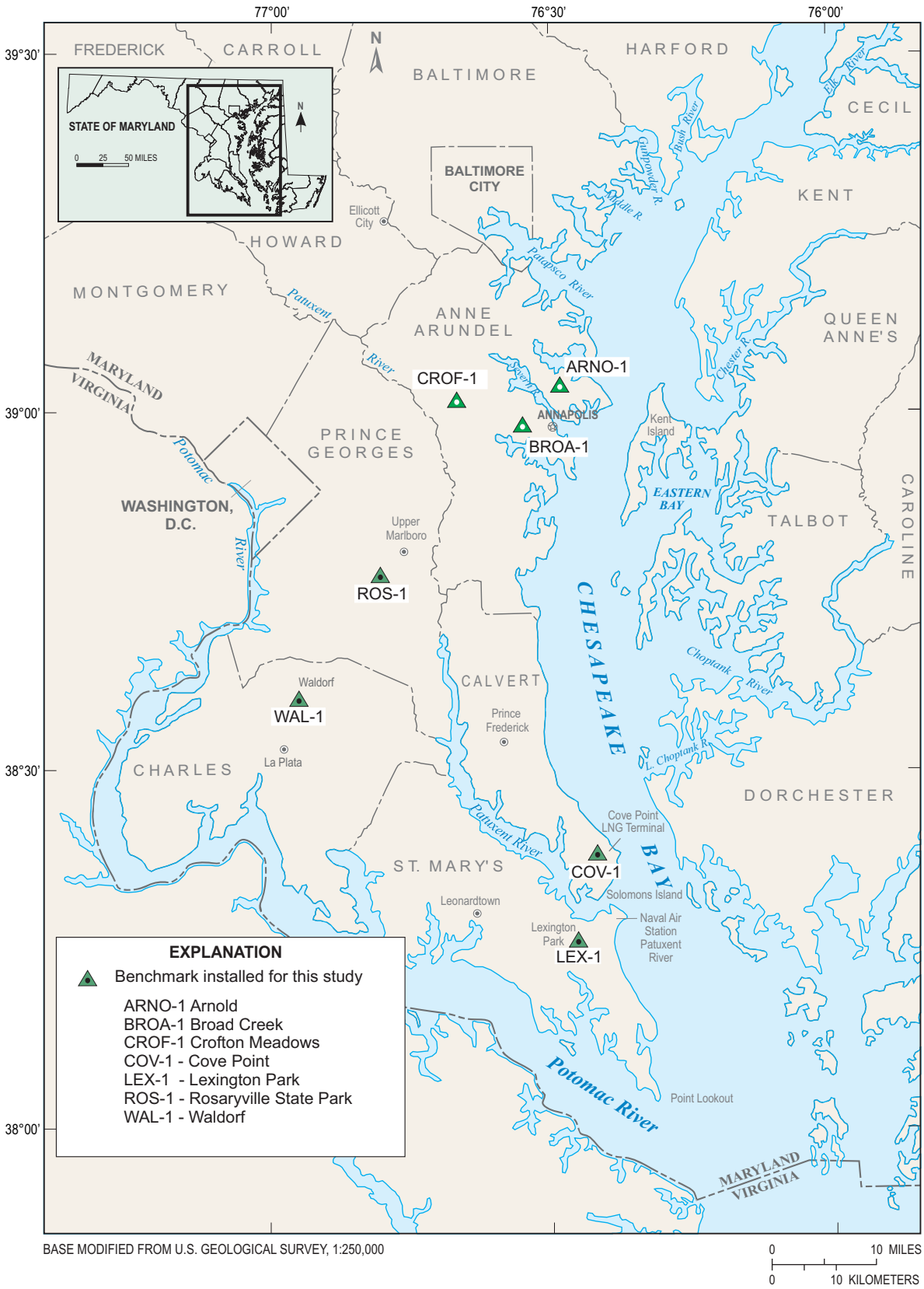

Figure 1. Location of GPS survey marks.

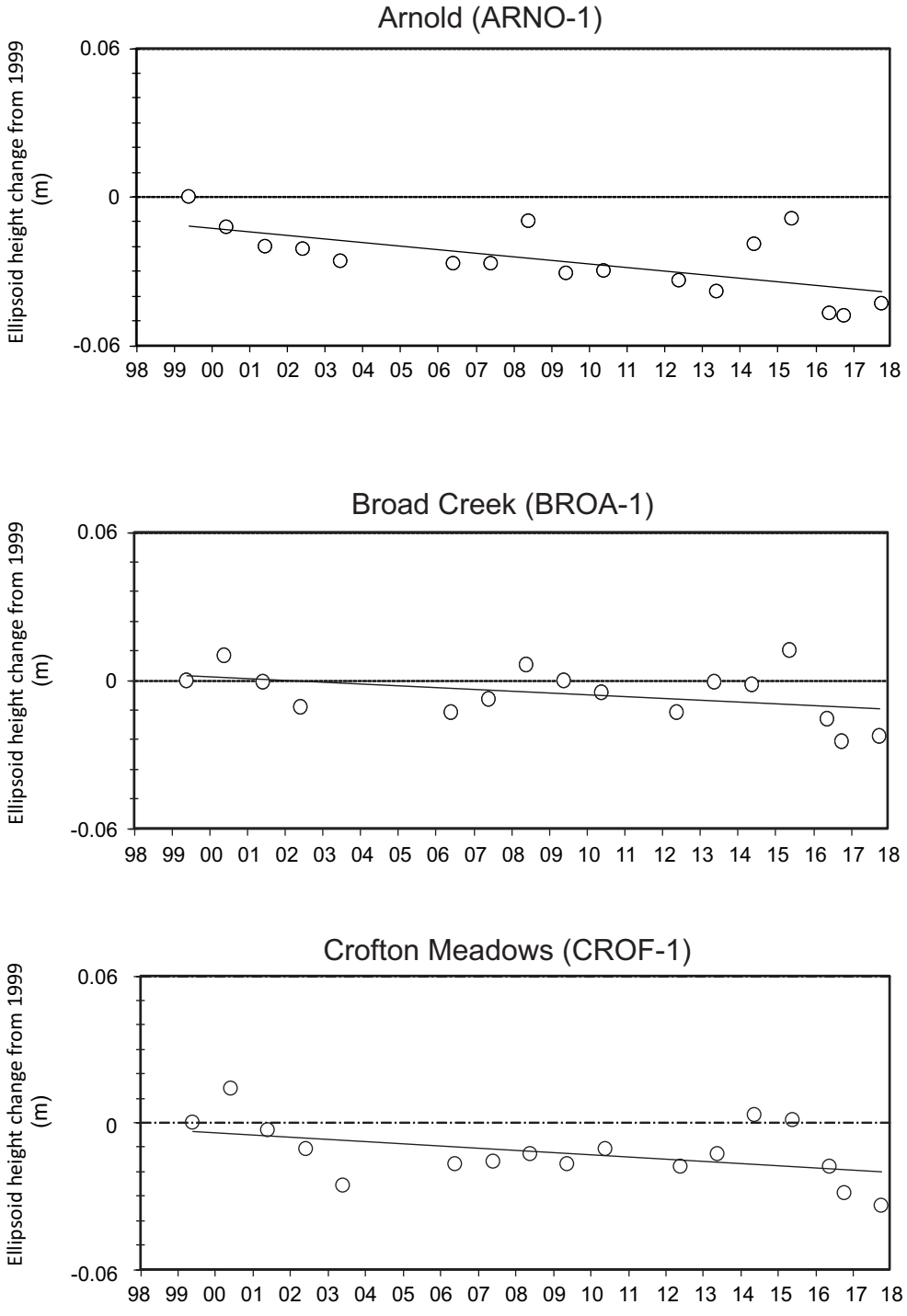

Figure 2. Change in ellipsoid height from 1999 at ARNO-1, BROA-1, and CROF-1.

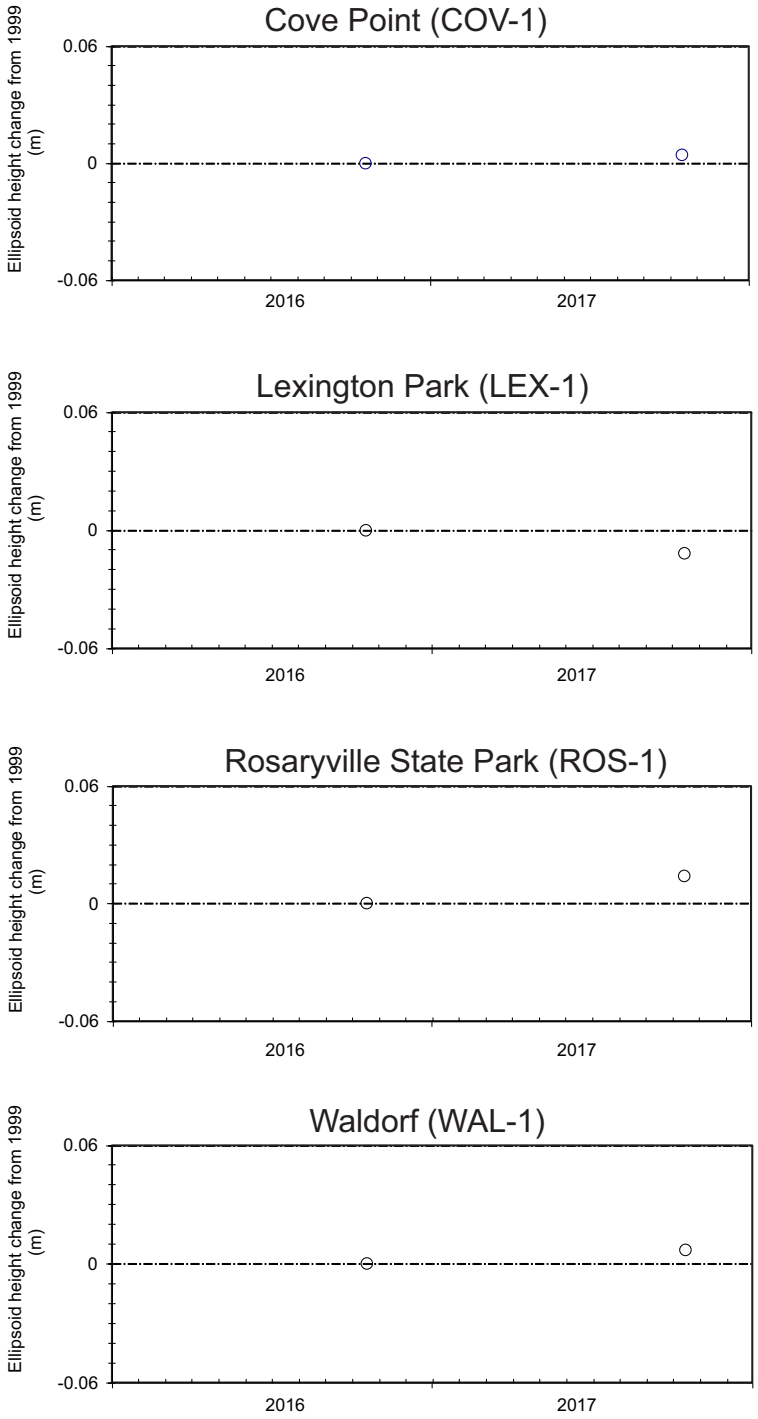

Figure 3. Change in ellipsoid height from 2016 at marks COV-1, LEX-1, ROS-1 and WAL-1.

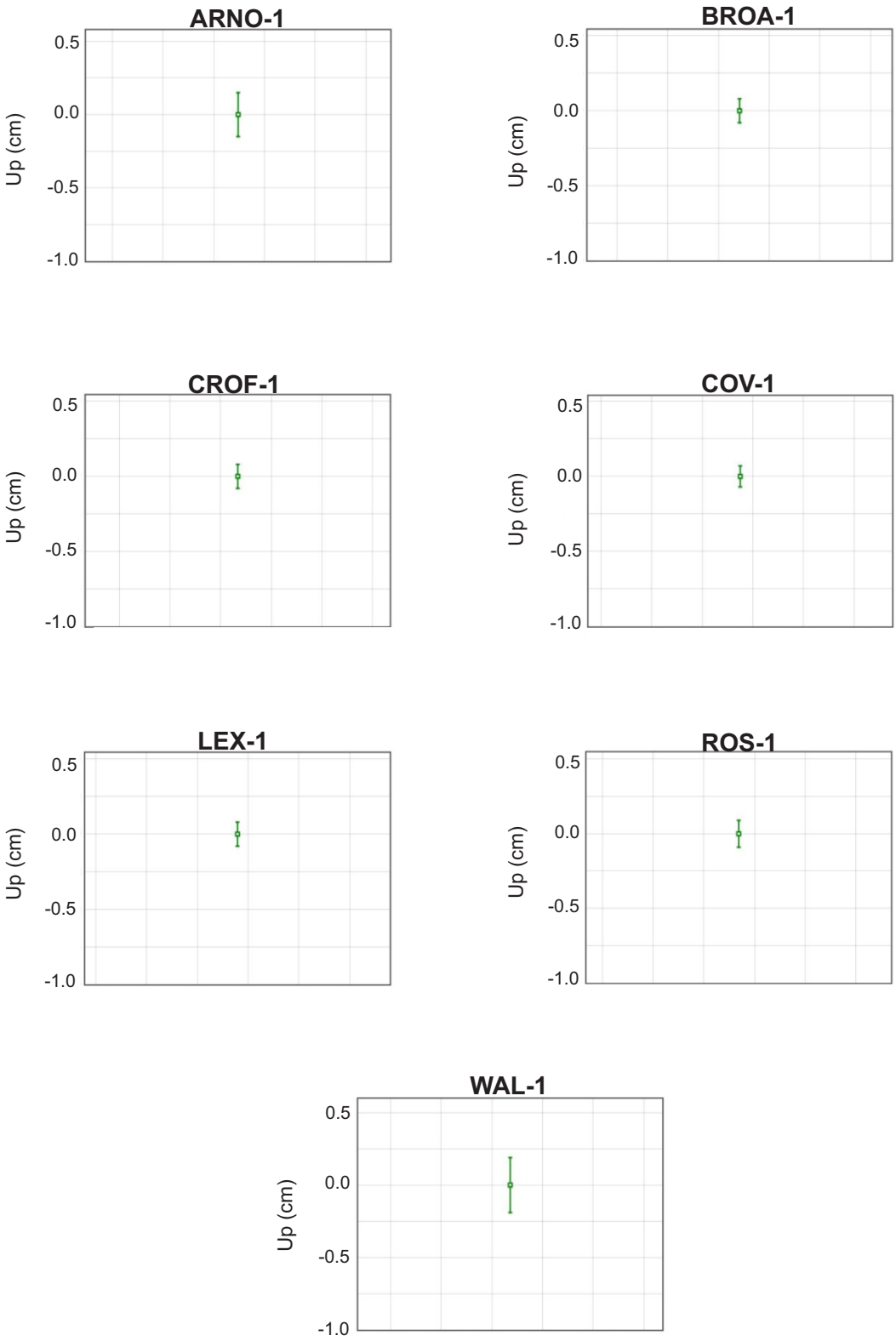

Figure 4. Height uncertainties.

Table 1. GPS sessions processed by OPUS-Projects

Session	Period (Coordinated Universal Time)
1 (Day 289-290)	10/16/17 14:10:10 to 10/17/17 23:59:45
2 (Day 291)	10/18/17 00:00:00 to 10/18/17 23:59:45
3 (Day 292-293)	10/19/17 00:00:00 to 10/20/17 15:50:00

Table 2. CORS sites used in processing GPS data.

CORS site	Start of record	State	Use in OPUS Projects	
GODE	1997 (99)	MD	Hub	Unconstrained
KYTG	2008 (31)	KY	Troposphere correction	Unconstrained
BACO	2007 (323)	MD		Constrained
HNPT	1999 (318)	MD		Constrained
LOYF	2009 (29)	MD		Constrained
LOYK	2009 (185)	MD		Constrained
LOYO	2009 (86)	MD		Constrained
UMBC	2009 (9)	MD		Constrained

Table 3. Summary of 2017 (Fall) GPS survey.

Mark	Horizontal (IGS08)		Vertical (IGS08)
	Latitude	Longitude	Ellipsoidal height (m)
ARNO-1	N39 02 05.55555	W076 29 25.28127	3.644
BROA-1	N38 58 54.34550	W076 33 31.12543	-6.182
CROF-1	N39 01 01.59405	W076 40 28.51455	7.085
COV-1	N38 23 11.19135	W76 25 22.10179	-1.508
LEX-1	N38 15 47.68737	W76 27 20.53777	-2.088
ROS-1	N38 46 27.64238	W76 49 11.98783	33.834
WAL-1	N38 35 56.66729	W76 56 23.51412	28.797

Appendix A. OPUS Projects network adjustment for the Fall, 2017 GPS survey.

NGS OPUS-PROJECTS NETWORK ADJUSTMENT REPORT
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All coordinate accuracies reported here are 1 times the formal uncertainties from the solution. For additional information: geodesy.noaa.gov/OPUS/Using_OPUS-Projects.html#accuracy

These positions were computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

SUBMITTED BY:	david.andreasen
SOLUTION FILE NAME:	network-final.sum
SOLUTION SOFTWARE:	GPSCOM(1504.22)
SOLUTION DATE:	2018-03-14T13:49:59 UTC
STANDARD ERROR OF UNIT WEIGHT:	0.746
TOTAL NUMBER OF OBSERVATIONS:	554273
TOTAL NUMBER OF MARKS:	15
NUMBER OF CONSTRAINED MARKS:	6
START TIME:	2017-10-16T00:15:00 GPS
STOP TIME:	2017-10-19T23:59:30 GPS
FREQUENCY:	L1 -> ION-FREE (L6)
OBSERVATION INTERVAL:	30 s
ELEVATION CUTOFF:	15 deg
TROPO INTERVAL:	7200 s [PIECE-WISE LINEAR PARAMETERIZATION]
DD CORRELATIONS:	ON

INCLUDED SOLUTION	RMS	SOFTWARE	RUN DATE
1) 2017-289 A	1.2 cm	page5(1603.24)	2018-03-13T16:22 UTC
2) 2017-291 A	1.2 cm	page5(1603.24)	2018-03-14T13:41 UTC
3) 2017-292 C	1.2 cm	page5(1603.24)	2018-03-14T13:30 UTC

BASELINE	LENGTH	RMS	OBS	OMITTED	FIXED	IN SOLUTION(S)
loyk-gode	12.538 km	1.1 cm	49442	1.0%	99.8%	1, 2, 3
crof-gode	13.195 km	1.2 cm	31951	6.1%	100.0%	1, 2, 3
broa-gode	23.651 km	1.3 cm	33961	2.6%	99.4%	1, 2, 3
loyf-gode	26.907 km	1.1 cm	49861	0.4%	99.6%	1, 2, 3
ros1-gode	27.469 km	1.6 cm	33506	13.4%	97.4%	1, 2, 3
umbc-gode	27.934 km	1.1 cm	49966	0.2%	99.8%	1, 2, 3
gode-arno	29.173 km	1.2 cm	34386	1.7%	100.0%	1, 2, 3
baco-gode	46.042 km	1.0 cm	49675	0.6%	99.8%	1, 2, 3
wal1-gode	47.936 km	1.5 cm	4804	9.2%	100.0%	1
hnpt-gode	77.261 km	1.0 cm	48996	0.9%	99.4%	1, 2, 3
cov1-gode	78.794 km	1.2 cm	40924	2.9%	99.5%	1, 2, 3
lex1-gode	90.184 km	1.5 cm	31501	10.8%	95.7%	1, 2, 3
loyo-gode	117.013 km	1.2 cm	49425	0.8%	99.2%	1, 2, 3
kytg-gode	675.912 km	1.3 cm	45875	1.1%	97.7%	1, 2, 3

Appendix A. Continued.

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UNCONSTRAINED MARKS
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MARK:      arno (arno    1)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2017.7961)
X:                 1158910.190 m    0.000 m          1158909.319 m    0.000 m
Y:                -4823629.212 m    0.001 m         -4823627.765 m    0.001 m
Z:                 3995327.627 m    0.001 m          3995327.569 m    0.001 m
LAT:            39 02 05.52412      0.000 m       39 02 05.55555      0.000 m
E LON:         283 30 34.73990      0.000 m      283 30 34.71873      0.000 m
W LON:          76 29 25.26010      0.000 m       76 29 25.28127      0.000 m
EL HGT:                  4.935 m    0.001 m                3.647 m    0.001 m
ORTHO HGT:              38.184 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4321702.609 m         152000.077 m
EASTING (X)        371008.300 m         444125.195 m
CONVERGENCE       -0.93874163 deg       0.31987372 deg
POINT SCALE        0.99980488           0.99995369
COMBINED FACTOR    0.99980411           0.99995292

US NATIONAL GRID DESIGNATOR: 18SUJ7100821702 (NAD 83)

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MARK:      broa (broa    1)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2017.7961)
X:                 1154021.101 m    0.000 m          1154020.229 m    0.000 m
Y:                -4828609.419 m    0.001 m         -4828607.971 m    0.001 m
Z:                 3990739.560 m    0.001 m          3990739.501 m    0.001 m
LAT:            38 58 54.31412      0.000 m       38 58 54.34550      0.000 m
E LON:         283 26 28.89581      0.000 m      283 26 28.87457      0.000 m
W LON:          76 33 31.10419      0.000 m       76 33 31.12543      0.000 m
EL HGT:                 -4.892 m    0.001 m               -6.182 m    0.001 m
ORTHO HGT:              28.275 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4315907.111 m         146073.156 m
EASTING (X)        364996.456 m         438241.241 m
CONVERGENCE       -0.98064614 deg       0.27701257 deg
POINT SCALE        0.99982443           0.99995155
COMBINED FACTOR    0.99982520           0.99995232

US NATIONAL GRID DESIGNATOR: 18SUJ6499615907 (NAD 83)
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Appendix A. Continued.

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 MARK:      cov1 (cov1    1)

 REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2017.7967)
 X:                 1175163.281 m    0.000 m          1175162.413 m    0.000 m
 Y:                -4866014.499 m    0.001 m         -4866013.042 m    0.001 m
 Z:                 3939155.593 m    0.001 m          3939155.531 m    0.001 m
 LAT:           38 23 11.16031      0.000 m       38 23 11.19135      0.000 m
 E LON:        283 34 37.91887      0.000 m      283 34 37.89821      0.000 m
 W LON:         76 25 22.08113      0.000 m       76 25 22.10179      0.000 m
 EL HGT:               -0.200 m    0.001 m               -1.508 m    0.001 m
 ORTHO HGT:             34.192 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                 UTM COORDINATES    STATE PLANE COORDINATES
                  UTM (Zone 18)         SPC (1900 MD)
 NORTHING (Y)      4249650.205 m          80056.579 m
 EASTING (X)        375737.328 m         450428.647 m
 CONVERGENCE       -0.88361819 deg       0.36227023 deg
 POINT SCALE        0.99979016           0.99998609
 COMBINED FACTOR    0.99979019           0.99998612

 US NATIONAL GRID DESIGNATOR: 18SUH7573749650 (NAD 83)

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 MARK:      crof (crof    1)

 REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2017.7960)
 X:                 1143680.983 m    0.000 m          1143680.112 m    0.000 m
 Y:                -4828541.827 m    0.001 m         -4828540.380 m    0.001 m
 Z:                 3993797.488 m    0.001 m          3993797.430 m    0.001 m
 LAT:           39 01 01.56268      0.000 m       39 01 01.59405      0.000 m
 E LON:        283 19 31.50683      0.000 m      283 19 31.48545      0.000 m
 W LON:         76 40 28.49317      0.000 m       76 40 28.51455      0.000 m
 EL HGT:                8.372 m    0.001 m                7.085 m    0.001 m
 ORTHO HGT:             41.182 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                 UTM COORDINATES    STATE PLANE COORDINATES
                  UTM (Zone 18)         SPC (1900 MD)
 NORTHING (Y)      4320008.242 m          149954.798 m
 EASTING (X)        355025.641 m          428181.665 m
 CONVERGENCE       -1.05442007 deg        0.20424380 deg
 POINT SCALE        0.99985880           0.99995288
 COMBINED FACTOR    0.99985749           0.99995157

 US NATIONAL GRID DESIGNATOR: 18SUJ5502520008 (NAD 83)
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Appendix A. Continued.

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MARK: gode (gode a 2)

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2017.7959)	
X:	1130774.435 m	0.000 m	1130773.562 m	0.000 m
Y:	-4831255.028 m	0.001 m	-4831253.574 m	0.001 m
Z:	3994200.522 m	0.001 m	3994200.458 m	0.001 m
LAT:	39 01 18.18968	0.000 m	39 01 18.22104	0.000 m
E LON:	283 10 23.42554	0.000 m	283 10 23.40399	0.000 m
W LON:	76 49 36.57446	0.000 m	76 49 36.59601	0.000 m
EL HGT:	15.789 m	0.001 m	14.494 m	0.001 m
ORTHO HGT:	48.169 m	0.016 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES UTM (Zone 18)	STATE PLANE COORDINATES SPC (1900 MD)
NORTHING (Y)	4320774.469 m	150431.507 m
EASTING (X)	341854.673 m	414996.120 m
CONVERGENCE	-1.15043527 deg	0.10868976 deg
POINT SCALE	0.99990796	0.99995308
COMBINED FACTOR	0.99990548	0.99995060

US NATIONAL GRID DESIGNATOR: 18SUJ4185420774 (NAD 83)

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MARK: kytg (kytg a 1)

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2017.7956)	
X:	482543.243 m	0.000 m	482542.384 m	0.000 m
Y:	-5004259.953 m	0.001 m	-5004258.524 m	0.001 m
Z:	3912211.810 m	0.001 m	3912211.709 m	0.001 m
LAT:	38 04 31.96486	0.000 m	38 04 31.99240	0.000 m
E LON:	275 30 28.08945	0.000 m	275 30 28.06000	0.000 m
W LON:	84 29 31.91055	0.000 m	84 29 31.94000	0.000 m
EL HGT:	265.096 m	0.001 m	263.849 m	0.001 m
ORTHO HGT:	298.412 m	0.013 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES UTM (Zone 16)	STATE PLANE COORDINATES SPC (1600 KY1Z)
NORTHING (Y)	4217166.878 m	1194099.192 m
EASTING (X)	719969.285 m	1610349.304 m
CONVERGENCE	1.54718165 deg	0.77224138 deg
POINT SCALE	1.00019597	0.99991096
COMBINED FACTOR	1.00015437	0.99986937

US NATIONAL GRID DESIGNATOR: 16SGH1996917166 (NAD 83)

Appendix A. Continued.

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MARK:      lex1 (lex1    1)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2017.7963)
X:                 1174354.971 m    0.000 m          1174354.103 m    0.000 m
Y:                -4874932.332 m    0.001 m         -4874930.875 m    0.001 m
Z:                 3928427.075 m    0.001 m          3928427.012 m    0.001 m
LAT:           38 15 47.65644      0.000 m       38 15 47.68737      0.000 m
E LON:        283 32 39.48289      0.000 m      283 32 39.46223      0.000 m
W LON:         76 27 20.51711      0.000 m       76 27 20.53777      0.000 m
EL HGT:               -0.777 m    0.001 m              -2.088 m    0.001 m
ORTHO HGT:            33.730 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4236024.449 m          66364.195 m
EASTING (X)        372648.477 m         447635.916 m
CONVERGENCE       -0.90159976 deg       0.34162176 deg
POINT SCALE        0.99979974           1.00000660
COMBINED FACTOR    0.99979986           1.00000672

US NATIONAL GRID DESIGNATOR: 18SUH7264836024 (NAD 83)

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MARK:      ros1 (ros1    1)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2017.7967)
X:                 1135286.289 m    0.000 m          1135285.419 m    0.000 m
Y:                -4847925.461 m    0.001 m         -4847924.011 m    0.001 m
Z:                 3972839.227 m    0.001 m          3972839.166 m    0.001 m
LAT:           38 46 27.61121      0.000 m       38 46 27.64238      0.000 m
E LON:        283 10 48.03355      0.000 m      283 10 48.01217      0.000 m
W LON:         76 49 11.96645      0.000 m       76 49 11.98783      0.000 m
EL HGT:               35.128 m    0.001 m              33.834 m    0.001 m
ORTHO HGT:            67.903 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4293307.782 m         122971.208 m
EASTING (X)        341898.650 m         415642.201 m
CONVERGENCE       -1.14001358 deg       0.11297999 deg
POINT SCALE        0.99990781           0.99995141
COMBINED FACTOR    0.99990230           0.99994590

US NATIONAL GRID DESIGNATOR: 18SUH4189893307 (NAD 83)
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Appendix A. Continued.

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 MARK:      wal1 (wal1    1)

 REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2017.7929)
 X:                 1127888.814 m    0.001 m          1127887.945 m    0.001 m
 Y:                -4862133.281 m    0.002 m         -4862131.829 m    0.002 m
 Z:                 3957648.565 m    0.001 m          3957648.502 m    0.001 m
 LAT:           38 35 56.63628      0.000 m       38 35 56.66729      0.000 m
 E LON:        283 03 36.50730      0.000 m      283 03 36.48588      0.000 m
 W LON:         76 56 23.49270      0.000 m       76 56 23.51412      0.000 m
 EL HGT:              30.096 m    0.002 m              28.797 m    0.002 m
 ORTHO HGT:           63.032 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                 UTM COORDINATES    STATE PLANE COORDINATES
                  UTM (Zone 18)         SPC (1900 MD)
 NORTHING (Y)      4274070.433 m         103501.647 m
 EASTING (X)        331073.122 m         405238.863 m
 CONVERGENCE       -1.21049977 deg       0.03774649 deg
 POINT SCALE        0.99995142           0.99996145
 COMBINED FACTOR    0.99994670           0.99995673

 US NATIONAL GRID DESIGNATOR: 18SUH3107374070 (NAD 83)


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CONSTRAINED MARKS
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 MARK:      baco (baco a  2)
 CONSTRAIN: 3-D NORMAL
 ADJUST  X:    0.007m (0.000m)   Y:   -0.009m (0.001m)   Z:    0.015m (0.001m)
 ADJUST  N:    0.005m (0.000m)   E:    0.005m (0.000m)   H:    0.017m (0.001m)

 REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2017.7956)
 X:                 1143199.194 m    0.000 m          1143198.317 m    0.000 m
 Y:                -4801171.618 m    0.001 m         -4801170.162 m    0.001 m
 Z:                 4026765.156 m    0.001 m          4026765.079 m    0.001 m
 LAT:           39 23 58.03765      0.000 m       39 23 58.06903      0.000 m
 E LON:        283 23 35.55711      0.000 m      283 23 35.53555      0.000 m
 W LON:         76 36 24.44289      0.000 m       76 36 24.46445      0.000 m
 EL HGT:             128.325 m    0.001 m             127.025 m    0.001 m
 ORTHO HGT:          160.888 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                 UTM COORDINATES    STATE PLANE COORDINATES
                  UTM (Zone 18)         SPC (1900 MD)
 NORTHING (Y)      4362337.565 m         192424.927 m
 EASTING (X)        361647.410 m         433869.650 m
 CONVERGENCE       -1.02002823 deg       0.24679221 deg
 POINT SCALE        0.99983568           0.99999155
 COMBINED FACTOR    0.99981555           0.99997142

 US NATIONAL GRID DESIGNATOR: 18SUJ6164762337 (NAD 83)
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Appendix A. Continued.

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MARK:      hnpt (hnpt a  4)
CONSTRAIN: 3-D NORMAL
ADJUST  X:   -0.002m (0.000m)   Y:   -0.005m (0.001m)   Z:    0.004m (0.001m)
ADJUST  N:    0.001m (0.000m)   E:   -0.003m (0.000m)   H:    0.006m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2017.7957)
X:                 1196627.024 m    0.000 m          1196626.155 m    0.000 m
Y:                -4846359.963 m    0.001 m         -4846358.492 m    0.001 m
Z:                 3956723.211 m    0.001 m          3956723.140 m    0.001 m
LAT:            38 35 19.71004      0.000 m       38 35 19.74134      0.000 m
E LON:         283 52 10.66797      0.000 m      283 52 10.64769      0.000 m
W LON:          76 07 49.33203      0.000 m       76 07 49.35231      0.000 m
EL HGT:                -26.669 m    0.001 m              -27.991 m    0.001 m
ORTHO HGT:               8.227 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                 UTM COORDINATES    STATE PLANE COORDINATES
                  UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)       4271753.563 m         102722.194 m
EASTING (X)         401553.850 m         475762.992 m
CONVERGENCE        -0.70509880 deg       0.54580947 deg
POINT SCALE         0.99971935           0.99996232
COMBINED FACTOR     0.99972353           0.99996650

US NATIONAL GRID DESIGNATOR: 18SVH0155371753 (NAD 83)

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MARK:      loyf (loyf a  1)
CONSTRAIN: 3-D NORMAL
ADJUST  X:    0.000m (0.000m)   Y:    0.006m (0.001m)   Z:   -0.004m (0.000m)
ADJUST  N:    0.001m (0.000m)   E:    0.001m (0.000m)   H:   -0.007m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2017.7956)
X:                 1157209.565 m    0.000 m          1157208.693 m    0.000 m
Y:                -4828361.996 m    0.001 m         -4828360.547 m    0.001 m
Z:                 3990104.473 m    0.000 m          3990104.415 m    0.000 m
LAT:            38 58 28.07415      0.000 m       38 58 28.10558      0.000 m
E LON:         283 28 40.11500      0.000 m      283 28 40.09379      0.000 m
W LON:          76 31 19.88500      0.000 m       76 31 19.90621      0.000 m
EL HGT:                -14.504 m    0.001 m              -15.794 m    0.001 m
ORTHO HGT:              18.758 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                 UTM COORDINATES    STATE PLANE COORDINATES
                  UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)       4315044.787 m         145279.930 m
EASTING (X)         368140.236 m         441403.607 m
CONVERGENCE        -0.95755590 deg       0.29988969 deg
POINT SCALE         0.99981410           0.99995133
COMBINED FACTOR     0.99981638           0.99995361

US NATIONAL GRID DESIGNATOR: 18SUJ6814015044 (NAD 83)
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Appendix A. Continued.

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MARK:      loyk (loyk a  1)
CONSTRAIN: 3-D NORMAL
ADJUST  X:    0.008m (0.000m)   Y:   -0.003m (0.001m)   Z:    0.001m (0.000m)
ADJUST  N:   -0.002m (0.000m)   E:    0.007m (0.000m)   H:    0.004m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                IGS08 (2017.7956)
X:                 1132081.316 m    0.000 m          1132080.443 m    0.000 m
Y:                -4823104.342 m    0.001 m         -4823102.896 m    0.001 m
Z:                 4003637.187 m    0.000 m          4003637.130 m    0.000 m
LAT:            39 07 51.85826      0.000 m       39 07 51.88970      0.000 m
E LON:         283 12 33.74109      0.000 m      283 12 33.71946      0.000 m
W LON:          76 47 26.25891      0.000 m       76 47 26.28054      0.000 m
EL HGT:                35.298 m    0.001 m                34.015 m    0.001 m
ORTHO HGT:             67.690 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4332848.501 m         162577.477 m
EASTING (X)        345227.721 m         418102.934 m
CONVERGENCE       -1.13028297 deg       0.13140934 deg
POINT SCALE        0.99989496           0.99995975
COMBINED FACTOR    0.99988942           0.99995421

US NATIONAL GRID DESIGNATOR: 18SUJ4522732848 (NAD 83)

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MARK:      loyo (loyo a  1)
CONSTRAIN: 3-D NORMAL
ADJUST  X:   -0.009m (0.000m)   Y:   -0.000m (0.001m)   Z:   -0.009m (0.000m)
ADJUST  N:   -0.006m (0.000m)   E:   -0.009m (0.000m)   H:   -0.007m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                IGS08 (2017.7956)
X:                 1101542.015 m    0.000 m          1101541.149 m    0.000 m
Y:                -4906910.942 m    0.001 m         -4906909.485 m    0.001 m
Z:                 3909857.633 m    0.000 m          3909857.563 m    0.000 m
LAT:            38 03 00.62614      0.000 m       38 03 00.65656      0.000 m
E LON:         282 39 08.82639      0.000 m      282 39 08.80482      0.000 m
W LON:          77 20 51.17361      0.000 m       77 20 51.19518      0.000 m
EL HGT:                43.180 m    0.001 m                41.868 m    0.001 m
ORTHO HGT:             75.861 m    0.021 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (4501 VA N)
NORTHING (Y)      4213983.641 m         2043203.425 m
EASTING (X)        294018.061 m         3601150.718 m
CONVERGENCE       -1.44742294 deg       0.71926574 deg
POINT SCALE        1.00012258           0.99999707
COMBINED FACTOR    1.00011580           0.99999029

US NATIONAL GRID DESIGNATOR: 18STH9401813983 (NAD 83)
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Appendix A. Continued.

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MARK:      umbc (umbc a  1)
CONSTRAIN: 3-D NORMAL
ADJUST  X:   -0.007m (0.000m)   Y:    0.006m (0.001m)   Z:    0.002m (0.000m)
ADJUST  N:    0.006m (0.000m)   E:   -0.006m (0.000m)   H:   -0.005m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                IGS08 (2017.7956)
X:                1136717.973 m    0.000 m          1136717.100 m    0.000 m
Y:               -4812977.284 m    0.001 m         -4812975.839 m    0.001 m
Z:                4014471.586 m    0.000 m          4014471.530 m    0.000 m
LAT:           39 15 24.36074      0.000 m       39 15 24.39230      0.000 m
E LON:        283 17 18.53158      0.000 m      283 17 18.50999      0.000 m
W LON:         76 42 41.46842      0.000 m       76 42 41.49001      0.000 m
EL HGT:               65.935 m    0.001 m              64.655 m    0.001 m
ORTHO HGT:            98.401 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4346666.824 m         176550.147 m
EASTING (X)        352329.285 m         424898.758 m
CONVERGENCE       -1.08323924 deg       0.18106052 deg
POINT SCALE        0.99986850           0.99997190
COMBINED FACTOR    0.99985816           0.99996156

US NATIONAL GRID DESIGNATOR: 18SUJ5232946666 (NAD 83)
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A message to Maryland's citizens

The Maryland Department of Natural Resources (DNR) seeks to balance the preservation and enhancement of the living and physical resources of the state with prudent extraction and utilization policies that benefit the citizens of Maryland. This publication provides information that will increase your understanding of how DNR strives to reach that goal through the earth science assessments conducted by the Maryland Geological Survey.

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