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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, 2021 SURVEY

by

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Prepared in cooperation with the
Anne Arundel County Department of Public Works, Dominion Cove Point LNG/LP,
and the U.S. Geological Survey

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FALL, 2021 SURVEY

KEY RESULTS

A GPS campaign was conducted from October 18-25, 2021, to determine heights of nine 3d marks to assess the potential effect of groundwater withdrawals from aquifer systems in the Coastal Plain of Maryland. Three marks are located at major well fields in Anne Arundel County, Maryland, at the Arnold Water Treatment Plant (ARNO), the Broad Creek Water Treatment Plant (BROA), and the Crofton Meadows Water Treatment Plant (CROF). Three marks are located at or near major well fields in southern Maryland, at Cove Point State Park (COV1), Lexington Park (LEX1), and Waldorf (WAL1). An additional southern Maryland mark is located at Rosaryville State Park (ROS1), where groundwater use is relatively low. Two marks are located on the eastern shore of Maryland in the Blackwater National Wildlife Refuge in Dorchester County, at Money Stump (MSTP) and Peter's Neck (PTNK). The marks at the Blackwater National Wildlife Refuge are located in low-lying areas near the shoreline of Chesapeake Bay where inundation, caused by relative sea-level rise, makes assessing the role of land subsidence all the more critical. The GPS data were processed using the National Geodetic Survey's Online Positioning User Service (OPUS) Projects tool utility in the International Terrestrial Reference System of 2014. The ellipsoid heights determined through OPUS Projects processing of GPS data were 3.618 meters at ARNO, -6.209 meters at BROA, 7.059 meters at CROF, -1.53 meters at COV1, -2.09 meters at LEX1, 33.808 meters at ROS1, 28.754 meters at WAL1, -35.647 meters at MSTP, and -36.041 meters at PTNK. OPUS Projects computed height uncertainties for all marks to be +/- 0.1 cm. Uncertainty computed in the latitudinal and longitudinal positions of MGS marks is smaller than could be detected by OPUS Projects.

INTRODUCTION

Groundwater has been withdrawn from the coastal plain aquifer systems of Maryland for decades as a major water supply. The geological formations of the coastal plain are composed of stacked layers of predominantly unconsolidated sediment consisting of gravel, sand, silt, and clay. Sand and gravel layers contain water stored in interstitial pore spaces between the sediment grains with relatively high permeability, forming aquifers. Clay layers, with relatively low permeability, form confining units. Withdrawal of water from confined aquifers has lowered groundwater levels in Maryland's coastal plain aquifer systems (Staley and others, 2020). A lowering of groundwater levels in a confined aquifer corresponds to a decrease in hydrostatic pressure in the interstitial pore spaces of the aquifer sediments and in the adjacent confining units. A decrease in hydrostatic pressure can lead to the compaction of unconsolidated sediment and the subsidence of the land surface as the load from overlying sediment increases.

Studies have shown that parts of the Atlantic Coastal Plain region are experiencing elevated rates of land subsidence compared to physiographic provinces west of the Fall Line (Karegar and others, 2016). The Fall Line is a boundary that separates the unconsolidated Atlantic Coastal Plain sediments from the consolidated bedrock of the Piedmont province (fig. 1). Land subsidence rates attributable to groundwater withdrawals from the Potomac Group aquifer system in the Lower Chesapeake Bay region (Franklin and Suffolk, Virginia) have been reported in the range of 1.5 to 3.7 mm/yr (Davis, 1987; Pope and Burbey, 2004).

HISTORICAL GPS DATA

Starting in 1994, the Maryland State Highway Administration Division of Plats and Surveys began GPS surveys of three 3d rod marks at the Arnold Water Treatment Plant (ARNO), the Broad Creek Water Treatment Plant (BROA), and the Crofton Meadows Water Treatment Plant (CROF). The surveys were conducted on a yearly basis, occupying marks for a minimum of 5.5 hours over three consecutive days. In 2016, the Maryland Geological Survey took over the surveying of the marks. In 2015, four 3d rod marks were constructed and added to the monitoring network at Cove Point State Park (COV1), Lexington Park (LEX1), Rosaryville State Park (ROS1), and Waldorf (WAL1) to bring the total monitoring network to seven. In 2019 and 2020, two additional 3d rod marks were constructed and added to the network in the Blackwater National Wildlife Refuge at Money Stump (MSTP) and Peter's Neck (PTNK). The historical GPS data from the Maryland State Highway Administration as well as GPS data collected since 2016 by the Maryland Geological Survey were reprocessed in OPUS Projects using the International Terrestrial Reference System (2014). Data available for reprocessing began in 1999.

GPS SURVEY

A GPS occupation of the marks ARNO, BROA, CROF, COV1, LEX1, ROS1, and WAL1 was conducted October 18-25, 2021. Because of site access constraints associated with its location in a public park, observation of COV1 stopped October 22, 2021. Observation of MSTP occurred October 14-19, 2021. Observation of PTNK occurred October 21-27, 2021. Trimble NetR9 receivers were used with Zephyr 3 Geodetic Antennas for marks, ARNO, BROA, CROF, LEX1, WAL1, MSTP, and PTNK. Trimble 5700 receivers were used with Ashtech Dorne Margolin choke ring antennas at COV1 and ROS1. Marks ARNO, BROA, CROF, and LEX1 operated continuously over that seven-day period[1]. Equipment malfunctions hampered data collection at COV1, ROS1, and to a lesser extent WAL1, preventing continuous occupation at those marks. On October 19, 2021, a fuse in a cable connecting the external power source to the receiver failed at COV1, causing the receiver to shut down after expending its internal power source. The fuse was replaced on October 19 and the receiver resumed data collection. The same issue occurred at WAL1 on October 19. No other issues occurred during the occupation of WAL1. There was concern that the Trimble 5700 receivers being used at COV1 and ROS1 were not operating properly due to the anomalous behavior of LED indicators on the receiver face. The receivers were powered down on October 20 and data was exported to a field laptop to ensure the receiver was collecting and saving data as desired.

[1] The use of company names, trade names, or product names in this report is for identification purposes only and does not constitute endorsement by the Maryland Geological Survey.

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 seven 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. The final network adjustment used nine Continuously Operating Reference Stations (CORS) to establish baselines with MGS survey marks. All CORS data were constrained in three dimensions during the network adjustment, with the exception of the distant CORS STKR used for tropospheric correction. 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 changes in ellipsoid height relative to the 1999 measurement at marks ARNO, BROA, and CROF are shown in Figure 2. Over the 23-year period of record, the ellipsoid height decreased by 68 mm at ARNO, 50 mm at BROA, and 52 mm at CROF. The changes in ellipsoid height relative to the 2016 measurement at the marks COV1, LEX1, ROS1, and WAL1 are shown in Figure 3. Over the 6-year period of record, the ellipsoid heights decreased by 9 mm at COV1, 6 mm at LEX1, 4 mm at ROS1, and 25 mm at WAL1. Ellipsoid heights decreased over time at marks ARNO, BROA, and CROF. This decrease can be described by a linear trend; the variance about this trend is quantified by the coefficients of determination (R^2) seen in Figures 2 and 3. Values of R^2 greater than 0.8 show a high correlation between ellipsoid height and time. The correlation between ellipsoid height and time is not as strong at marks COV1, LEX1, ROS1, and WAL1. The shorter period of record at these marks, compared to the three marks in Anne Arundel County, does not provide enough data to reveal a strong trend. Year-to-year variation in computed ellipsoid heights may obscure trends that would be present over a longer period of record.

ACKNOWLEDGMENTS

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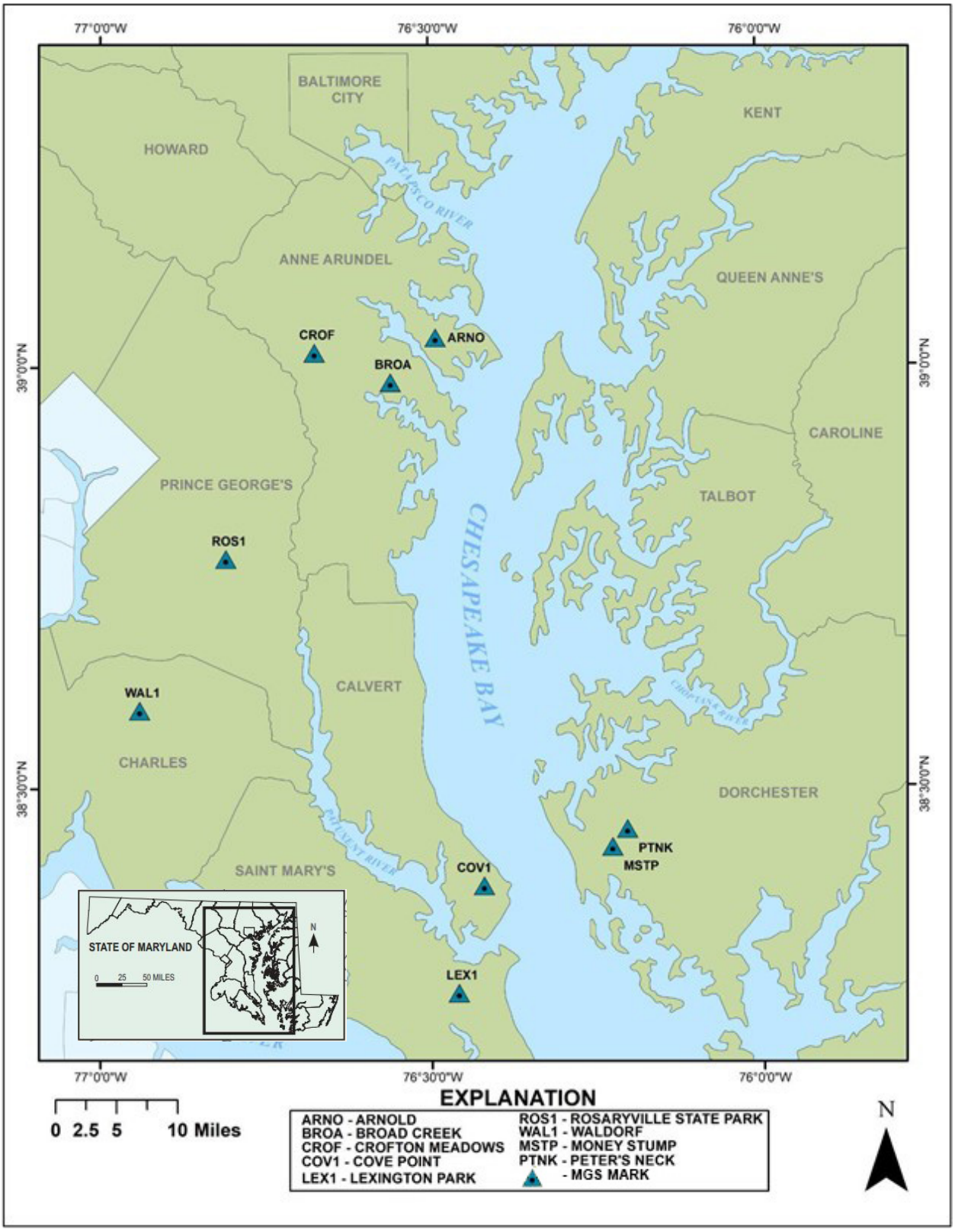

Figure 1. Location of the study area and MGS survey marks.

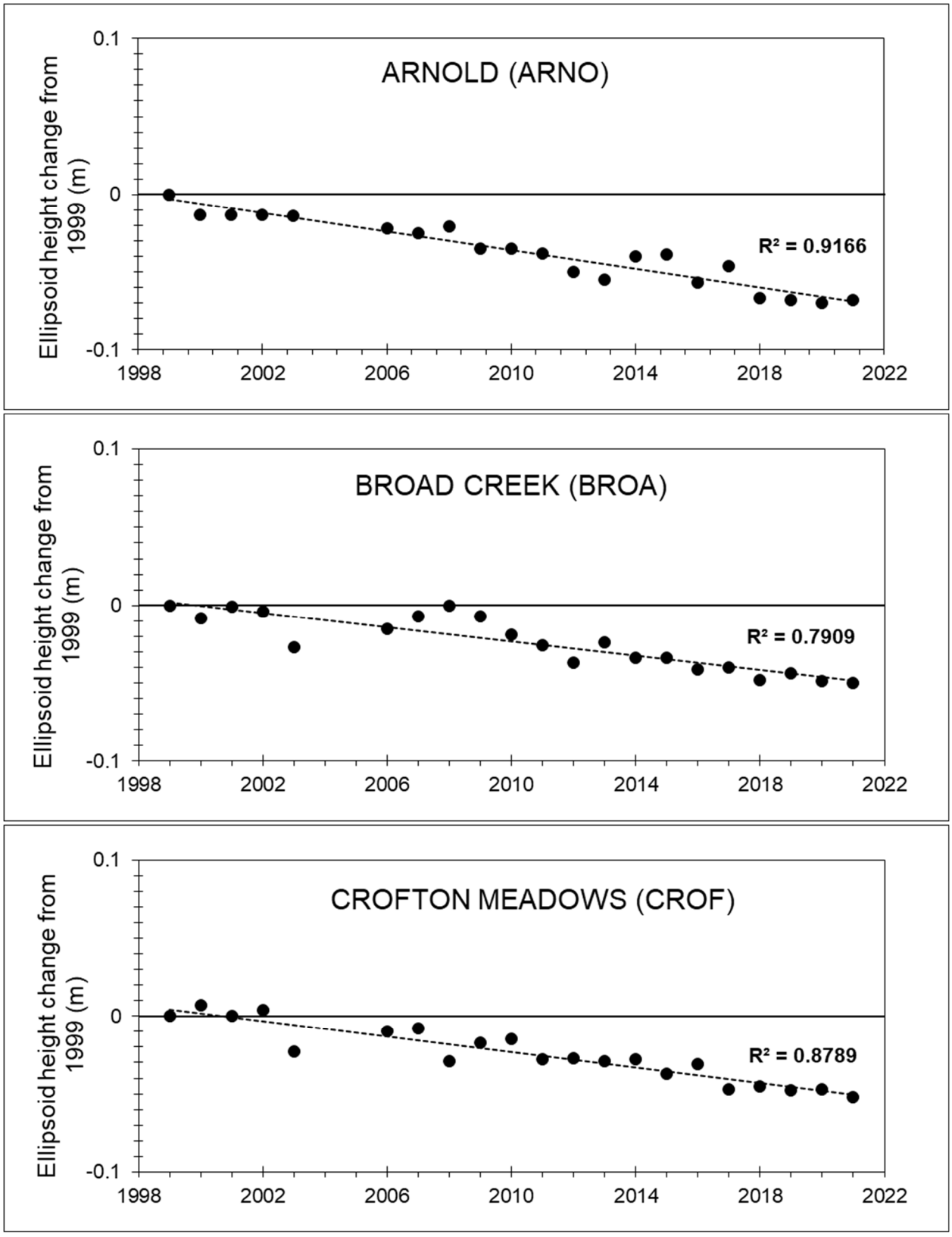

Figure 2. Change in ellipsoid heights from 1999 to present for marks ARNO, BROA, CROF.

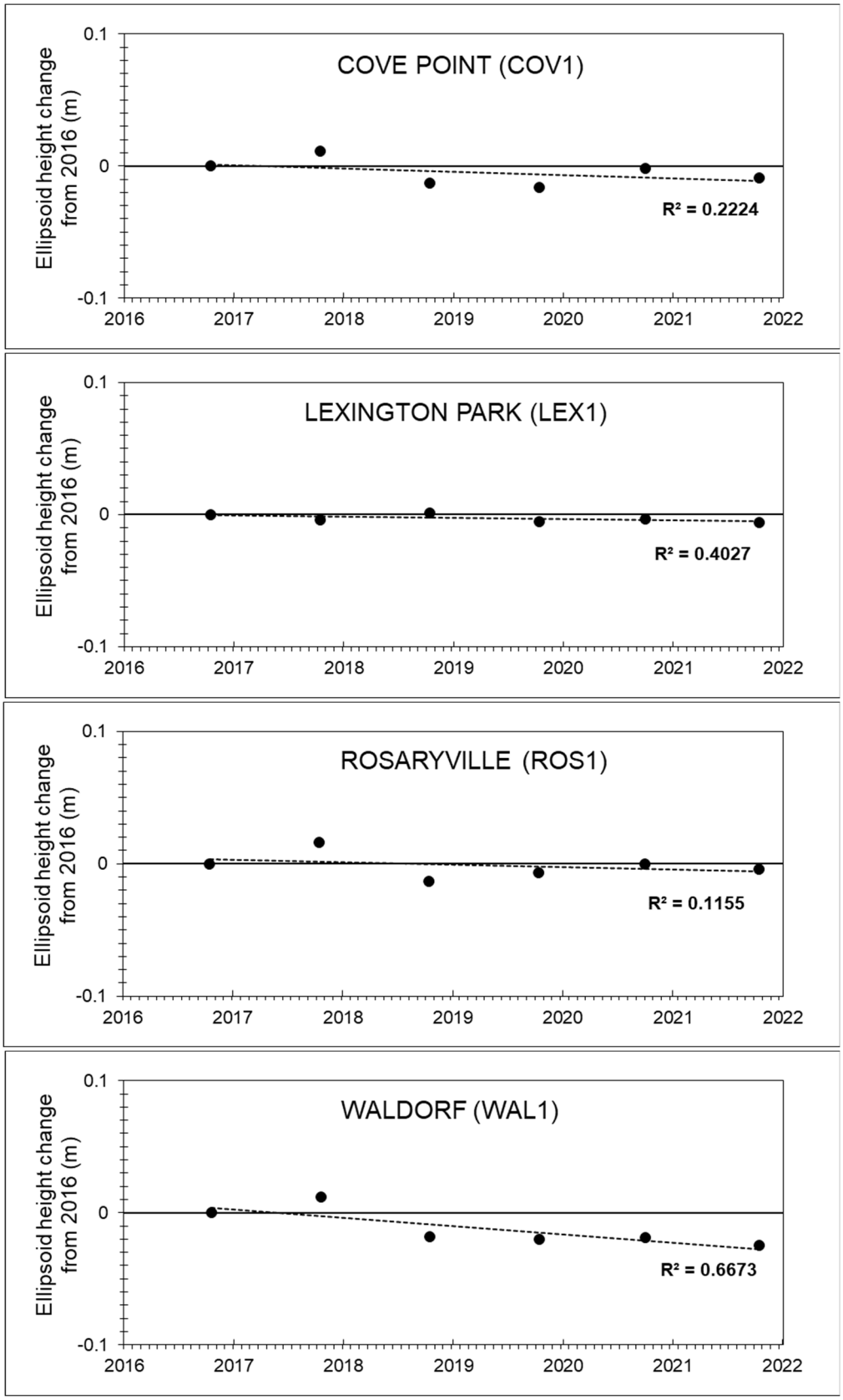

Figure 3. Change in ellipsoid heights from 2016 to present for marks COV1, LEX1, ROS1, WAL1.

Table 1. GPS Sessions processed by OPUS Projects.

Session	Period (Coordinated Universal Time)	Hub CORS
1 (Day 291-GODZ)	10/18/2021 0:00 to 23:59	GODZ
2 (Day 292-GODZ)	10/19/2021 0:00 to 23:59	GODZ
3 (Day 293-GODZ)	10/20/2021 0:00 to 23:59	GODZ
4 (Day 294-A)	10/21/2021 0:00 to 23:59	GODZ
5 (Day 295-GODZ)	10/22/2021 0:00 to 23:59	GODZ
6 (Day 297-GODZ)	10/24/2021 0:00 to 23:59	GODZ
7 (Day 298-GODZ)	10/25/2021 0:00 to 23:59	GODZ

Table 2. CORS sites used in processing GPS data.

CORS site	Start of record	State	Use in OPUS Projects	
BACO	1999	MD		Constrained
DENE	2007	DE		Constrained
GODZ (E)	1993	MD	Hub	Constrained
HNPT	1995	MD		Constrained
LOYF	2006	MD		Constrained
LOYO	2006	VA		Constrained
STKR	2000	OH	Troposphere Correction	Unconstrained
UMBC	2002	MD		Constrained
ZDC1	2003	VA		Constrained

Table 3. Summary of 2021 (Fall) GPS data.

Mark	Horizontal (ITRF14)		Vertical (ITRF14)
	Latitude	Longitude	Ellipsoid height (m)
ARNO	39.03488°	-76.49036°	3.618
BROA	38.98176°	-76.55865°	-6.209
COV1	38.38644°	-76.42281°	-1.530
CROF	39.01711°	-76.67459°	7.059
LEX1	38.26325°	-76.45571°	-2.090
MSTP	38.42997°	-76.22608°	-35.647
PTNK	38.45109°	-76.20379°	-36.041
ROS1	38.77435°	-76.82000°	33.808
WAL1	38.59907°	-76.93987°	28.754

Appendix A. Continued.

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NGS OPUS-Projects 4.0.1 NETWORK ADJUSTMENT REPORT
             ================================================

All coordinate accuracies reported here are 1x 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:                   thomas.ulizio
SOLUTION FILE NAME:             network-final_GODZ.sum
SOLUTION SOFTWARE:              GPSCOM(2008.25)
SOLUTION DATE:                  2021-12-09T10:25:39 UTC
STANDARD ERROR OF UNIT WEIGHT: 0.813
TOTAL NUMBER OF OBSERVATIONS:  1678563
TOTAL NUMBER OF MARKS:          19
CONSTRAINED MARKS:              8 HORIZONTAL, 0 VERTICAL
baco N39:23:58.06805 W076:36:24.45999 127.0283m        ITRF2014 @ 2010.0000
baco         0.12cm           0.11cm     0.12cm        NEU SIGMAS
dene N39:40:36.28071 W075:44:34.84496   5.2706m        ITRF2014 @ 2010.0000
dene         0.12cm           0.10cm     0.13cm        NEU SIGMAS
godz N39:01:18.21996 W076:49:36.59160  14.4977m        ITRF2014 @ 2010.0000
godz         0.13cm           0.07cm     0.13cm        NEU SIGMAS
hnpt N38:35:19.74021 W076:07:49.34788 -27.9747m        ITRF2014 @ 2010.0000
hnpt         0.08cm           0.15cm     0.10cm        NEU SIGMAS
loyf N38:58:28.10461 W076:31:19.90184 -15.7881m        ITRF2014 @ 2010.0000
loyf         0.12cm           0.10cm     0.13cm        NEU SIGMAS
loyo N38:03:00.65565 W077:20:51.19103  41.8661m        ITRF2014 @ 2010.0000
loyo         0.12cm           0.10cm     0.12cm        NEU SIGMAS
umbc N39:15:24.39128 W076:42:41.48560  64.6597m        ITRF2014 @ 2010.0000
umbc         0.13cm           0.08cm     0.13cm        NEU SIGMAS
zdc1 N39:06:05.74479 W077:32:33.88523  79.6180m        ITRF2014 @ 2010.0000
zdc1         0.14cm           0.06cm     0.13cm        NEU SIGMAS

START TIME:                     2021-10-18T00:00:00 GPS
STOP TIME:                      2021-10-25T23:59:30 GPS
FREQUENCY:                      L1-ONLY TO ION-FREE [BY BASELINE LENGTH]
OBSERVATION INTERVAL:           30 s
ELEVATION CUTOFF:               15 deg
TROPO INTERVAL:                 7200 s [PIECEWISE LINEAR PARAMETERIZATION]
DD CORRELATIONS:                ON

    INCLUDED SOLUTION             RMS    SOFTWARE         RUN DATE
-------------------------------------------------------------------------------
 1) 2021-291 GODZ                1.3 cm  page5(2008.25)   2021-12-07T13:51 UTC
 2) 2021-292 GODZ                1.3 cm  page5(2008.25)   2021-12-07T11:17 UTC
 3) 2021-293 GODZ                1.3 cm  page5(2008.25)   2021-12-07T13:54 UTC
 4) 2021-294 A                   1.4 cm  page5(2008.25)   2021-12-07T13:55 UTC
 5) 2021-295 GODZ                1.5 cm  page5(2008.25)   2021-12-07T14:14 UTC
 6) 2021-297 GODZ                1.4 cm  page5(2008.25)   2021-12-07T13:50 UTC
 7) 2021-298 GODZ                1.5 cm  page5(2008.25)   2021-12-07T14:14 UTC

  BASELINE      LENGTH          RMS       OBS    OMITTED    FIXED IN SOLUTION(S)
-------------------------------------------------------------------------------
 crof-godz     13.195 km      1.2 cm    97264     8.9%    98.6%    1, 2, 3,...
 broa-godz     23.651 km      1.4 cm    99574     7.8%    97.3%    1, 2, 3,...
 loyf-godz     26.907 km      1.3 cm   125594     0.9%    98.2%    1, 2, 3,...
 a001-godz     27.469 km      1.5 cm    63809    13.8%    97.6%    2, 3, 4,...
 umbc-godz     27.934 km      1.3 cm   126815     0.8%    98.9%    1, 2, 3,...
 arno-godz     29.173 km      1.3 cm   102733     4.0%    98.2%    1, 2, 3,...
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Appendix A. Continued.

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 84tb-godz     34.288 km      1.1 cm   108084     1.5%    99.3%    1, 2, 3,...
 baco-godz     46.042 km      1.3 cm   125335     1.8%    99.2%    1, 2, 3,...
 wal1-godz     47.936 km      1.8 cm    70965    21.8%    97.3%    1, 2, 3,...
 zdc1-godz     62.595 km      1.4 cm   124087     2.6%    99.6%    1, 2, 3,...
 hnpt-godz     77.261 km      1.4 cm   124506     1.1%    99.4%    1, 2, 3,...
 cov1-godz     78.794 km      1.1 cm    16706     2.0%   100.0%    2, 3
 ptnk-godz     83.350 km      2.1 cm    27255    31.5%    97.9%    6, 7
 mstp-godz     83.930 km      1.7 cm    22143    25.6%    96.8%    1, 2
 lex1-godz     90.184 km      1.7 cm    74822    20.0%    95.3%    1, 2, 3,...
 loyo-godz    117.013 km      1.3 cm   124369     1.9%    99.4%    1, 2, 3,...
 dene-godz    118.388 km      1.3 cm   125123     1.0%    95.9%    1, 2, 3,...
 stkr-godz    457.384 km      1.3 cm   119379     1.9%    94.3%    1, 2, 3,...

 MARK  ESTIMATED - A PRIORI COORDINATE SHIFTS
-------------------------------------------------------------------------------
 84tb  N:    0.002 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.002 m (0.001 m)
 a001  N:    0.000 m (0.000 m) E:    0.000 m (0.000 m) H:    0.016 m (0.001 m)
 arno  N:    0.000 m (0.000 m) E:    0.000 m (0.000 m) H:   -0.004 m (0.001 m)
 baco  N:    0.002 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.003 m (0.000 m)
 broa  N:    0.000 m (0.000 m) E:    0.000 m (0.000 m) H:   -0.006 m (0.001 m)
 cov1  N:   -0.002 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.011 m (0.001 m)
 crof  N:   -0.001 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.005 m (0.001 m)
 dene  N:   -0.001 m (0.000 m) E:   -0.001 m (0.000 m) H:   -0.002 m (0.000 m)
 godz  N:    0.002 m (0.000 m) E:    0.001 m (0.000 m) H:    0.001 m (0.000 m)
 hnpt  N:   -0.001 m (0.000 m) E:    0.000 m (0.000 m) H:    0.005 m (0.000 m)
 lex1  N:    0.002 m (0.000 m) E:    0.002 m (0.000 m) H:    0.006 m (0.001 m)
 loyf  N:   -0.001 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.003 m (0.000 m)
 loyo  N:   -0.001 m (0.000 m) E:    0.000 m (0.000 m) H:    0.000 m (0.000 m)
 mstp  N:   -0.002 m (0.000 m) E:   -0.002 m (0.000 m) H:    0.003 m (0.001 m)
 ptnk  N:    0.000 m (0.000 m) E:    0.006 m (0.000 m) H:   -0.016 m (0.001 m)
 stkr  N:    0.000 m (0.000 m) E:   -0.001 m (0.000 m) H:   -0.003 m (0.001 m)
 umbc  N:    0.001 m (0.000 m) E:    0.000 m (0.000 m) H:    0.004 m (0.000 m)
 wal1  N:    0.007 m (0.000 m) E:    0.003 m (0.000 m) H:    0.001 m (0.001 m)
 zdc1  N:   -0.002 m (0.000 m) E:   -0.001 m (0.000 m) H:   -0.004 m (0.000 m)

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UNCONSTRAINED MARKS
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MARK:      84tb (84tb    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2021.8055
X:                1147537.224 m    0.000 m          1147536.289 m    0.000 m
Y:               -4809805.658 m    0.001 m         -4809804.218 m    0.001 m
Z:                4015048.340 m    0.000 m          4015048.293 m    0.000 m
LAT:           39 15 50.88789      0.000 m       39 15 50.91990      0.000 m
E LON:        283 25 08.16619      0.000 m      283 25 08.14218      0.000 m
W LON:         76 34 51.83381      0.000 m       76 34 51.85782      0.000 m
EL HGT:              -23.600 m    0.001 m             -24.882 m    0.001 m
ORTHO HGT:             9.248 m    0.015 m  (= EL HGT - -32.848 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4347279.910 m         177411.813 m
EASTING (X)        363599.810 m         436154.410 m
CONVERGENCE       -1.00080556 deg       0.26293889 deg
POINT SCALE        0.99982908           0.99997277
COMBINED FACTOR    0.99983278           0.99997647

US NATIONAL GRID DESIGNATOR: 18SUJ6359947279 (NAD 83)
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Appendix A. Continued.

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MARK:      a001 (a001    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2021.8058
X:                 1135286.272 m    0.000 m          1135285.341 m    0.000 m
Y:                -4847925.433 m    0.001 m         -4847923.987 m    0.001 m
Z:                 3972839.227 m    0.001 m          3972839.175 m    0.001 m
LAT:           38 46 27.61184      0.000 m       38 46 27.64344      0.000 m
E LON:        283 10 48.03313      0.000 m      283 10 48.00923      0.000 m
W LON:         76 49 11.96687      0.000 m       76 49 11.99077      0.000 m
EL HGT:               35.103 m    0.001 m               33.808 m    0.001 m
ORTHO HGT:            67.891 m    0.016 m  (= EL HGT - -32.788 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4293307.802 m         122971.227 m
EASTING (X)        341898.641 m         415642.190 m
CONVERGENCE       -1.14001389 deg       0.11298056 deg
POINT SCALE        0.99990781           0.99995141
COMBINED FACTOR    0.99990230           0.99994590

US NATIONAL GRID DESIGNATOR: 18SUH4189893307 (NAD 83)

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MARK:      arno (arno    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2021.8055
X:                 1158910.179 m    0.000 m          1158909.246 m    0.000 m
Y:                -4823629.190 m    0.001 m         -4823627.747 m    0.001 m
Z:                 3995327.613 m    0.000 m          3995327.565 m    0.000 m
LAT:           39 02 05.52426      0.000 m       39 02 05.55615      0.000 m
E LON:        283 30 34.73967      0.000 m      283 30 34.71599      0.000 m
W LON:         76 29 25.26033      0.000 m       76 29 25.28401      0.000 m
EL HGT:                4.908 m    0.001 m                3.618 m    0.001 m
ORTHO HGT:            38.163 m    0.015 m  (= EL HGT - -33.255 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4321702.613 m         152000.081 m
EASTING (X)        371008.294 m         444125.189 m
CONVERGENCE       -0.93874167 deg       0.31987500 deg
POINT SCALE        0.99980488           0.99995369
COMBINED FACTOR    0.99980411           0.99995292

US NATIONAL GRID DESIGNATOR: 18SUJ7100821702 (NAD 83)

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

MARK:      broa (broa    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2021.8055
X:                 1154021.088 m    0.000 m          1154020.155 m    0.000 m
Y:                -4828609.401 m    0.001 m         -4828607.958 m    0.001 m
Z:                 3990739.544 m    0.000 m          3990739.495 m    0.000 m
LAT:           38 58 54.31414      0.000 m       38 58 54.34597      0.000 m
E LON:        283 26 28.89545      0.000 m      283 26 28.87170      0.000 m
W LON:         76 33 31.10455      0.000 m       76 33 31.12830      0.000 m
EL HGT:               -4.918 m    0.001 m               -6.209 m    0.001 m
ORTHO HGT:            28.267 m    0.015 m  (= EL HGT - -33.185 GEOID18 HGT)
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Appendix A. Continued.

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                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4315907.111 m         146073.156 m
EASTING (X)        364996.448 m         438241.232 m
CONVERGENCE       -0.98064722 deg       0.27701389 deg
POINT SCALE        0.99982443           0.99995155
COMBINED FACTOR    0.99982520           0.99995232

US NATIONAL GRID DESIGNATOR: 18SUJ6499615907 (NAD 83)

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MARK:      cov1 (cov1    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2021.8002
X:                1175163.272 m    0.000 m          1175162.344 m    0.000 m
Y:               -4866014.477 m    0.001 m         -4866013.025 m    0.001 m
Z:                3939155.590 m    0.001 m          3939155.538 m    0.001 m
LAT:           38 23 11.16071      0.000 m       38 23 11.19219      0.000 m
E LON:        283 34 37.91873      0.000 m      283 34 37.89561      0.000 m
W LON:         76 25 22.08127      0.000 m       76 25 22.10439      0.000 m
EL HGT:               -0.220 m    0.001 m               -1.530 m    0.001 m
ORTHO HGT:            34.172 m    0.017 m  (= EL HGT - -34.392 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4249650.218 m          80056.592 m
EASTING (X)        375737.324 m         450428.644 m
CONVERGENCE       -0.88361944 deg       0.36226944 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             ITRF2014 @ 2021.8054
X:                1143680.968 m    0.000 m          1143680.036 m    0.000 m
Y:               -4828541.806 m    0.001 m         -4828540.364 m    0.001 m
Z:                3993797.478 m    0.000 m          3993797.429 m    0.000 m
LAT:           39 01 01.56291      0.000 m       39 01 01.59471      0.000 m
E LON:        283 19 31.50643      0.000 m      283 19 31.48254      0.000 m
W LON:         76 40 28.49357      0.000 m       76 40 28.51746      0.000 m
EL HGT:                8.348 m    0.001 m                7.059 m    0.001 m
ORTHO HGT:            41.163 m    0.015 m  (= EL HGT - -32.815 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4320008.249 m         149954.805 m
EASTING (X)        355025.631 m         428181.656 m
CONVERGENCE       -1.05441944 deg       0.20424444 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:      lex1 (lex1    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2021.8043
X:                 1174354.963 m    0.000 m          1174354.035 m    0.000 m
Y:                -4874932.332 m    0.001 m         -4874930.878 m    0.001 m
Z:                 3928427.077 m    0.001 m          3928427.023 m    0.001 m
LAT:            38 15 47.65653      0.000 m       38 15 47.68791      0.000 m
E LON:         283 32 39.48257      0.000 m      283 32 39.45947      0.000 m
W LON:          76 27 20.51743      0.000 m       76 27 20.54053      0.000 m
EL HGT:                -0.777 m    0.001 m               -2.090 m    0.001 m
ORTHO HGT:             33.727 m    0.017 m  (= EL HGT - -34.504 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4236024.452 m          66364.198 m
EASTING (X)        372648.469 m         447635.908 m
CONVERGENCE       -0.90160000 deg       0.34162222 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:      mstp (mstp    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2021.7968
X:                 1191143.029 m    0.000 m          1191142.101 m    0.000 m
Y:                -4859009.487 m    0.001 m         -4859008.036 m    0.001 m
Z:                 3942920.452 m    0.001 m          3942920.400 m    0.001 m
LAT:            38 25 47.85547      0.000 m       38 25 47.88703      0.000 m
E LON:         283 46 26.14144      0.000 m      283 46 26.11852      0.000 m
W LON:          76 13 33.85856      0.000 m       76 13 33.88148      0.000 m
EL HGT:               -34.337 m    0.001 m              -35.647 m    0.001 m
ORTHO HGT:              0.571 m    0.015 m  (= EL HGT - -34.908 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4254233.466 m          85015.135 m
EASTING (X)        392983.819 m         467575.056 m
CONVERGENCE       -0.76214722 deg       0.48574444 deg
POINT SCALE        0.99974104           0.99997993
COMBINED FACTOR    0.99974643           0.99998532

US NATIONAL GRID DESIGNATOR: 18SUH9298354233 (NAD 83)

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MARK:      ptnk (ptnk    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2021.8136
X:                 1192685.681 m    0.000 m          1192684.752 m    0.000 m
Y:                -4857129.980 m    0.001 m         -4857128.528 m    0.001 m
Z:                 3944756.417 m    0.001 m          3944756.365 m    0.001 m
LAT:            38 27 03.88508      0.000 m       38 27 03.91667      0.000 m
E LON:         283 47 46.38800      0.000 m      283 47 46.36508      0.000 m
W LON:          76 12 13.61200      0.000 m       76 12 13.63492      0.000 m
EL HGT:               -34.732 m    0.001 m              -36.041 m    0.001 m
ORTHO HGT:              0.213 m    0.015 m  (= EL HGT - -34.945 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
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Appendix A. Continued.

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                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4256551.348 m          87376.082 m
EASTING (X)        394960.118 m         469500.860 m
CONVERGENCE       -0.74863611 deg       0.49973333 deg
POINT SCALE        0.99973588           0.99997715
COMBINED FACTOR    0.99974133           0.99998260

US NATIONAL GRID DESIGNATOR: 18SUH9496056551 (NAD 83)

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MARK:      stkr (stkr a  3)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2021.8049
X:                 678451.042 m    0.000 m           678450.110 m    0.000 m
Y:                -4893799.716 m    0.001 m         -4893798.284 m    0.001 m
Z:                 4020496.780 m    0.000 m          4020496.699 m    0.000 m
LAT:           39 19 33.82493      0.000 m       39 19 33.85468      0.000 m
E LON:        277 53 34.37023      0.000 m      277 53 34.33988      0.000 m
W LON:         82 06 25.62977      0.000 m       82 06 25.66012      0.000 m
EL HGT:              178.033 m    0.001 m             176.785 m    0.001 m
ORTHO HGT:           212.219 m    0.018 m  (= EL HGT - -34.186 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 17)         SPC (3402 OH S)
NORTHING (Y)      4353545.420 m         147284.041 m
EASTING (X)        404572.967 m         633874.817 m
CONVERGENCE       -0.70166944 deg       0.24929167 deg
POINT SCALE        0.99971212           0.99993642
COMBINED FACTOR    0.99968420           0.99990849

US NATIONAL GRID DESIGNATOR: 17SMD0457253545 (NAD 83)

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MARK:      wal1 (wal1    1)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2021.8046
X:                 1127888.802 m    0.000 m          1127887.873 m    0.000 m
Y:                -4862133.242 m    0.001 m         -4862131.795 m    0.001 m
Z:                 3957648.548 m    0.001 m          3957648.495 m    0.001 m
LAT:           38 35 56.63667      0.000 m       38 35 56.66809      0.000 m
E LON:        283 03 36.50719      0.000 m      283 03 36.48329      0.000 m
W LON:         76 56 23.49281      0.000 m       76 56 23.51671      0.000 m
EL HGT:              30.053 m    0.001 m              28.754 m    0.001 m
ORTHO HGT:           62.963 m    0.016 m  (= EL HGT - -32.910 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4274070.446 m         103501.659 m
EASTING (X)        331073.120 m         405238.860 m
CONVERGENCE       -1.21050000 deg       0.03774722 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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Appendix A. Continued.

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MARK:      baco (baco a  2)
CONSTRAIN: 3-D NORMAL
     N39:23:58.06805 W076:36:24.45999 127.0283m        ITRF2014 @ 2010.0000
             0.12cm           0.11cm     0.12cm        NEU SIGMAS
SHIFTS N:    0.002 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.003 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2021.8049
X:                1143199.186 m    0.000 m          1143198.249 m    0.000 m
Y:               -4801171.604 m    0.000 m         -4801170.164 m    0.000 m
Z:                4026765.138 m    0.000 m          4026765.092 m    0.000 m
LAT:           39 23 58.03751      0.000 m       39 23 58.06966      0.000 m
E LON:        283 23 35.55692      0.000 m      283 23 35.53277      0.000 m
W LON:         76 36 24.44308      0.000 m       76 36 24.46723      0.000 m
EL HGT:              128.302 m    0.000 m             127.023 m    0.000 m
ORTHO HGT:           160.870 m    0.015 m  (= EL HGT - -32.568 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4362337.561 m         192424.923 m
EASTING (X)        361647.405 m         433869.645 m
CONVERGENCE       -1.02002778 deg       0.24679167 deg
POINT SCALE        0.99983568           0.99999155
COMBINED FACTOR    0.99981555           0.99997142

US NATIONAL GRID DESIGNATOR: 18SUJ6164762337 (NAD 83)

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MARK:      dene (dene a  3)
CONSTRAIN: 3-D NORMAL
     N39:40:36.28071 W075:44:34.84496   5.2706m        ITRF2014 @ 2010.0000
             0.12cm           0.10cm     0.13cm        NEU SIGMAS
SHIFTS N:   -0.001 m (0.000 m) E:   -0.001 m (0.000 m) H:   -0.002 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2021.8049
X:                1210598.678 m    0.000 m          1210597.737 m    0.000 m
Y:               -4764306.697 m    0.000 m         -4764305.249 m    0.000 m
Z:                4050429.565 m    0.000 m          4050429.522 m    0.000 m
LAT:           39 40 36.24961      0.000 m       39 40 36.28238      0.000 m
E LON:        284 15 25.17099      0.000 m      284 15 25.14768      0.000 m
W LON:         75 44 34.82901      0.000 m       75 44 34.85232      0.000 m
EL HGT:              6.543 m      0.000 m             5.257 m      0.000 m
ORTHO HGT:          39.545 m      0.015 m  (= EL HGT - -33.002 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (0700 DE)
NORTHING (Y)      4392142.877 m         186188.493 m
EASTING (X)        436278.662 m         172001.596 m
CONVERGENCE       -0.47439444 deg      -0.20835556 deg
POINT SCALE        0.99964999           1.00000465
COMBINED FACTOR    0.99964896           1.00000362

US NATIONAL GRID DESIGNATOR: 18SVJ3627892142 (NAD 83)

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MARK:      godz (godz a  4)
CONSTRAIN: 3-D NORMAL
     N39:01:18.21996 W076:49:36.59160  14.4977m        ITRF2014 @ 2010.0000
             0.13cm           0.07cm     0.13cm        NEU SIGMAS
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Appendix A. Continued.

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SHIFTS N:    0.002 m (0.000 m) E:    0.001 m (0.000 m) H:    0.001 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2021.8050
X:                1130774.430 m    0.000 m          1130773.493 m    0.000 m
Y:               -4831255.024 m    0.000 m         -4831253.571 m    0.000 m
Z:                3994200.522 m    0.000 m          3994200.465 m    0.000 m
LAT:           39 01 18.18978      0.000 m       39 01 18.22160      0.000 m
E LON:        283 10 23.42538      0.000 m      283 10 23.40120      0.000 m
W LON:         76 49 36.57462      0.000 m       76 49 36.59880      0.000 m
EL HGT:              15.785 m    0.000 m              14.484 m    0.000 m
ORTHO HGT:           48.165 m    0.015 m  (= EL HGT - -32.380 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4320774.472 m         150431.510 m
EASTING (X)        341854.669 m         414996.116 m
CONVERGENCE       -1.15043611 deg       0.10868889 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:      hnpt (hnpt a  4)
CONSTRAIN: 3-D NORMAL
     N38:35:19.74021 W076:07:49.34788 -27.9747m        ITRF2014 @ 2010.0000
            0.08cm           0.15cm     0.10cm        NEU SIGMAS
SHIFTS N:   -0.001 m (0.000 m) E:    0.000 m (0.000 m) H:    0.005 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2021.8049
X:                1196627.026 m    0.000 m          1196626.087 m    0.000 m
Y:               -4846359.966 m    0.000 m         -4846358.492 m    0.000 m
Z:                3956723.213 m    0.000 m          3956723.149 m    0.000 m
LAT:           38 35 19.71002      0.000 m       38 35 19.74189      0.000 m
E LON:        283 52 10.66802      0.000 m      283 52 10.64497      0.000 m
W LON:         76 07 49.33198      0.000 m       76 07 49.35503      0.000 m
EL HGT:             -26.665 m    0.000 m             -27.999 m    0.000 m
ORTHO HGT:            8.235 m    0.015 m  (= EL HGT - -34.900 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4271753.562 m         102722.194 m
EASTING (X)        401553.851 m         475762.994 m
CONVERGENCE       -0.70510000 deg       0.54580833 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  2)
CONSTRAIN: 3-D NORMAL
     N38:58:28.10461 W076:31:19.90184 -15.7881m        ITRF2014 @ 2010.0000
            0.12cm           0.10cm     0.13cm        NEU SIGMAS
SHIFTS N:   -0.001 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.003 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2021.8049
X:                1157209.558 m    0.000 m          1157208.620 m    0.000 m
Y:               -4828361.998 m    0.000 m         -4828360.536 m    0.000 m
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Appendix A. Continued.

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Z:                3990104.478 m    0.000 m          3990104.418 m    0.000 m
LAT:           38 58 28.07427      0.000 m       38 58 28.10623      0.000 m
E LON:        283 28 40.11469      0.000 m      283 28 40.09095      0.000 m
W LON:         76 31 19.88531      0.000 m       76 31 19.90905      0.000 m
EL HGT:             -14.501 m    0.000 m              -15.814 m    0.000 m
ORTHO HGT:           18.779 m    0.015 m  (= EL HGT - -33.280 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4315044.791 m         145279.934 m
EASTING (X)        368140.229 m         441403.599 m
CONVERGENCE       -0.95755556 deg       0.29988889 deg
POINT SCALE        0.99981410           0.99995133
COMBINED FACTOR    0.99981637           0.99995361

US NATIONAL GRID DESIGNATOR: 18SUJ6814015044 (NAD 83)

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MARK:      loyo (loyo a  3)
CONSTRAIN: 3-D NORMAL
     N38:03:00.65565 W077:20:51.19103  41.8661m        ITRF2014 @ 2010.0000
            0.12cm           0.10cm     0.12cm        NEU SIGMAS
SHIFTS N:   -0.001 m (0.000 m) E:    0.000 m (0.000 m) H:    0.000 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2021.8049
X:                1101542.004 m    0.000 m          1101541.077 m    0.000 m
Y:               -4906910.941 m    0.000 m         -4906909.478 m    0.000 m
Z:                3909857.634 m    0.000 m          3909857.569 m    0.000 m
LAT:           38 03 00.62623      0.000 m       38 03 00.65716      0.000 m
E LON:        282 39 08.82596      0.000 m      282 39 08.80199      0.000 m
W LON:         77 20 51.17404      0.000 m       77 20 51.19801      0.000 m
EL HGT:              43.178 m    0.000 m               41.854 m    0.000 m
ORTHO HGT:           75.862 m    0.021 m  (= EL HGT - -32.684 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (4501 VA N)
NORTHING (Y)      4213983.645 m        2043203.428 m
EASTING (X)        294018.051 m        3601150.708 m
CONVERGENCE       -1.44742222 deg       0.71926667 deg
POINT SCALE        1.00012258           0.99999707
COMBINED FACTOR    1.00011580           0.99999029

US NATIONAL GRID DESIGNATOR: 18STH9401813983 (NAD 83)

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MARK:      umbc (umbc a  3)
CONSTRAIN: 3-D NORMAL
     N39:15:24.39128 W076:42:41.48560  64.6597m        ITRF2014 @ 2010.0000
            0.13cm           0.08cm     0.13cm        NEU SIGMAS
SHIFTS N:    0.001 m (0.000 m) E:    0.000 m (0.000 m) H:    0.004 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2021.8049
X:                1136717.967 m    0.000 m          1136717.030 m    0.000 m
Y:               -4812977.290 m    0.000 m         -4812975.842 m    0.000 m
Z:                4014471.594 m    0.000 m          4014471.542 m    0.000 m
LAT:           39 15 24.36085      0.000 m       39 15 24.39288      0.000 m
E LON:        283 17 18.53128      0.000 m      283 17 18.50714      0.000 m
W LON:         76 42 41.46872      0.000 m       76 42 41.49286      0.000 m
EL HGT:              65.944 m    0.000 m               64.653 m    0.000 m
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Appendix A. Continued.

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ORTHO HGT:             98.409 m    0.015 m  (= EL HGT - -32.465 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4346666.828 m         176550.151 m
EASTING (X)        352329.278 m         424898.750 m
CONVERGENCE       -1.08323889 deg       0.18106111 deg
POINT SCALE        0.99986850           0.99997190
COMBINED FACTOR    0.99985816           0.99996155

US NATIONAL GRID DESIGNATOR: 18SUJ5232946666 (NAD 83)

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MARK:      zdc1 (zdc1 a  2)
CONSTRAIN: 3-D NORMAL
     N39:06:05.74479 W077:32:33.88523  79.6180m        ITRF2014 @ 2010.0000
             0.14cm           0.06cm     0.13cm        NEU SIGMAS
SHIFTS N:   -0.002 m (0.000 m) E:   -0.001 m (0.000 m) H:   -0.004 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2021.8049
X:                 1069126.499 m    0.000 m          1069125.558 m    0.000 m
Y:                -4839600.093 m    0.000 m         -4839598.646 m    0.000 m
Z:                 4001126.298 m    0.000 m          4001126.236 m    0.000 m
LAT:            39 06 05.71463      0.000 m       39 06 05.74613      0.000 m
E LON:         282 27 26.13247      0.000 m      282 27 26.10721      0.000 m
W LON:          77 32 33.86753      0.000 m       77 32 33.89279      0.000 m
EL HGT:                80.893 m    0.000 m               79.600 m    0.000 m
ORTHO HGT:            113.246 m    0.016 m  (= EL HGT - -32.353 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (4501 VA N)
NORTHING (Y)      4331128.272 m         2159710.546 m
EASTING (X)        280119.881 m         3582802.374 m
CONVERGENCE       -1.60434167 deg       0.59744167 deg
POINT SCALE        1.00019535           0.99998402
COMBINED FACTOR    1.00018266           0.99997133

US NATIONAL GRID DESIGNATOR: 18STJ8011931128 (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.

MARYLAND DEPARTMENT OF NATURAL RESOURCES
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