

Department of Natural Resources
Resource Assessment Service
MARYLAND GEOLOGICAL SURVEY
Richard A. Ortt, Jr., Director

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LAND SUBSIDENCE MONITORING AT ARNOLD, BROAD CREEK, AND
CROFTON MEADOWS WELLS FIELDS IN ANNE ARUNDEL COUNTY,
MARYLAND:

FALL, 2016 SURVEY

by

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Prepared in cooperation with
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ABBREVIATIONS USED IN THIS REPORT

ARNO-1	Arnold survey mark
BROA-1	Broad Creek survey mark
CORS	Continuously Operating Reference Stations
CROF-1	Crofton Meadows survey mark
GPS	global positioning system
NGS	National Geodetic Survey
OPUS	Online Positioning User Service
UTC	Coordinated Universal Time

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KEY RESULTS

A GPS survey was completed October 17-20, 2016 to determine the heights of 3d marks at the Arnold (ARNO-1), Broad Creek (BROA-1), and Crofton Meadows (CROF-1) well fields in Anne Arundel County, Maryland. 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 3.639 meters at ARNO-1, -6.184 meters at BROA-1, and 7.090 meters at CROF-1. The rate of change in ellipsoid height over a 17-year period of record is approximately 1.3, 0.62, and 0.75 millimeters/year at ARNO-1, BROA-1, AND CROF-1, respectively. Height uncertainty for the Fall 2016 measurements is +/- 0.1 centimeter.

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 four marks in Southern Maryland (COV-1, LEX-1, ROS-1, and WAL-1), was conducted October 17-20, 2016. The survey on the Anne Arundel County marks was performed by staff of the NGS using dual frequency (L1/L2) GPS receivers (CHC X90D-OPUS) oriented north. The receivers were attached to 1.5 m (CROF-1) and 2.0 m (ARNO-1 and BROA-1) fixed-height range poles with level vials. GPS readings were recorded at a 15-second sampling rate. Weather conditions were clear with temperatures ranging from ~60-80 degrees Fahrenheit.

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). Since OPUS Projects doesn't process GPS data crossing 24-0h UTC more than once, the occupations were divided into four 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 at ARNO-1, BROA-1, and CROF-1 marks 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 are shown in Figure 2. Over the 17-year period, ellipsoid height varied by 0.048 m at ARNO-1, 0.037 m at

BROA-1, and 0.043 m at CROF-1. The rate of change in ellipsoid height is ~1.3, 0.62, and 0.75 mm/year at ARNO-1, BROA-1, AND CROF-1, respectively. Height uncertainty for the Fall 2016 measurements are +/- 0.1 cm (fig. 3).

REFERENCES

- Andreasen, D.C.**, 2007, Optimization of ground-water withdrawals in Anne Arundel County, Maryland, from the Upper Patapsco, Lower Patapsco, and Patuxent aquifers projected through 2044: Maryland Geological Survey Report of Investigations No. 77, 107 p.
- 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.
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- Staley, A.W., Andreasen, D.C., and Curtin, S.E.**, 2016, Potentiometric surface and water-level difference maps of selected confined aquifers in Southern Maryland and Maryland's Eastern Shore, 1975-2015: Maryland Geological Survey Open-File Report 16-02-02, 30 p.

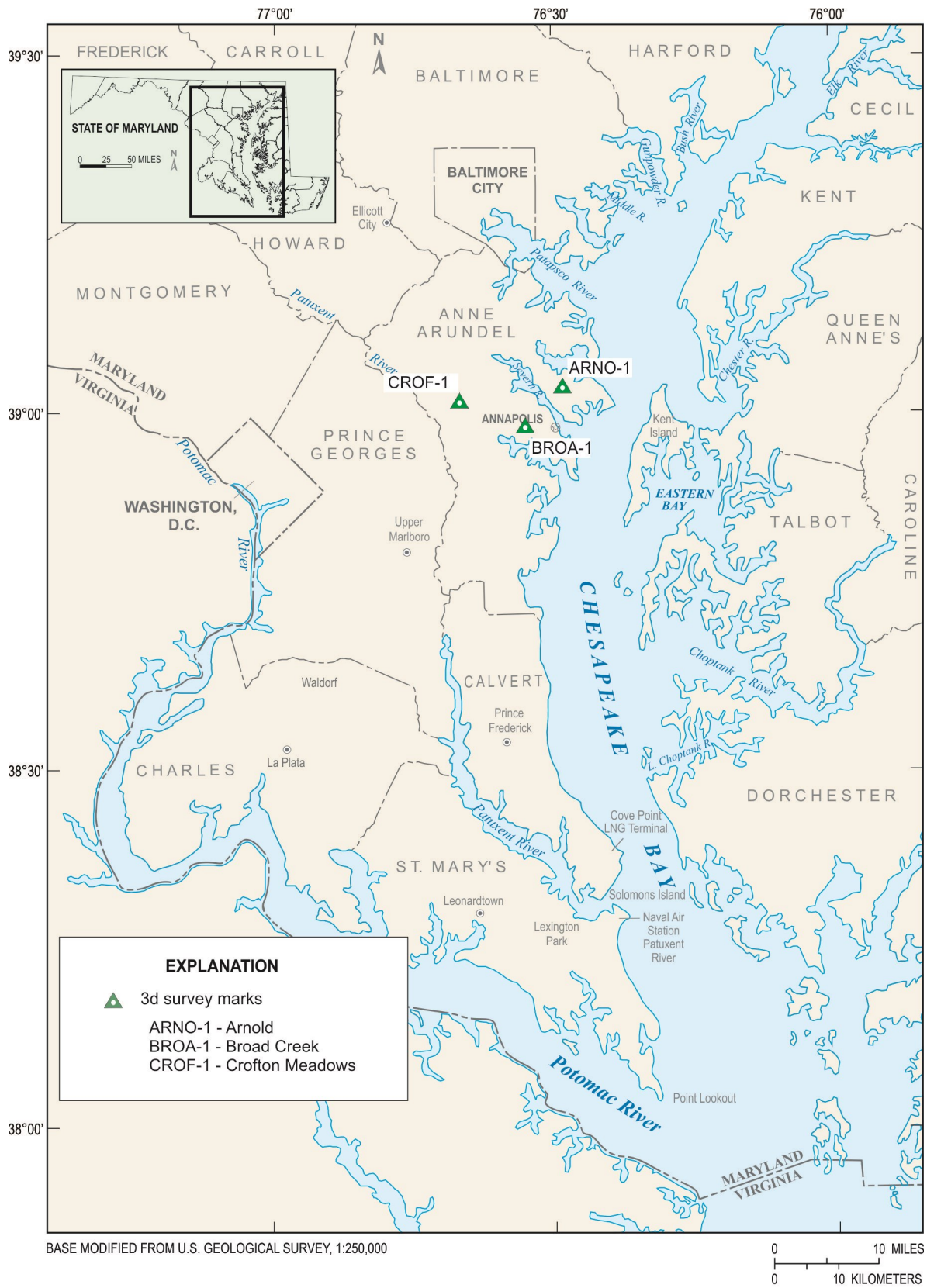


Figure 1. Location of GPS survey marks.

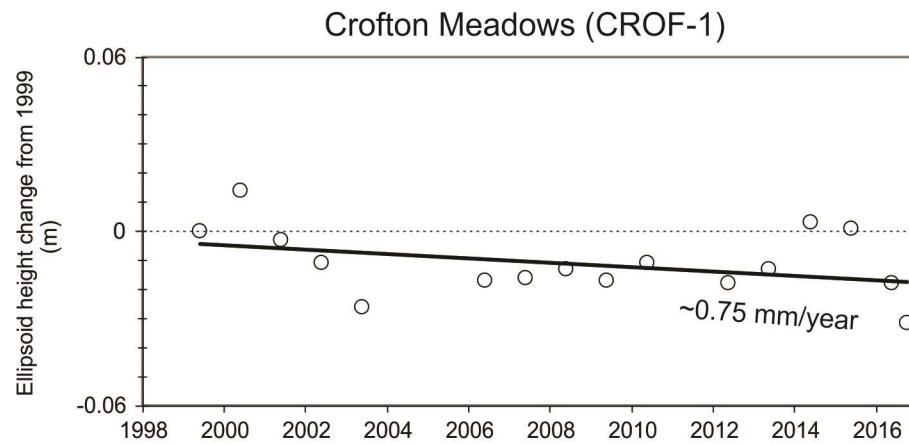
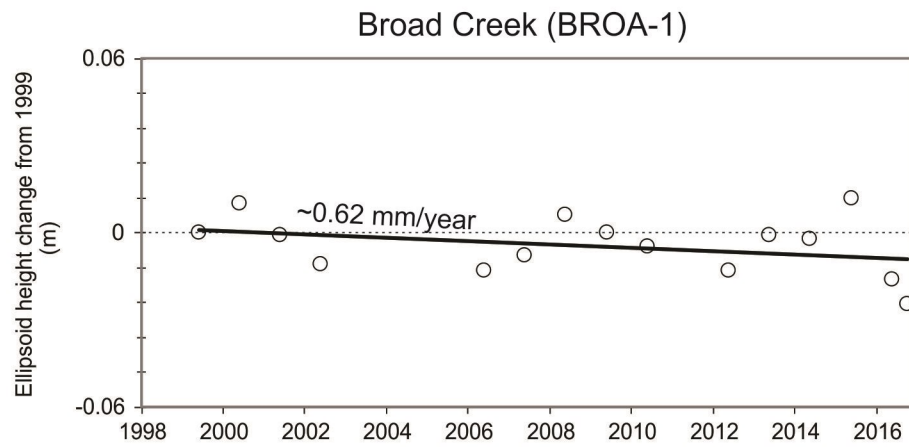
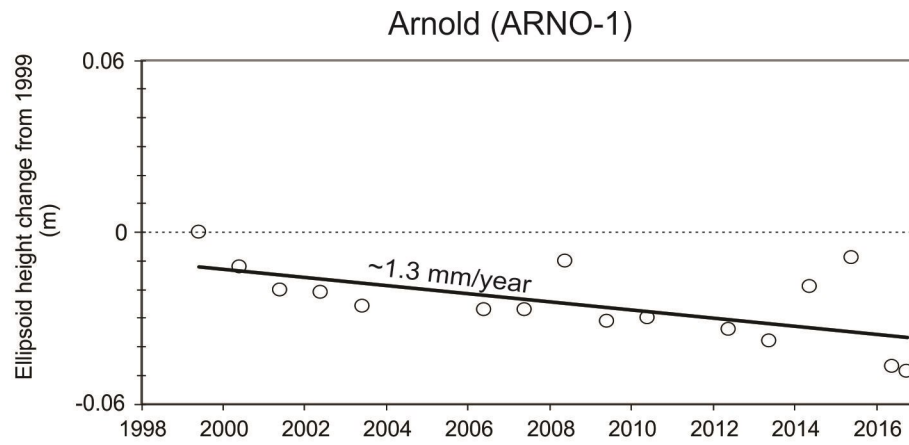
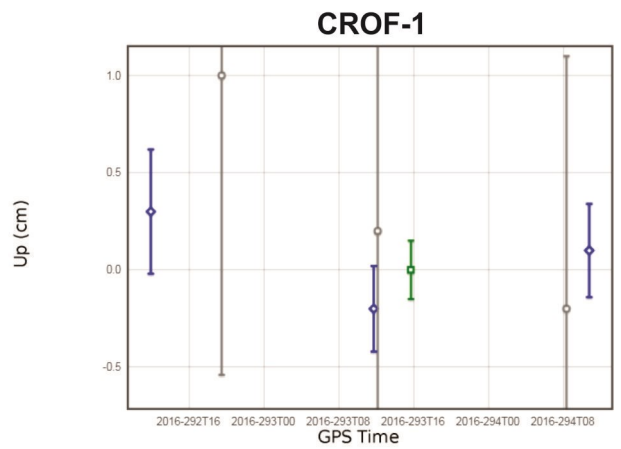
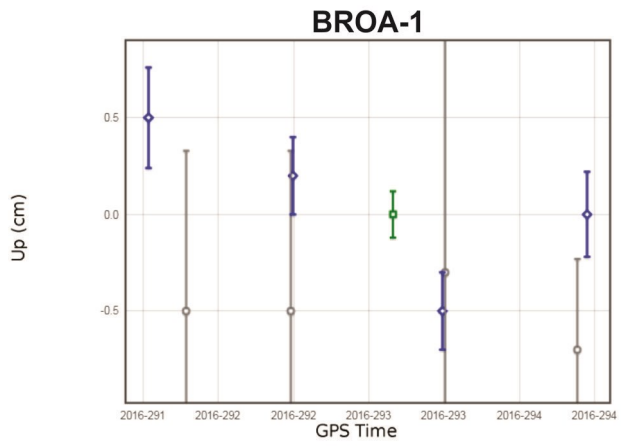
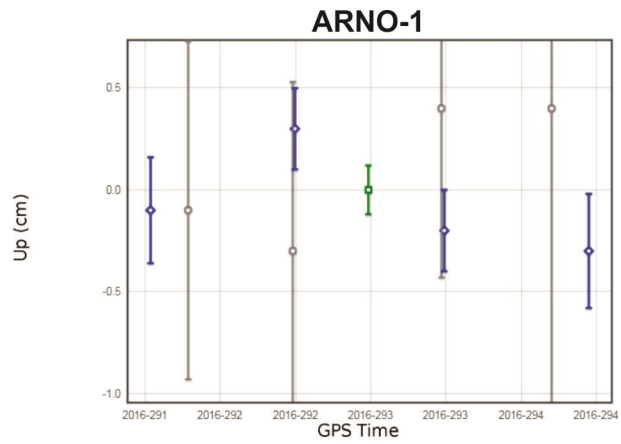


Figure 2. Change in ellipsoid height from 1999 at Arnold, Broad Creek and Crofton Meadows well fields.



○ | OPUS static
 ◇ | Session
 □ | Network

Figure 3. Height uncertainties.

Table 1. GPS sessions processed by OPUS-Projects.

Session	Period (Eastern Standard Time)
1 (Day 291)	10/17/16 13:00:00 to 10/17/16 23:59:45
2 (Day 292)	10/18/16 00:00:15 to 10/18/16 23:59:45
3 (Day 293)	10/19/16 00:00:15 to 10/19/16 23:59:45
4 (Day 294)	10/20/16 00:00:15 to 10/20/16 21:31:45

Table 2. CORS sites used in processing GPS data.

CORS site	State	Use in OPUS Projects	
GODE	MD	Hub	Unconstrained
KYTG	KY	Troposphere correction	Unconstrained
BACO	MD		Constrained
HNPT	MD		Constrained
LOYB	MD		Constrained
LOYF	MD		Constrained
LOYK	MD		Constrained
LOYM	MD		Constrained
LOYO	MD		Constrained
NRL1	DC		Constrained
UMBC	MD		Constrained

Table 3. Summary of Fall, 2016 GPS survey.

Mark	Horizontal (IGS08)		Vertical (IGS08)
	Latitude	Longitude	Ellipsoidal height (m)
ARNO-1	N39 02 05.55545	W076 29 25.28059	3.639
BROA-1	N38 58 54.34537	W076 33 31.12550	-6.184
CROF-1	N39 01 01.59387	W076 40 28.51400	7.090

Appendix A. OPUS Projects network adjustment for the Fall, 2016 GPS

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: 2017-07-29T16:29:53 UTC
 STANDARD ERROR OF UNIT WEIGHT: 0.759
 TOTAL NUMBER OF OBSERVATIONS: 1095555
 TOTAL NUMBER OF MARKS: 18
 NUMBER OF CONSTRAINED MARKS: 9

START TIME: 2016-10-17T00:00:00 GPS
 STOP TIME: 2016-10-20T23:59:30 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) 2016-291 A	1.2 cm	page5(1603.24)	2017-07-29T13:02 UTC
2) 2016-292 A	1.2 cm	page5(1603.24)	2017-07-29T15:49 UTC
3) 2016-293 A	1.4 cm	page5(1603.24)	2017-07-29T15:31 UTC
4) 2016-294 A	1.3 cm	page5(1603.24)	2017-07-29T15:33 UTC

BASELINE (S)	LENGTH	RMS	OBS	OMITTED	FIXED	IN SOLUTION
loyk-gode	12.538 km	1.0 cm	75092	0.6%	99.8%	1, 2, 3, 4
crof-gode	13.195 km	1.3 cm	36381	5.5%	94.5%	2, 3, 4
broa-gode	23.651 km	1.3 cm	58328	2.6%	99.0%	1, 2, 3, 4
loyf-gode	26.907 km	1.1 cm	75544	0.3%	99.8%	1, 2, 3, 4
ross-gode	27.469 km	1.6 cm	45333	13.5%	98.5%	1, 2, 3, 4
umbc-gode	27.934 km	1.2 cm	75696	0.2%	99.8%	1, 2, 3, 4
nr11-gode	28.131 km	1.1 cm	75829	0.2%	100.0%	1, 2, 3, 4
gode-arno	29.173 km	1.3 cm	52984	1.6%	100.0%	1, 2, 3, 4
loyb-gode	44.959 km	1.3 cm	75269	0.5%	99.8%	1, 2, 3, 4
baco-gode	46.042 km	1.1 cm	75175	0.9%	99.8%	1, 2, 3, 4
wals-gode	47.936 km	1.8 cm	49169	17.5%	96.6%	1, 2, 3, 4
hnpt-gode	77.261 km	1.0 cm	75112	0.3%	99.8%	1, 2, 3, 4
covs-gode	78.794 km	1.3 cm	55242	2.4%	99.0%	1, 2, 3, 4
loym-gode	80.728 km	1.0 cm	74159	2.3%	99.3%	1, 2, 3, 4
lexs-gode	90.184 km	1.7 cm	50162	10.3%	96.7%	1, 2, 3, 4
loyo-gode	117.013 km	1.2 cm	75141	0.7%	99.6%	1, 2, 3, 4

Appendix A. Continued.

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 UNCONSTRAINED MARKS
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MARK: ARNO-1

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2016.7978)	
X:	1158910.190 m	0.000 m	1158909.333 m	0.000 m
Y:	-4823629.205 m	0.001 m	-4823627.757 m	0.001 m
Z:	3995327.622 m	0.001 m	3995327.561 m	0.001 m
LAT:	39 02 05.52413	0.000 m	39 02 05.55544	0.000 m
E LON:	283 30 34.73997	0.000 m	283 30 34.71941	0.000 m
W LON:	76 29 25.26003	0.000 m	76 29 25.28059	0.000 m
EL HGT:	4.927 m	0.001 m	3.639 m	0.001 m
ORTHO HGT:	38.176 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)	371008.301 m	444125.197 m
CONVERGENCE	-0.93874162 deg	0.31987373 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-1

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2016.7983)	
X:	1154021.085 m	0.000 m	1154020.228 m	0.000 m
Y:	-4828609.421 m	0.001 m	-4828607.973 m	0.001 m
Z:	3990739.559 m	0.000 m	3990739.497 m	0.000 m
LAT:	38 58 54.31414	0.000 m	38 58 54.34537	0.000 m
E LON:	283 26 28.89514	0.000 m	283 26 28.87450	0.000 m
W LON:	76 33 31.10486	0.000 m	76 33 31.12550	0.000 m
EL HGT:	-4.894 m	0.001 m	-6.184 m	0.001 m
ORTHO HGT:	28.273 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)	364996.440 m	438241.225 m
CONVERGENCE	-0.98064625 deg	0.27701245 deg
POINT SCALE	0.99982443	0.99995155
COMBINED FACTOR	0.99982520	0.99995232

US NATIONAL GRID DESIGNATOR: 18SUJ6499615907 (NAD 83)

Appendix A. Continued.

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MARK: COV-1

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2016.7980)	
X:	1175163.278 m	0.000 m	1175162.425 m	0.000 m
Y:	-4866014.493 m	0.001 m	-4866013.036 m	0.001 m
Z:	3939155.595 m	0.001 m	3939155.529 m	0.001 m
LAT:	38 23 11.16049	0.000 m	38 23 11.19138	0.000 m
E LON:	283 34 37.91881	0.000 m	283 34 37.89875	0.000 m
W LON:	76 25 22.08119	0.000 m	76 25 22.10125	0.000 m
EL HGT:	-0.204 m	0.001 m	-1.512 m	0.001 m
ORTHO HGT:	34.188 m	0.016 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4249650.211 m	80056.585 m
EASTING (X)	375737.326 m	450428.646 m
CONVERGENCE	-0.88361820 deg	0.36227021 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-1

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2016.7996)	
X:	1143680.983 m	0.000 m	1143680.126 m	0.000 m
Y:	-4828541.831 m	0.001 m	-4828540.383 m	0.001 m
Z:	3993797.490 m	0.001 m	3993797.428 m	0.001 m
LAT:	39 01 01.56265	0.000 m	39 01 01.59387	0.000 m
E LON:	283 19 31.50679	0.000 m	283 19 31.48600	0.000 m
W LON:	76 40 28.49321	0.000 m	76 40 28.51400	0.000 m
EL HGT:	8.377 m	0.001 m	7.090 m	0.001 m
ORTHO HGT:	41.187 m	0.016 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4320008.241 m	149954.797 m
EASTING (X)	355025.640 m	428181.665 m
CONVERGENCE	-1.05442007 deg	0.20424379 deg
POINT SCALE	0.99985880	0.99995288
COMBINED FACTOR	0.99985749	0.99995157

US NATIONAL GRID DESIGNATOR: 18SUJ5502520008 (NAD 83)

Appendix A. Continued.

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MARK: GODE

REF FRAME:	NAD_83 (2011) (2010.0000)		IGS08 (2016.7980)	
X:	1130774.433 m	0.000 m	1130773.575 m	0.000 m
Y:	-4831255.031 m	0.001 m	-4831253.577 m	0.001 m
Z:	3994200.524 m	0.000 m	3994200.458 m	0.000 m
LAT:	39 01 18.18968	0.000 m	39 01 18.22092	0.000 m
E LON:	283 10 23.42543	0.000 m	283 10 23.40449	0.000 m
W LON:	76 49 36.57457	0.000 m	76 49 36.59551	0.000 m
EL HGT:	15.792 m	0.001 m	14.499 m	0.001 m
ORTHO HGT:	48.172 m	0.016 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES	STATE PLANE COORDINATES
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	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4320774.469 m	150431.507 m
EASTING (X)	341854.670 m	414996.118 m
CONVERGENCE	-1.15043529 deg	0.10868974 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

REF FRAME:	NAD_83 (2011) (2010.0000)		IGS08 (2016.7978)	
X:	482543.240 m	0.000 m	482542.396 m	0.000 m
Y:	-5004259.958 m	0.001 m	-5004258.529 m	0.001 m
Z:	3912211.819 m	0.001 m	3912211.717 m	0.001 m
LAT:	38 04 31.96500	0.000 m	38 04 31.99247	0.000 m
E LON:	275 30 28.08931	0.000 m	275 30 28.06047	0.000 m
W LON:	84 29 31.91069	0.000 m	84 29 31.93953	0.000 m
EL HGT:	265.105 m	0.001 m	263.858 m	0.001 m
ORTHO HGT:	298.421 m	0.013 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES	STATE PLANE COORDINATES
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	UTM (Zone 16)	SPC (1600 KY1Z)
NORTHING (Y)	4217166.882 m	1194099.196 m
EASTING (X)	719969.281 m	1610349.301 m
CONVERGENCE	1.54718163 deg	0.77224136 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: LEX-1

REF FRAME:	NAD_83 (2011) (2010.0000)	IGS08 (2016.7985)
X:	1174354.969 m 0.000 m	1174354.117 m 0.000 m
Y:	-4874932.344 m 0.001 m	-4874930.885 m 0.001 m
Z:	3928427.081 m 0.001 m	3928427.015 m 0.001 m
LAT:	38 15 47.65637 0.000 m	38 15 47.68718 0.000 m
E LON:	283 32 39.48269 0.000 m	283 32 39.46267 0.000 m
W LON:	76 27 20.51731 0.000 m	76 27 20.53733 0.000 m
EL HGT:	-0.764 m 0.001 m	-2.076 m 0.001 m
ORTHO HGT:	33.743 m 0.016 m	(H = h - N WHERE N = GEOID12B HGT)

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4236024.447 m	66364.193 m
EASTING (X)	372648.472 m	447635.911 m
CONVERGENCE	-0.90159979 deg	0.34162173 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: ROS-1

REF FRAME:	NAD_83 (2011) (2010.0000)	IGS08 (2016.7985)
X:	1135286.290 m 0.000 m	1135285.434 m 0.000 m
Y:	-4847925.459 m 0.001 m	-4847924.008 m 0.001 m
Z:	3972839.206 m 0.001 m	3972839.142 m 0.001 m
LAT:	38 46 27.61071 0.000 m	38 46 27.64175 0.000 m
E LON:	283 10 48.03361 0.000 m	283 10 48.01280 0.000 m
W LON:	76 49 11.96639 0.000 m	76 49 11.98720 0.000 m
EL HGT:	35.113 m 0.001 m	33.820 m 0.001 m
ORTHO HGT:	67.888 m 0.016 m	(H = h - N WHERE N = GEOID12B HGT)

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4293307.767 m	122971.192 m
EASTING (X)	341898.651 m	415642.202 m
CONVERGENCE	-1.14001356 deg	0.11298000 deg
POINT SCALE	0.99990781	0.99995141
COMBINED FACTOR	0.99990230	0.99994590

US NATIONAL GRID DESIGNATOR: 18SUH4189893307 (NAD 83)

Appendix A. Continued.

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MARK: WAL-1

REF FRAME:	NAD_83(2011) (2010.0000)	IGS08 (2016.7987)
X:	1127888.807 m 0.000 m	1127887.953 m 0.000 m
Y:	-4862133.275 m 0.001 m	-4862131.822 m 0.001 m
Z:	3957648.561 m 0.001 m	3957648.495 m 0.001 m
LAT:	38 35 56.63633 0.000 m	38 35 56.66720 0.000 m
E LON:	283 03 36.50708 0.000 m	283 03 36.48626 0.000 m
W LON:	76 56 23.49292 0.000 m	76 56 23.51374 0.000 m
EL HGT:	30.087 m 0.001 m	28.790 m 0.001 m
ORTHO HGT:	63.023 m 0.016 m	(H = h - N WHERE N = GEOID12B HGT)

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4274070.435 m	103501.648 m
EASTING (X)	331073.117 m	405238.857 m
CONVERGENCE	-1.21049981 deg	0.03774645 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

CONSTRAIN: 3-D NORMAL

ADJUST X:	0.004m (0.000m)	Y:	-0.012m (0.000m)	Z:	0.017m (0.000m)
ADJUST N:	0.005m (0.000m)	E:	0.002m (0.000m)	H:	0.021m (0.000m)

REF FRAME:	NAD_83(2011) (2010.0000)	IGS08 (2016.7978)
X:	1143199.192 m 0.000 m	1143198.330 m 0.000 m
Y:	-4801171.622 m 0.000 m	-4801170.166 m 0.000 m
Z:	4026765.158 m 0.000 m	4026765.081 m 0.000 m
LAT:	39 23 58.03763 0.000 m	39 23 58.06894 0.000 m
E LON:	283 23 35.55699 0.000 m	283 23 35.53604 0.000 m
W LON:	76 36 24.44301 0.000 m	76 36 24.46396 0.000 m
EL HGT:	128.329 m 0.000 m	127.031 m 0.000 m
ORTHO HGT:	160.892 m 0.016 m	(H = h - N WHERE N = GEOID12B HGT)

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4362337.564 m	192424.926 m
EASTING (X)	361647.407 m	433869.647 m
CONVERGENCE	-1.02002825 deg	0.24679219 deg
POINT SCALE	0.99983568	0.99999155
COMBINED FACTOR	0.99981555	0.99997142

US NATIONAL GRID DESIGNATOR: 18SUJ6164762337 (NAD 83)

Appendix A. Continued.

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MARK: hnpt (hnpt a 4)
 CONSTRAIN: 3-D NORMAL
 ADJUST X: -0.001m (0.000m) Y: -0.005m (0.000m) Z: 0.006m (0.000m)
 ADJUST N: 0.002m (0.000m) E: -0.003m (0.000m) H: 0.007m (0.000m)

REF FRAME: NAD_83(2011) (2010.0000) IGS08 (2016.7978)
 X: 1196627.024 m 0.000 m 1196626.171 m 0.000 m
 Y: -4846359.963 m 0.000 m -4846358.494 m 0.000 m
 Z: 3956723.213 m 0.000 m 3956723.140 m 0.000 m
 LAT: 38 35 19.71009 0.000 m 38 35 19.74124 0.000 m
 E LON: 283 52 10.66797 0.000 m 283 52 10.64828 0.000 m
 W LON: 76 07 49.33203 0.000 m 76 07 49.35172 0.000 m
 EL HGT: -26.667 m 0.000 m -27.988 m 0.000 m
 ORTHO HGT: 8.229 m 0.016 m (H = h - N WHERE N = GEOID12B HGT)

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4271753.565 m	102722.196 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: loyb (loyb a 1)
 CONSTRAIN: 3-D NORMAL
 ADJUST X: 0.005m (0.000m) Y: 0.002m (0.000m) Z: -0.003m (0.000m)
 ADJUST N: -0.001m (0.000m) E: 0.005m (0.000m) H: -0.003m (0.000m)

REF FRAME: NAD_83(2011) (2010.0000) IGS08 (2016.7978)
 X: 1105168.969 m 0.000 m 1105168.114 m 0.000 m
 Y: -4858128.336 m 0.000 m -4858126.886 m 0.000 m
 Z: 3968834.106 m 0.000 m 3968834.040 m 0.000 m
 LAT: 38 43 42.02173 0.000 m 38 43 42.05259 0.000 m
 E LON: 282 48 57.70209 0.000 m 282 48 57.68089 0.000 m
 W LON: 77 11 02.29791 0.000 m 77 11 02.31911 0.000 m
 EL HGT: -1.558 m 0.000 m -2.850 m 0.000 m
 ORTHO HGT: 30.657 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)	4288895.082 m	2118664.839 m
EASTING (X)	310154.955 m	3614427.842 m
CONVERGENCE	-1.36676290 deg	0.82135681 deg
POINT SCALE	1.00004384	0.99995025
COMBINED FACTOR	1.00004408	0.99995049

US NATIONAL GRID DESIGNATOR: 18SUH1015488895 (NAD 83)

Appendix A. Continued.

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MARK: loyf (loyf a 1)
CONSTRAIN: 3-D NORMAL
ADJUST X: -0.003m (0.000m) Y: 0.004m (0.000m) Z: -0.002m (0.000m)
ADJUST N: 0.001m (0.000m) E: -0.002m (0.000m) H: -0.005m (0.000m)

REF FRAME: NAD_83(2011) (2010.0000) IGS08 (2016.7978)
X: 1157209.562 m 0.000 m 1157208.705 m 0.000 m
Y: -4828361.999 m 0.000 m -4828360.548 m 0.000 m
Z: 3990104.475 m 0.000 m 3990104.414 m 0.000 m
LAT: 38 58 28.07416 0.000 m 38 58 28.10547 0.000 m
E LON: 283 28 40.11485 0.000 m 283 28 40.09426 0.000 m
W LON: 76 31 19.88515 0.000 m 76 31 19.90574 0.000 m
EL HGT: -14.501 m 0.000 m -15.791 m 0.000 m
ORTHO HGT: 18.761 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)	368140.232 m	441403.603 m
CONVERGENCE	-0.95755593 deg	0.29988966 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: loyk (loyk a 1)
CONSTRAIN: 3-D NORMAL
ADJUST X: 0.003m (0.000m) Y: -0.004m (0.000m) Z: 0.001m (0.000m)
ADJUST N: -0.002m (0.000m) E: 0.002m (0.000m) H: 0.004m (0.000m)

REF FRAME: NAD_83(2011) (2010.0000) IGS08 (2016.7978)
X: 1132081.311 m 0.000 m 1132080.453 m 0.000 m
Y: -4823104.344 m 0.000 m -4823102.896 m 0.000 m
Z: 4003637.187 m 0.000 m 4003637.127 m 0.000 m
LAT: 39 07 51.85824 0.000 m 39 07 51.88957 0.000 m
E LON: 283 12 33.74087 0.000 m 283 12 33.71987 0.000 m
W LON: 76 47 26.25913 0.000 m 76 47 26.28013 0.000 m
EL HGT: 35.299 m 0.000 m 34.015 m 0.000 m
ORTHO HGT: 67.691 m 0.016 m (H = h - N WHERE N = GEOID12B
HGT)

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4332848.500 m	162577.476 m
EASTING (X)	345227.716 m	418102.929 m
CONVERGENCE	-1.13028301 deg	0.13140930 deg
POINT SCALE	0.99989496	0.99995975
COMBINED FACTOR	0.99988942	0.99995421

Appendix A. Continued.

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

REF FRAME: NAD_83(2011) (2010.0000) IGS08 (2016.7978)
 X: 1158531.863 m 0.000 m 1158531.010 m 0.000 m
 Y: -4875375.216 m 0.000 m -4875373.758 m 0.000 m
 Z: 3932556.881 m 0.000 m 3932556.813 m 0.000 m
 LAT: 38 18 38.11893 0.000 m 38 18 38.14969 0.000 m
 E LON: 283 22 02.02620 0.000 m 283 22 02.00591 0.000 m
 W LON: 76 37 57.97380 0.000 m 76 37 57.99409 0.000 m
 EL HGT: 6.103 m 0.000 m 4.793 m 0.000 m
 ORTHO HGT: 39.976 m 0.016 m (H = h - N WHERE N = GEOID12B HGT)

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4241537.500 m	71542.812 m
EASTING (X)	357249.301 m	432118.015 m
CONVERGENCE	-1.01236453 deg	0.23048577 deg
POINT SCALE	0.99985096	0.99999817
COMBINED FACTOR	0.99985000	0.99999721

US NATIONAL GRID DESIGNATOR: 18SUH5724941537 (NAD 83)

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MARK: loyo (loyo a 1)
 CONSTRAIN: 3-D NORMAL
 ADJUST X: -0.013m (0.000m) Y: -0.003m (0.000m) Z: -0.008m (0.000m)
 ADJUST N: -0.006m (0.000m) E: -0.013m (0.000m) H: -0.006m (0.000m)

REF FRAME: NAD_83(2011) (2010.0000) IGS08 (2016.7978)
 X: 1101542.011 m 0.000 m 1101541.160 m 0.000 m
 Y: -4906910.944 m 0.000 m -4906909.486 m 0.000 m
 Z: 3909857.634 m 0.000 m 3909857.561 m 0.000 m
 LAT: 38 03 00.62614 0.000 m 38 03 00.65643 0.000 m
 E LON: 282 39 08.82621 0.000 m 282 39 08.80524 0.000 m
 W LON: 77 20 51.17379 0.000 m 77 20 51.19476 0.000 m
 EL HGT: 43.182 m 0.000 m 41.870 m 0.000 m
 ORTHO HGT: 75.863 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)	4213983.642 m	2043203.425 m
EASTING (X)	294018.057 m	3601150.714 m
CONVERGENCE	-1.44742297 deg	0.71926571 deg
POINT SCALE	1.00012258	0.99999707
COMBINED FACTOR	1.00011580	0.99999029

US NATIONAL GRID DESIGNATOR: 18STH9401813983 (NAD 83)

Appendix A. Continued.

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MARK: nrl1 (nrl1 a 1)
 CONSTRAIN: 3-D NORMAL
 ADJUST X: 0.004m (0.000m) Y: -0.002m (0.000m) Z: -0.010m (0.000m)
 ADJUST N: -0.010m (0.000m) E: 0.004m (0.000m) H: -0.004m (0.000m)

REF FRAME: NAD_83(2011) (2010.0000) IGS08 (2016.7978)
 X: 1117249.856 m 0.000 m 1117249.001 m 0.000 m
 Y: -4848760.140 m 0.000 m -4848758.688 m 0.000 m
 Z: 3976821.281 m 0.000 m 3976821.219 m 0.000 m
 LAT: 38 49 14.65941 0.000 m 38 49 14.69050 0.000 m
 E LON: 282 58 32.16458 0.000 m 282 58 32.14356 0.000 m
 W LON: 77 01 27.83542 0.000 m 77 01 27.85644 0.000 m
 EL HGT: -16.917 m 0.000 m -18.209 m 0.000 m
 ORTHO HGT: 15.308 m 0.016 m (H = h - N WHERE N = GEOID12B HGT)

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4298830.855 m	128107.007 m
EASTING (X)	324254.390 m	397881.208 m
CONVERGENCE	-1.26939151 deg	-0.01531347 deg
POINT SCALE	0.99998035	0.99995031
COMBINED FACTOR	0.99998300	0.99995296

US NATIONAL GRID DESIGNATOR: 18SUH2425498830 (NAD 83)

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MARK: umbc (umbc a 1)
 CONSTRAIN: 3-D NORMAL
 ADJUST X: -0.009m (0.000m) Y: 0.002m (0.000m) Z: 0.007m (0.000m)
 ADJUST N: 0.008m (0.000m) E: -0.009m (0.000m) H: 0.001m (0.000m)

REF FRAME: NAD_83(2011) (2010.0000) IGS08 (2016.7978)
 X: 1136717.972 m 0.000 m 1136717.113 m 0.000 m
 Y: -4812977.288 m 0.000 m -4812975.842 m 0.000 m
 Z: 4014471.590 m 0.000 m 4014471.531 m 0.000 m
 LAT: 39 15 24.36077 0.000 m 39 15 24.39221 0.000 m
 E LON: 283 17 18.53150 0.000 m 283 17 18.51050 0.000 m
 W LON: 76 42 41.46850 0.000 m 76 42 41.48950 0.000 m
 EL HGT: 65.940 m 0.000 m 64.661 m 0.000 m
 ORTHO HGT: 98.406 m 0.016 m (H = h - N WHERE N = GEOID12B HGT)

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4346666.825 m	176550.148 m
EASTING (X)	352329.283 m	424898.756 m
CONVERGENCE	-1.08323925 deg	0.18106051 deg
POINT SCALE	0.99986850	0.99997190
COMBINED FACTOR	0.99985816	0.99996155

US NATIONAL GRID DESIGNATOR: 18SUJ5232946666 (NAD 83)

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Secretary

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Deputy Secretary

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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