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

ADMINISTRATIVE REPORT NO. 23-02-01

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

FALL, 2022 SURVEY

by

Thomas P. Ulizio

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

DNR Publication No. 12-122222-342

2023

CONTENTS

ILLUSTRATIONS

TABLES

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

FALL, 2022 SURVEY

KEY RESULTS

A GPS campaign was conducted October 17-24, 2022 to determine heights of nine 3d marks to assess the potential effect of groundwater withdrawals from aquifers 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 the 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 2022 ellipsoid heights determined through OPUS Projects processing of GPS data were 3.608 meters at ARNO, -6.225 meters at BROA, 7.052 meters at CROF, -1.537 meters at COV1, -2.098 meters at LEX1, 33.822 meters at ROS1, 28.738 meters at WAL1, -35.665 meters at MSTP, and -36.056 meters at PTNK. Computed height uncertainties for all marks is +/- 0.1 cm. Uncertainty computed in the latitudinal and longitudinal positions of MGS marks is smaller than could be detected by OPUS Projects. Including these ellipsoid height data from 2022, vertical velocities have been updated for the nine 3d marks. In Anne Arundel County, ARNO is subsiding at 3.0 mm/yr., BROA is subsiding at 2.4 mm/yr., and CROF is subsiding at 2.5 mm/yr. In Southern Maryland, COV1 is subsiding at 2.7 mm/yr., LEX1 is subsiding at 1.8 mm/yr., and WAL1 is subsiding at 7.1 mm/yr. Data from ROS1, where groundwater use is relatively low, indicate an increase in ellipsoid height through time of 0.1 mm/yr. In the Blackwater National Wildlife Refuge, MSTP is subsiding at 12.5 mm/yr. and PTNK is subsiding at 6.5 mm/yr.

INTRODUCTION

Groundwater from the confined aquifers of the Maryland coastal plain has been withdrawn for decades as the primary source of 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 millimeters per year (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 in Anne Arundel County at 3d rod marks at the Arnold Water Treatment Plant (ARNO) and the Broad Creek Water Treatment Plant (BROA), and a 3d mark embedded in a concrete structure at 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 of 2014 (ITRF2014). Data available for reprocessing began in 1999.

GPS SURVEY

A GPS occupation of the mark ARNO was conducted October 17-24, 2022. Marks BROA and CROF were occupied October 17-22, 2022. Marks COV1, LEX1, ROS1, and WAL1 were occupied October 17-21, 2022. The occupations of the three Anne Arundel County sites were extended to October 24 because the tripod tip at ARNO was found off the survey mark during site visits. The tripod had to be reset twice; during the mornings of October 18 and October 19. The intent was to also extend the occupations of BROA and CROF to October 24, but problems providing the receivers with external power limited the occupation of these marks to October 22. Observation of MSTP occurred October 14-19, 2022. Observation of PTNK occurred October 21-27, 2022. Trimble NetR9 receivers were used with Zephyr 3 Geodetic Antennas for marks ARNO, BROA, CROF, LEX1, WAL1, MSTP, and PTNK. OPUS X90-D receivers with built-in antennas were used at COV1 and ROS1[1].

[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 GPS occupation of each survey mark was documented on a standardized observation log sheet (app A). Observation log sheets contain information about equipment deployed at each mark that is essential in data processing, such as antenna type and antenna reference point (ARP). Observation log sheets and RINEX data files will be archived, as in previous years, for open access at UNAVCO and Zenodo as part of a larger archive of data for the Chesapeake Bay region (Kronebusch and others, 2022; Troia and others, 2022).

The data were processed using the National Geodetic Survey'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 through 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 six sessions (tab. 1). Data processing parameters specified in OPUS Projects included a piecewise linear tropospheric model with an interval of 7,200 seconds, an elevation cutoff of 15.0 degrees, and normal constraint weights. Session processing was done using user-established data quality thresholds. If GPS data did not meet these data quality thresholds for a given GPS day of occupation, they were removed from that GPS day's session processing. The final network adjustment used eleven Continuously Operating Reference Stations (CORS) to establish baselines with MGS survey marks. All CORS data were constrained in three dimensions during the network adjustment, except for 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 24-year period of record, the ellipsoid height decreased by 78 millimeters (mm) at ARNO, 66 mm at BROA, and 59 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 7-year period of record, the ellipsoid heights decreased by 16 mm at COV1, 14 mm at LEX1, -10 mm at ROS1 (increase), and 41 mm at WAL1. The changes in ellipsoid height relative to the 2020 measurement at the marks MSTP and PTNK are shown in Figure 4. Over the 3-year period of record, the ellipsoid heights decreased by 25 mm at MSTP and 13 mm at PTNK. Ellipsoid heights decreased over time at marks ARNO, BROA, CROF, COV1, LEX1, WAL1, MSTP, and PTNK while the ellipsoid height increased at ROS1. These changes can be described by a linear trend; the variance about this trend is quantified by the coefficients of determination (R^2) seen in Figures 2-4. 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 Southern Maryland 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. A similar situation exists for the data from the Eastern Shore marks (MSTP and PTNK), having only a 3-year period of record. Year-to-year variation in computed ellipsoid heights and a shorter length of data record may obscure trends that would be present over a longer period of record.

Vertical velocities for each mark were computed by plotting the ellipsoid height derived from data processing in OPUS Projects versus time (figs. 2, 3, and 4). A linear trendline was fit to the ellipsoid height data and the slope of that trendline is the reported vertical velocity (tab. 3). The vertical velocities for the three Anne Arundel County marks ARNO, BROA, and CROF are -3.0 mm/yr., -2.4 mm/yr., and -2.5 mm/yr. respectively. The vertical velocities for the four southern Maryland marks, ROS1, WAL1, COV1 and LEX1 are 0.1 mm/yr., -7.1 mm/yr., -2.7 mm/yr., and -1.8 mm/yr. The vertical velocities for the two marks on the eastern shore of Maryland, MSTP and PTNK are -12.5 mm/yr. and -6.5 mm/yr.

ACKNOWLEDGMENTS

Funding for this project was provided by the Anne Arundel County Department of Public Works, Dominion Cove Point LNG, LP, and the United States Geological Survey (USGS). Special thanks are extended to Edward Cope of Anne Arundel County Department of Public Works, Dwayne Cantrell of St. Mary's County Metropolitan Commission, and Sam Seymonovsky of Charles County Department of Public Works for providing access to marks. Ryan Hippenstiel and Philippe Hensel of the National Geodetic Survey (NGS) graciously loaned equipment and technical expertise. David Andreasen (Maryland Geological Survey-retired) provided a technical review of this report. Additional thanks to David Walters (USGS), Philippe Hensel (NGS), Andrew Staley and Heather Quinn of the Maryland Geological Survey for their participation in setting up GPS equipment and field checking GPS equipment during occupation.

REFERENCES

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.

Davis, G.H., 1987, Land Subsidence and Sea Level Rise on the Atlantic Coastal Plain of the United States: Environmental Geology and Water Sciences, vol. 10, no. 2, p. 67-80.

Karegar, M.A., Dixon, T.H., and Engelhar, S.E., 2016, Subsidence along the Atlantic Coast of North America: Insights from GPS and late Holocene relative sea level data. Geophysical Research Letters, vol. 43, issue 7. p. 3126-3127.

Kronebusch, M., Troia, G., Stamps, S.D., Duda, J., Hensel, P., Hippenstiel, R., Moore, W.B., Geohegan, C., Ulizio, T.P., Franco, S., Anderson, R., Giron, M., Jordan, K.S., Walters, D., Crossman, B., Lerberg, S., Demeo, A., Fernish, K., Quinn, H., Lynch, J., Staley, A., Downey, L., Gavin, B., 2022, Chesapeake Bay Vertical Land Motions 2021, The GAGE Facility operated by UNAVCO, Inc., GPS/GNSS Observations Dataset, https://doi.org/10.7283/4ENN-6906.

Pope, J.P., and Burbey, T.J., 2004, Multiple-aquifer characterization from single borehole extensometer records: Ground Water, v. 42, no. 1, p. 45–58.

Staley, A.W., Andreasen, D.C., and Marchand, E.H., 2020, Potentiometric surface maps of selected confined aquifers in Southern Maryland and Maryland's Eastern Shore, 2019: Maryland Geological Survey Open File Report 20-02-01, 38 p.

Troia, G., Stamps, D.S., Lotspeich, R.R., Duda, J., McCoy, K.J., Moore, W., Hensel, P., Hippenstiel, R., McKenna, T., Andreasen, D., Geoghegan, C., Ulizio, T.P., Kronenbusch, M., Carr, J., Walters, D., Winn, N., 2022, GPS data from 2019 and 2020 campaigns in the Chesapeake Bay region towards quantifying vertical land motions. Scientific Data 9, 744, 5 p.

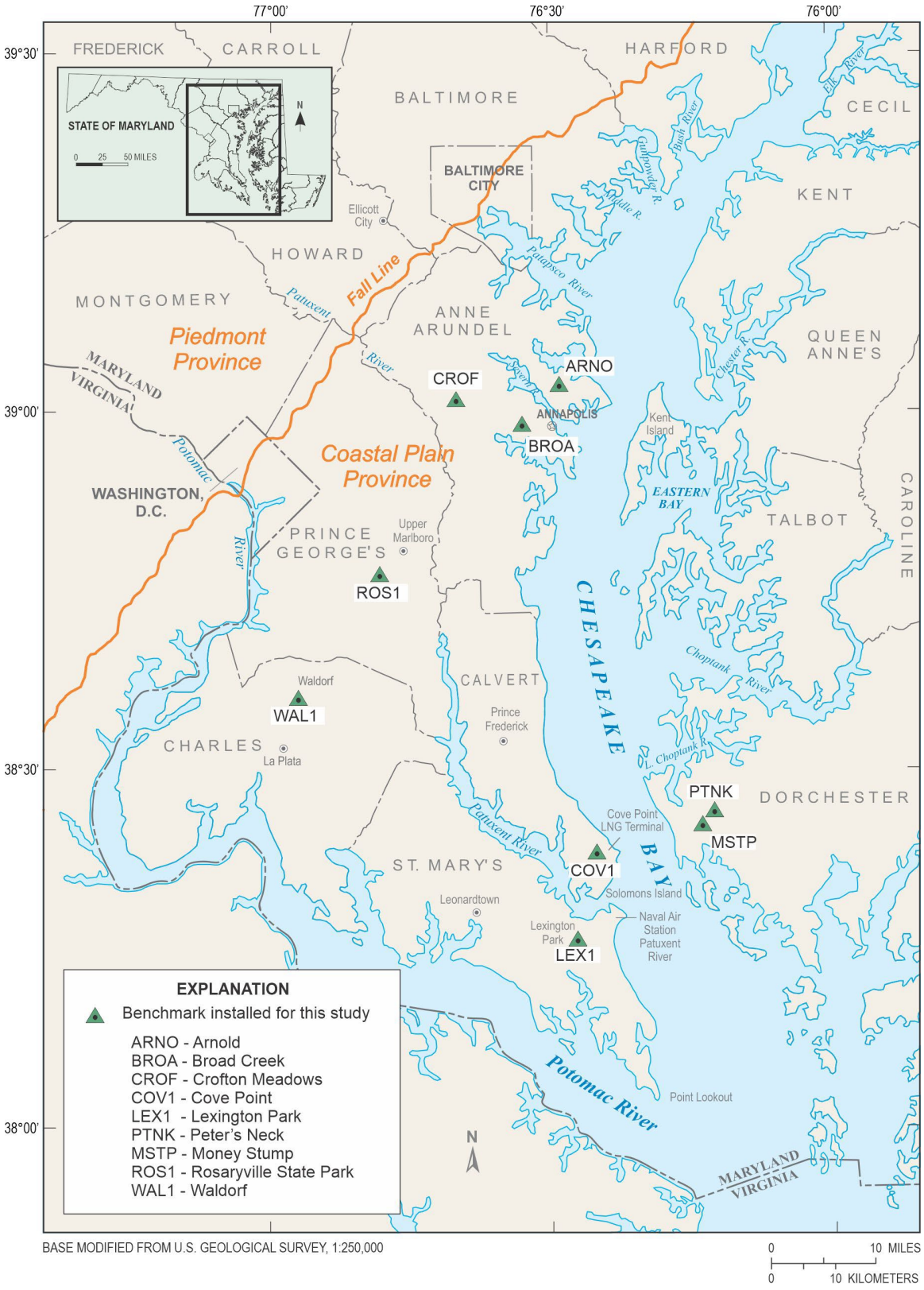

Figure 1. Location of the study area and MGS survey marks.

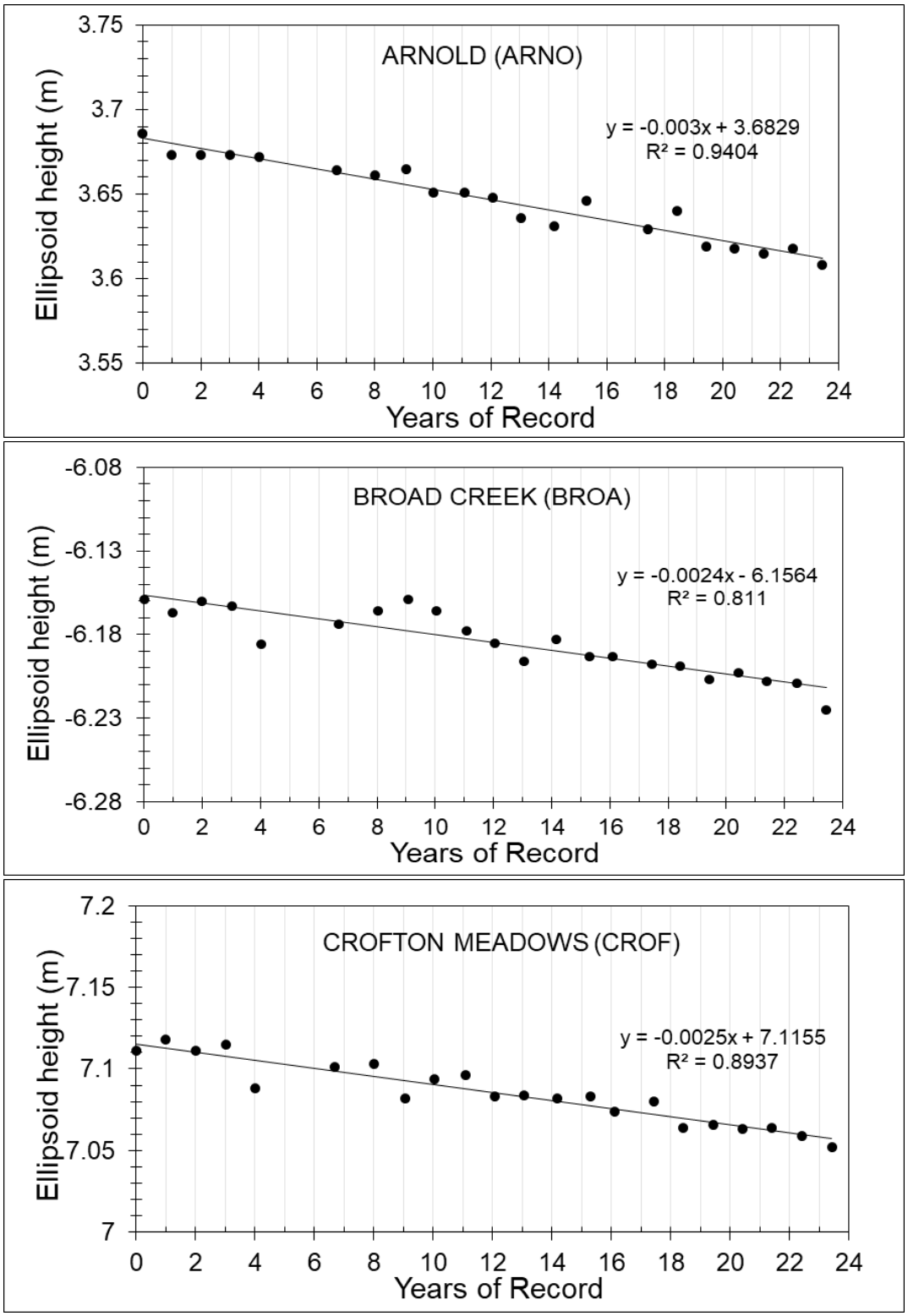

Figure 2. Change in ellipsoid heights from 1999 to present for marks ARNO, BROA, CROF.

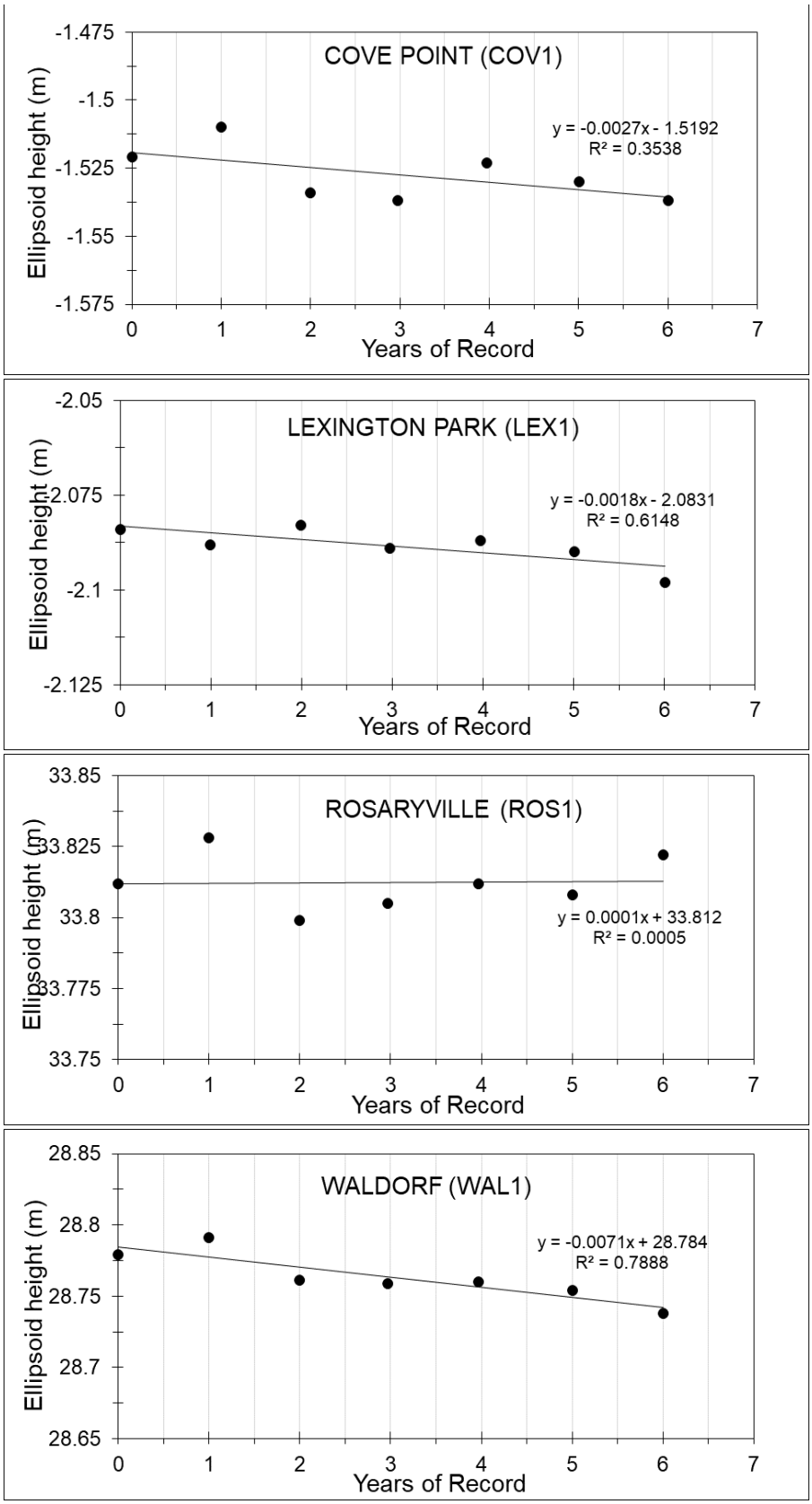

Figure 3. Change in ellipsoid heights from 2016 to present for marks COV1, LEX1, ROS1, WAL1.

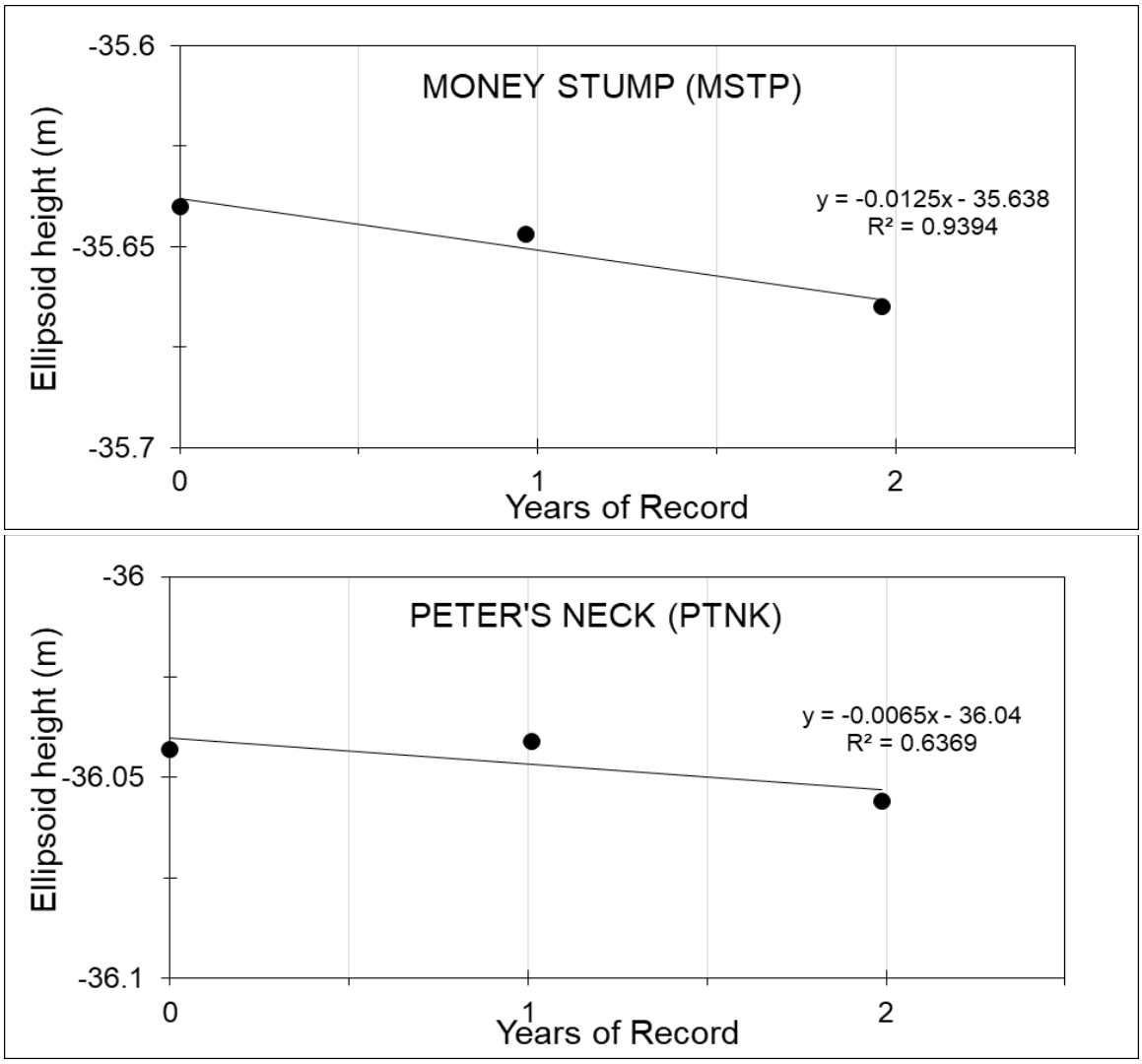

Figure 4. Change in ellipsoid heights from 2020 to present for marks MSTP and PTNK.

Table 1. GPS Sessions processed by OPUS Projects.

Session	Period (Coordinated Universal Time)	Hub CORS
1 (Day 290-A)	10/18/2022 0:00 to 23:59	GODE
2 (Day 291-A)	10/19/2022 0:00 to 23:59	GODE
3 (Day 292-A)	10/20/2022 0:00 to 23:59	GODE
4 (Day 293-A)	10/21/2022 0:00 to 23:59	GODE
5 (Day 294-A)	10/22/2022 0:00 to 23:59	GODE
6 (Day 295-A)	10/24/2022 0:00 to 23:59	GODE

Table 2. CORS sites used in processing GPS data.

CORS site	Start of record	State	Use in OPUS Projects	
BACO	1999	MD		Constrained
DED2	2012	DE		Constrained
DENE	2007	DE		Constrained
GODZ (E)	1993	MD	Hub	Constrained
LOY8	2005	VA		Constrained
LOYF	2006	MD		Constrained
LOYO	2006	VA		Constrained
MDAI	2017	MD		Constrained
STKR	2000	OH	Troposphere Correction	Unconstrained
UMBC	2002	MD		Constrained
ZDC1	2003	VA		Constrained

Table 3. Summary of 2022 (Fall) GPS data.

Mark	Horizontal (ITRF2014)		Vertical (ITRF2014)	
	Latitude	Longitude	Ellipsoid height (m)	Vertical Velocity (mm/yr)
ARNO	39.03487°	-76.49036°	3.608	-3.0
BROA	38.98176°	-76.55865°	-6.225	-2.4
COV1	38.38644°	-76.42281°	-1.537	-2.7
CROF	39.01711°	-76.67459°	7.052	-2.5
LEX1	38.26325°	-76.45571°	-2.098	-1.8
MSTP	38.42997°	-76.22608°	-35.665	-12.5
PTNK	38.45109°	-76.20379°	-36.056	-6.5
ROS1	38.77435°	-76.82000°	33.822	0.1
WAL1	38.59907°	-76.93987°	28.738	-7.1

Appendix A. Observation form used to document the occupation of GPS benchmark.

Chesapeake Bay Regional Vertical Land Motion Project

STATIC GNSS OBSERVATION FORM

CAMPAIGN YEAR (circle one): 2020 2021 ✓ 2022 2023
STATION 4CID: ARNO
DAY OF YEAR: 290

NAME / PARTY	STATION NAME / DESCRIPTION	NGS PID (if applicable)
Thomas Ulizio	ARNO/ Arnold Water Treatment Plant	N/A

AFFILIATION	CONTACT INFORMATION
Maryland Geological Survey	PHONE NUMBER (____) ___ - ____ EMAIL thomas.ulizio@maryland.gov

STATION CITY	STATION STATE	GEOGRAPHIC INFORMATION
Arnold	Maryland	SOURCE Google Earth Pro ELEVATION 126 ✓ Feet Meters (Circle one) +/- ____ DATUM WGS84 LAT (Dec.Deg) 39 . 03467 LONG (Dec.Deg) -76 . 49047 DATUM WGS84

OBSERVATION SESSION START TIME (GMT)	OBSERVATION SESSION END TIME (GMT)	TIME DATUM ADJUSTMENT
DATE 10 / 17 / 2021 TIME 16 : 25	DATE 10 / 21 / 2022 TIME 14 : 26	EST + 5 = GMT EDT + 4 = GMT

EQUIPMENT INVENTORY

GNSS RECEIVER
Model: Trimble NetR9
Part no: 67668-30
S/N: 5834R50357
Firmware version: 5.45
Agency ID: NGS FOB K

GNSS ANTENNA
Model: Trimble Zephyr 3
Part no: 115000-00
S/N: 6122223804
Agency ID: NGS FOB K
Radome: Yes ✓ No

TRIPOD
Type: Collapsible ✓ Fixed-Height
Agency ID: MGS 27
Calibration date: 10 / 4 / 2022

BATTERY
Voltage: 12 V Amp-hr: 18
Start: 12.38 V End: 11.89 V

SOLAR PANEL ✓ Yes No
Wattage 50 W
Agency ID: MGS

ANTENNA HEIGHT (m)
START: 1.9986 m
END: 1.9986 m
(1 ft = 0.3048 m)

RECEIVER PROGAMMING INFORMATION
COLLECTION INTERVAL 30 seconds (30-seconds is standard)
ELEVATION MASK 0 degrees (0 degrees is standard)

PHOTOGRAPHS (Take the following photographs and archive in campaign database)

	Description	Filename	Comments
1.	Close-up of monument	ARNO_closeup_20221017.jpg	
2.	Equipment setup	ARNO_setup_20221017.jpg	
3.	Horizon view North	ARNO_north_20221017.jpg	
4.	Horizon view East	ARNO_east_20221017.jpg	
5.	Horizon view South	ARNO_south_20221017.jpg	
6.	Horizon view West	ARNO_west_20221017	
7.	Receiver serial number	ARNO_receiver_20221017.jpg	
8.	Antenna serial number	ARNO_antenna_20221017.jpg	

GENERAL COMMENTS

Tripod tip was drifting off the mark initially. Field checks on 291 and 292 observed the tip off the mark. Tripod was reset each time. Day 293 circuit check observed tip ON the mark. Equipment was left for additional days to get data lost at the beginning of the survey.

File Download Date: 10 / 24 / 2022
Downloaded by: Thomas Ulizio
Raw Filename: ARNO290-ARNO297.T02
Raw File Size: 0.152-0.48[illegible] MB
Edits made to raw file? Yes
If edits made to raw file, explain: Edited raw files to include 4CID & GPS day. Raw files were originally named with S/N and calendar day

RINEX Conversion Date: 10 / 24 / 2022
Converted by: Thomas Ulizio
RINEX filename: ARNO290-ARNO297.22o
RINEX File Size: 0.588-1.86 MB

Ver. 20200909

page 1 of 1

Appendix B. OPUS Projects network adjustment for the Fall, 2022 GPS survey.

```
    ================================================

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_STKR.sum
SOLUTION SOFTWARE:             GPSCOM(2008.25)
SOLUTION DATE:                 2022-12-06T15:49:47 UTC
STANDARD ERROR OF UNIT WEIGHT: 0.798
TOTAL NUMBER OF OBSERVATIONS:  1697062
TOTAL NUMBER OF MARKS:         21
CONSTRAINED MARKS:             11 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
ded2 N38:39:52.31284 W075:22:38.77734 -14.8765m        ITRF2014 @ 2010.0000
ded2         0.13cm           0.08cm     0.13cm        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
gode N39:01:18.21996 W076:49:36.59163  14.4978m        ITRF2014 @ 2010.0000
gode         0.12cm           0.12cm     0.12cm        NEU SIGMAS
loy8 N38:16:58.72119 W077:27:09.48584  -6.2142m        ITRF2014 @ 2010.0000
loy8         0.12cm           0.10cm     0.12cm        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
mdai N38:08:20.62172 W075:11:19.85741 -34.4832m        ITRF2014 @ 2010.0000
mdai         0.12cm           0.12cm     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
wdc5 N38:55:14.03173 W077:03:58.74054  58.9778m        ITRF2014 @ 2010.0000
wdc5         0.12cm           0.12cm     0.12cm        NEU SIGMAS
zdc1 N39:06:05.74479 W077:32:33.88523  79.6180m        ITRF2014 @ 2010.0000
zdc1         0.14cm           0.06cm     0.14cm        NEU SIGMAS

START TIME:                    2022-10-17T00:00:00 GPS
STOP TIME:                     2022-10-22T23:59:30 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) 2022-290 A_STKR             1.4 cm  page5(2008.25)   2022-12-06T15:19 UTC
 2) 2022-291 A_STKR             1.4 cm  page5(2008.25)   2022-12-06T15:24 UTC
 3) 2022-292 A_STKR             1.3 cm  page5(2008.25)   2022-12-06T15:44 UTC
 4) 2022-293 A_STKR             1.2 cm  page5(2008.25)   2022-12-06T15:46 UTC
 5) 2022-294 A_STKR             1.2 cm  page5(2008.25)   2022-12-06T15:43 UTC
 6) 2022-295 A_STKR             1.1 cm  page5(2008.25)   2022-12-06T15:45 UTC

  BASELINE      LENGTH         RMS       OBS   OMITTED    FIXED IN SOLUTION(S)
-------------------------------------------------------------------------------
 crof-gode     13.195 km      1.1 cm    75160     7.5%    99.5%    2, 3, 4,...
 wdc5-gode     23.598 km      1.1 cm   112799     2.2%    99.6%    1, 2, 3,...
```

Appendix B. Continued.

```
 broa-gode     23.651 km      1.3 cm    70297     5.7%    98.8%    2, 3, 4, 5
 loyf-gode     26.907 km      1.2 cm   111139     0.8%    97.2%    1, 2, 3,...
 ros1-gode     27.469 km      2.0 cm    27013    15.3%    96.3%    2, 3
 umbc-gode     27.934 km      1.3 cm   111927     0.6%    98.9%    1, 2, 3,...
 arno-gode     29.173 km      1.3 cm    90476     3.6%    99.1%    2, 3, 4,...
 baco-gode     46.042 km      1.1 cm   110740     1.2%    97.7%    1, 2, 3,...
 wal1-gode     47.936 km      1.7 cm    63798    13.5%    98.5%    1, 2, 3,...
 zdc1-gode     62.595 km      1.2 cm   111630     1.8%    98.7%    1, 2, 3,...
 cov1-gode     78.794 km      1.3 cm    70834     3.0%    98.5%    1, 2, 3,...
 ptnk-gode     83.350 km      2.1 cm    28475    30.7%    98.1%    2, 3
 mstp-gode     83.930 km      1.6 cm    22319    23.8%    94.8%    1, 2
 lex1-gode     90.184 km      1.5 cm    59343    18.4%    95.0%    1, 2, 3,...
 loy8-gode     98.451 km      1.2 cm   110299     1.1%    97.9%    1, 2, 3,...
 loyo-gode    117.013 km      1.2 cm    91910     1.1%    99.0%    1, 2, 3,...
 dene-gode    118.388 km      1.1 cm   109533     0.8%    97.2%    1, 2, 3,...
 ded2-gode    131.928 km      1.5 cm   104269     6.0%    96.8%    1, 2, 3,...
 mdai-gode    173.112 km      0.9 cm   109961     0.4%    99.6%    1, 2, 3,...
 stkr-gode    457.384 km      1.1 cm   105140     1.4%    96.6%    1, 2, 3,...

 MARK  ESTIMATED - A PRIORI COORDINATE SHIFTS
--------------------------------------------------------------------------------
 arno  N:    0.000 m (0.000 m) E:   -0.003 m (0.000 m) H:    0.000 m (0.001 m)
 baco  N:    0.002 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.005 m (0.000 m)
 broa  N:    0.004 m (0.000 m) E:    0.003 m (0.000 m) H:   -0.080 m (0.001 m)
 cov1  N:    0.001 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.010 m (0.001 m)
 crof  N:    0.003 m (0.000 m) E:    0.000 m (0.000 m) H:   -0.010 m (0.001 m)
 ded2  N:   -0.007 m (0.000 m) E:    0.002 m (0.000 m) H:    0.013 m (0.000 m)
 dene  N:   -0.001 m (0.000 m) E:   -0.004 m (0.000 m) H:   -0.003 m (0.000 m)
 gode  N:    0.001 m (0.000 m) E:    0.002 m (0.000 m) H:   -0.001 m (0.000 m)
 lex1  N:    0.003 m (0.000 m) E:    0.000 m (0.000 m) H:   -0.014 m (0.001 m)
 loy8  N:    0.000 m (0.000 m) E:    0.000 m (0.000 m) H:    0.005 m (0.000 m)
 loyf  N:    0.001 m (0.000 m) E:    0.000 m (0.000 m) H:   -0.001 m (0.000 m)
 loyo  N:    0.002 m (0.000 m) E:   -0.001 m (0.000 m) H:    0.003 m (0.000 m)
 mdai  N:   -0.001 m (0.000 m) E:    0.002 m (0.000 m) H:   -0.001 m (0.000 m)
 mstp  N:    0.009 m (0.000 m) E:    0.001 m (0.000 m) H:    0.023 m (0.001 m)
 ptnk  N:    0.004 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.004 m (0.001 m)
 ros1  N:    0.002 m (0.000 m) E:    0.005 m (0.000 m) H:    0.022 m (0.001 m)
 stkr  N:   -0.001 m (0.000 m) E:    0.000 m (0.000 m) H:    0.001 m (0.001 m)
 umbc  N:    0.001 m (0.000 m) E:    0.000 m (0.000 m) H:    0.002 m (0.000 m)
 wal1  N:    0.006 m (0.000 m) E:   -0.002 m (0.000 m) H:   -0.011 m (0.001 m)
 wdc5  N:    0.002 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.007 m (0.000 m)
 zdc1  N:   -0.002 m (0.000 m) E:   -0.001 m (0.000 m) H:    0.000 m (0.000 m)

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
UNCONSTRAINED MARKS
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

MARK:      arno (arno    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.8014
X:                1158910.177 m    0.000 m          1158909.229 m    0.000 m
Y:               -4823629.182 m    0.000 m         -4823627.740 m    0.000 m
Z:                3995327.608 m    0.000 m          3995327.563 m    0.000 m
LAT:           39 02 05.52430      0.000 m       39 02 05.55632      0.000 m
E LON:        283 30 34.73967      0.000 m      283 30 34.71537      0.000 m
W LON:         76 29 25.26033      0.000 m       76 29 25.28463      0.000 m
EL HGT:                4.898 m    0.001 m                3.608 m    0.001 m
ORTHO HGT:            38.153 m    0.015 m  (= EL HGT - -33.255 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
```

Appendix B. Continued.

```
NORTHING (Y)      4321702.614 m         152000.082 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: 18SUJ7100821703 (NAD 83)

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

MARK:      broa (broa    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.8000
X:                1154021.085 m    0.000 m          1154020.137 m    0.000 m
Y:               -4828609.388 m    0.001 m         -4828607.945 m    0.001 m
Z:                3990739.536 m    0.000 m          3990739.490 m    0.000 m
LAT:           38 58 54.31421      0.000 m       38 58 54.34616      0.000 m
E LON:        283 26 28.89546      0.000 m      283 26 28.87109      0.000 m
W LON:         76 33 31.10454      0.000 m       76 33 31.12891      0.000 m
EL HGT:               -4.934 m    0.001 m               -6.225 m    0.001 m
ORTHO HGT:            28.251 m    0.015 m  (= EL HGT - -33.185 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4315907.113 m         146073.159 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)

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

MARK:      cov1 (cov1    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.7989
X:                1175163.271 m    0.000 m          1175162.329 m    0.000 m
Y:               -4866014.476 m    0.001 m         -4866013.024 m    0.001 m
Z:                3939155.582 m    0.000 m          3939155.533 m    0.000 m
LAT:           38 23 11.16053      0.000 m       38 23 11.19215      0.000 m
E LON:        283 34 37.91870      0.000 m      283 34 37.89499      0.000 m
W LON:         76 25 22.08130      0.000 m       76 25 22.10501      0.000 m
EL HGT:               -0.226 m    0.001 m               -1.536 m    0.001 m
ORTHO HGT:            34.166 m    0.017 m  (= EL HGT - -34.392 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4249650.212 m          80056.586 m
EASTING (X)        375737.323 m         450428.643 m
CONVERGENCE       -0.88361944 deg       0.36226944 deg
POINT SCALE        0.99979016           0.99998609
COMBINED FACTOR    0.99979020           0.99998613

US NATIONAL GRID DESIGNATOR: 18SUH7573749650 (NAD 83)

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

MARK:      crof (crof    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.8006
```

Appendix B. Continued.

```
X:                1143680.967 m    0.000 m          1143680.020 m    0.000 m
Y:               -4828541.801 m    0.001 m         -4828540.359 m    0.001 m
Z:                3993797.474 m    0.000 m          3993797.428 m    0.000 m
LAT:           39 01 01.56291      0.000 m       39 01 01.59485      0.000 m
E LON:        283 19 31.50644      0.000 m      283 19 31.48194      0.000 m
W LON:         76 40 28.49356      0.000 m       76 40 28.51806      0.000 m
EL HGT:                8.341 m    0.001 m                7.052 m    0.001 m
ORTHO HGT:            41.156 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: 18SUJ5502620008 (NAD 83)

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

MARK:      lex1 (lex1    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.7991
X:                1174354.961 m    0.000 m          1174354.019 m    0.000 m
Y:               -4874932.326 m    0.001 m         -4874930.873 m    0.001 m
Z:                3928427.073 m    0.001 m          3928427.022 m    0.001 m
LAT:           38 15 47.65656      0.000 m       38 15 47.68807      0.000 m
E LON:        283 32 39.48254      0.000 m      283 32 39.45887      0.000 m
W LON:         76 27 20.51746      0.000 m       76 27 20.54113      0.000 m
EL HGT:               -0.784 m    0.001 m               -2.098 m    0.001 m
ORTHO HGT:            33.720 m    0.017 m  (= EL HGT - -34.504 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4236024.453 m          66364.199 m
EASTING (X)        372648.469 m         447635.907 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)

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

MARK:      mstp (mstp    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.7940
X:                1191143.028 m    0.000 m          1191142.085 m    0.000 m
Y:               -4859009.468 m    0.001 m         -4859008.017 m    0.001 m
Z:                3942920.446 m    0.001 m          3942920.397 m    0.001 m
LAT:           38 25 47.85570      0.000 m       38 25 47.88738      0.000 m
E LON:        283 46 26.14158      0.000 m      283 46 26.11808      0.000 m
W LON:         76 13 33.85842      0.000 m       76 13 33.88192      0.000 m
EL HGT:               -34.356 m    0.001 m              -35.666 m    0.001 m
ORTHO HGT:              0.552 m    0.015 m  (= EL HGT - -34.908 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4254233.473 m          85015.142 m
EASTING (X)        392983.823 m         467575.059 m
```

Appendix B. Continued.

```
CONVERGENCE       -0.76214722 deg       0.48574444 deg
POINT SCALE        0.99974104           0.99997993
COMBINED FACTOR    0.99974643           0.99998532

US NATIONAL GRID DESIGNATOR: 18SUH9298454233 (NAD 83)

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

MARK:      ptnk (ptnk    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.7973
X:                 1192685.681 m    0.000 m          1192684.738 m    0.000 m
Y:                -4857129.967 m    0.001 m         -4857128.516 m    0.001 m
Z:                 3944756.409 m    0.001 m          3944756.361 m    0.001 m
LAT:            38 27 03.88513      0.000 m       38 27 03.91686      0.000 m
E LON:         283 47 46.38812      0.000 m      283 47 46.36461      0.000 m
W LON:          76 12 13.61188      0.000 m       76 12 13.63539      0.000 m
EL HGT:               -34.747 m    0.001 m              -36.056 m    0.001 m
ORTHO HGT:              0.198 m    0.015 m  (= EL HGT - -34.945 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4256551.349 m          87376.084 m
EASTING (X)        394960.121 m         469500.863 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)

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

MARK:      ros1 (ros1    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.7973
X:                 1135286.279 m    0.000 m          1135285.333 m    0.000 m
Y:                -4847925.447 m    0.001 m         -4847924.002 m    0.001 m
Z:                 3972839.231 m    0.001 m          3972839.183 m    0.001 m
LAT:            38 46 27.61163      0.000 m       38 46 27.64337      0.000 m
E LON:         283 10 48.03328      0.000 m      283 10 48.00878      0.000 m
W LON:          76 49 11.96672      0.000 m       76 49 11.99122      0.000 m
EL HGT:               35.118 m    0.001 m              33.822 m    0.001 m
ORTHO HGT:            67.906 m    0.016 m  (= EL HGT - -32.788 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4293307.795 m         122971.221 m
EASTING (X)        341898.644 m         415642.194 m
CONVERGENCE       -1.14001389 deg       0.11298056 deg
POINT SCALE        0.99990781           0.99995141
COMBINED FACTOR    0.99990230           0.99994590

US NATIONAL GRID DESIGNATOR: 18SUH4189993308 (NAD 83)

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

MARK:      stkr (stkr a  3)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.8000
X:                  678451.044 m    0.000 m           678450.096 m    0.000 m
Y:                -4893799.719 m    0.000 m         -4893798.286 m    0.000 m
```

Appendix B. Continued.

```
Z:                4020496.781 m    0.000 m          4020496.701 m    0.000 m
LAT:           39 19 33.82489      0.000 m       39 19 33.85473      0.000 m
E LON:        277 53 34.37029      0.000 m      277 53 34.33931      0.000 m
W LON:         82 06 25.62971      0.000 m       82 06 25.66069      0.000 m
EL HGT:              178.036 m    0.001 m             176.787 m    0.001 m
ORTHO HGT:           212.222 m    0.018 m  (= EL HGT - -34.186 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 17)         SPC (3402 OH S)
NORTHING (Y)      4353545.419 m         147284.039 m
EASTING (X)        404572.968 m         633874.819 m
CONVERGENCE       -0.70166944 deg       0.24929167 deg
POINT SCALE        0.99971212           0.99993642
COMBINED FACTOR    0.99968420           0.99990849

US NATIONAL GRID DESIGNATOR: 17SMD0457353545 (NAD 83)

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

MARK:      wal1 (wal1    1)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.7992
X:                1127888.796 m    0.000 m          1127887.852 m    0.000 m
Y:               -4862133.230 m    0.001 m         -4862131.783 m    0.001 m
Z:                3957648.540 m    0.000 m          3957648.490 m    0.000 m
LAT:           38 35 56.63673      0.000 m       38 35 56.66829      0.000 m
E LON:        283 03 36.50706      0.000 m      283 03 36.48256      0.000 m
W LON:         76 56 23.49294      0.000 m       76 56 23.51744      0.000 m
EL HGT:              30.038 m    0.001 m              28.738 m    0.001 m
ORTHO HGT:           62.948 m    0.016 m  (= EL HGT - -32.910 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4274070.448 m         103501.661 m
EASTING (X)        331073.116 m         405238.857 m
CONVERGENCE       -1.21050000 deg       0.03774722 deg
POINT SCALE        0.99995142           0.99996145
COMBINED FACTOR    0.99994671           0.99995674

US NATIONAL GRID DESIGNATOR: 18SUH3107374070 (NAD 83)


++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
CONSTRAINED MARKS
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

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:   -0.005 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.8000
X:                1143199.185 m    0.000 m          1143198.234 m    0.000 m
Y:               -4801171.601 m    0.000 m         -4801170.163 m    0.000 m
Z:                4026765.136 m    0.000 m          4026765.094 m    0.000 m
LAT:           39 23 58.03753      0.000 m       39 23 58.06980      0.000 m
E LON:        283 23 35.55691      0.000 m      283 23 35.53216      0.000 m
W LON:         76 36 24.44309      0.000 m       76 36 24.46784      0.000 m
EL HGT:              128.298 m    0.000 m             127.020 m    0.000 m
ORTHO HGT:           160.866 m    0.015 m  (= EL HGT - -32.568 GEOID18 HGT)
```

Appendix B. Continued.

```
                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    0.99981556           0.99997142

US NATIONAL GRID DESIGNATOR: 18SUJ6164762338 (NAD 83)

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

MARK:      ded2 (ded2 a  1)
CONSTRAIN: 3-D NORMAL
     N38:39:52.31284 W075:22:38.77734 -14.8765m        ITRF2014 @ 2010.0000
             0.13cm           0.08cm     0.13cm        NEU SIGMAS
SHIFTS N:   -0.007 m (0.000 m) E:    0.002 m (0.000 m) H:    0.013 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2022.8000
X:                 1258886.971 m    0.000 m          1258886.013 m    0.000 m
Y:                -4825149.970 m    0.000 m         -4825148.489 m    0.000 m
Z:                 3963297.567 m    0.000 m          3963297.518 m    0.000 m
LAT:            38 39 52.28219      0.000 m       38 39 52.31488      0.000 m
E LON:         284 37 21.23783      0.000 m      284 37 21.21494      0.000 m
W LON:          75 22 38.76217      0.000 m       75 22 38.78506      0.000 m
EL HGT:               -13.557 m    0.000 m             -14.896 m    0.000 m
ORTHO HGT:             22.097 m    0.015 m  (= EL HGT - -35.654 GEOID18 HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (0700 DE)
NORTHING (Y)      4279616.964 m           73764.241 m
EASTING (X)        467163.510 m          203414.564 m
CONVERGENCE       -0.23580833 deg       0.02451111 deg
POINT SCALE        0.99961328           0.99999514
COMBINED FACTOR    0.99961541           0.99999727

US NATIONAL GRID DESIGNATOR: 18SVH6716479617 (NAD 83)

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

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:   -0.004 m (0.000 m) H:   -0.003 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2022.8000
X:                 1210598.675 m    0.000 m          1210597.719 m    0.000 m
Y:                -4764306.697 m    0.000 m         -4764305.249 m    0.000 m
Z:                 4050429.565 m    0.000 m          4050429.524 m    0.000 m
LAT:            39 40 36.24962      0.000 m       39 40 36.28253      0.000 m
E LON:         284 15 25.17087      0.000 m      284 15 25.14695      0.000 m
W LON:          75 44 34.82913      0.000 m       75 44 34.85305      0.000 m
EL HGT:                6.543 m      0.000 m                5.255 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)        436278.659 m          172001.594 m
```

Appendix B. Continued.

```
CONVERGENCE       -0.47439444 deg      -0.20835556 deg
POINT SCALE        0.99964999           1.00000465
COMBINED FACTOR    0.99964896           1.00000362

US NATIONAL GRID DESIGNATOR: 18SVJ3627992143 (NAD 83)

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

MARK:      gode (gode a  4)
CONSTRAIN: 3-D NORMAL
     N39:01:18.21996 W076:49:36.59163  14.4978m        ITRF2014 @ 2010.0000
             0.12cm           0.12cm     0.12cm        NEU SIGMAS
SHIFTS N:    0.001 m (0.000 m) E:    0.002 m (0.000 m) H:   -0.001 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.7998
X:                1130774.429 m    0.000 m          1130773.478 m    0.000 m
Y:               -4831255.023 m    0.000 m         -4831253.567 m    0.000 m
Z:                3994200.520 m    0.000 m          3994200.465 m    0.000 m
LAT:           39 01 18.18976      0.000 m       39 01 18.22175      0.000 m
E LON:        283 10 23.42535      0.000 m      283 10 23.40063      0.000 m
W LON:         76 49 36.57465      0.000 m       76 49 36.59937      0.000 m
EL HGT:               15.783 m    0.000 m              14.479 m    0.000 m
ORTHO HGT:            48.163 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         150431.509 m
EASTING (X)        341854.668 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: 18SUJ4185520774 (NAD 83)

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

MARK:      loy8 (loy8 a  2)
CONSTRAIN: 3-D NORMAL
     N38:16:58.72119 W077:27:09.48584  -6.2142m        ITRF2014 @ 2010.0000
             0.12cm           0.10cm     0.12cm        NEU SIGMAS
SHIFTS N:    0.000 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 @ 2022.8000
X:                1089063.552 m    0.000 m          1089062.603 m    0.000 m
Y:               -4893299.386 m    0.000 m         -4893297.921 m    0.000 m
Z:                3930144.038 m    0.000 m          3930143.971 m    0.000 m
LAT:           38 16 58.69165      0.000 m       38 16 58.72284      0.000 m
E LON:        282 32 50.53140      0.000 m      282 32 50.50638      0.000 m
W LON:         77 27 09.46860      0.000 m       77 27 09.49362      0.000 m
EL HGT:               -4.905 m    0.000 m              -6.230 m    0.000 m
ORTHO HGT:            27.632 m    0.015 m  (= EL HGT - -32.537 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (4501 VA N)
NORTHING (Y)      4240057.446 m        2068930.986 m
EASTING (X)        285480.305 m        3591633.297 m
CONVERGENCE       -1.52009444 deg       0.65368333 deg
POINT SCALE        1.00016678           0.99996533
COMBINED FACTOR    1.00016755           0.99996610

US NATIONAL GRID DESIGNATOR: 18STH8548040057 (NAD 83)
```

Appendix B. Continued.

```
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

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:    0.000 m (0.000 m) H:   -0.001 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000             ITRF2014 @ 2022.8000
X:                 1157209.557 m    0.000 m          1157208.603 m    0.000 m
Y:                -4828361.999 m    0.000 m         -4828360.536 m    0.000 m
Z:                 3990104.480 m    0.000 m          3990104.423 m    0.000 m
LAT:            38 58 28.07431      0.000 m       38 58 28.10642      0.000 m
E LON:         283 28 40.11464      0.000 m      283 28 40.09029      0.000 m
W LON:          76 31 19.88536      0.000 m       76 31 19.90971      0.000 m
EL HGT:               -14.499 m    0.000 m             -15.814 m    0.000 m
ORTHO HGT:             18.781 m    0.015 m  (= EL HGT - -33.280 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4315044.792 m         145279.935 m
EASTING (X)        368140.228 m         441403.598 m
CONVERGENCE       -0.95755556 deg       0.29988889 deg
POINT SCALE        0.99981410           0.99995133
COMBINED FACTOR    0.99981637           0.99995360

US NATIONAL GRID DESIGNATOR: 18SUJ6814015045 (NAD 83)

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

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:    0.002 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 @ 2022.7986
X:                 1101542.003 m    0.000 m          1101541.062 m    0.000 m
Y:                -4906910.942 m    0.000 m         -4906909.479 m    0.000 m
Z:                 3909857.637 m    0.000 m          3909857.575 m    0.000 m
LAT:            38 03 00.62629      0.000 m       38 03 00.65736      0.000 m
E LON:         282 39 08.82591      0.000 m      282 39 08.80138      0.000 m
W LON:          77 20 51.17409      0.000 m       77 20 51.19862      0.000 m
EL HGT:               43.180 m     0.000 m              41.855 m     0.000 m
ORTHO HGT:            75.864 m     0.021 m  (= EL HGT - -32.684 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (4501 VA N)
NORTHING (Y)      4213983.646 m         2043203.430 m
EASTING (X)        294018.050 m         3601150.707 m
CONVERGENCE       -1.44742222 deg        0.71926667 deg
POINT SCALE        1.00012258           0.99999707
COMBINED FACTOR    1.00011580           0.99999029

US NATIONAL GRID DESIGNATOR: 18STH9401813984 (NAD 83)

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

MARK:      mdai (mdai a  1)
CONSTRAIN: 3-D NORMAL
```

Appendix B. Continued.

```
     N38:08:20.62172 W075:11:19.85741 -34.4832m        ITRF2014 @ 2010.0000
             0.12cm           0.12cm     0.12cm        NEU SIGMAS
SHIFTS N:   -0.001 m (0.000 m) E:    0.002 m (0.000 m) H:   -0.001 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2022.8000
X:                1284020.350 m    0.000 m          1284019.408 m    0.000 m
Y:               -4855993.774 m    0.000 m         -4855992.315 m    0.000 m
Z:                3917574.578 m    0.000 m          3917574.534 m    0.000 m
LAT:           38 08 20.59159      0.000 m       38 08 20.62353      0.000 m
E LON:        284 48 40.15729      0.000 m      284 48 40.13519      0.000 m
W LON:         75 11 19.84271      0.000 m       75 11 19.86481      0.000 m
EL HGT:              -33.160 m    0.000 m             -34.486 m    0.000 m
ORTHO HGT:             3.131 m    0.019 m  (= EL HGT - -36.291 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4221260.289 m          54012.449 m
EASTING (X)        483451.245 m         558771.986 m
CONVERGENCE       -0.11662500 deg       1.13674167 deg
POINT SCALE        0.99960337           1.00003190
COMBINED FACTOR    0.99960857           1.00003710

US NATIONAL GRID DESIGNATOR: 18SVH8345121260 (NAD 83)

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

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:    0.002 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2022.8000
X:                1136717.967 m    0.000 m          1136717.015 m    0.000 m
Y:               -4812977.288 m    0.000 m         -4812975.841 m    0.000 m
Z:                4014471.593 m    0.000 m          4014471.543 m    0.000 m
LAT:           39 15 24.36087      0.000 m       39 15 24.39301      0.000 m
E LON:        283 17 18.53130      0.000 m      283 17 18.50654      0.000 m
W LON:         76 42 41.46870      0.000 m       76 42 41.49346      0.000 m
EL HGT:              65.941 m     0.000 m              64.650 m     0.000 m
ORTHO HGT:           98.406 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         424898.751 m
CONVERGENCE       -1.08323889 deg       0.18106111 deg
POINT SCALE        0.99986850           0.99997190
COMBINED FACTOR    0.99985816           0.99996155

US NATIONAL GRID DESIGNATOR: 18SUJ5232946667 (NAD 83)

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

MARK:      wdc5 (wdc5 a  1)
CONSTRAIN: 3-D NORMAL
     N38:55:14.03173 W077:03:58.74054  58.9778m        ITRF2014 @ 2010.0000
             0.12cm           0.12cm     0.12cm        NEU SIGMAS
SHIFTS N:    0.002 m (0.000 m) E:    0.001 m (0.000 m) H:   -0.007 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2022.8000
```

Appendix B. Continued.

```
X:                1112159.532 m    0.000 m          1112158.585 m    0.000 m
Y:               -4842857.052 m    0.000 m         -4842855.610 m    0.000 m
Z:                3985497.033 m    0.000 m          3985496.985 m    0.000 m
LAT:           38 55 14.00170      0.000 m       38 55 14.03344      0.000 m
E LON:        282 56 01.27666      0.000 m      282 56 01.25172      0.000 m
W LON:         77 03 58.72334      0.000 m       77 03 58.74828      0.000 m
EL HGT:               60.258 m    0.000 m              58.969 m    0.000 m
ORTHO HGT:            92.249 m    0.014 m  (= EL HGT - -31.991 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4309990.458 m         139189.278 m
EASTING (X)        320866.237 m         394249.496 m
CONVERGENCE       -1.29848889 deg      -0.04161944 deg
POINT SCALE        0.99999515           0.99995015
COMBINED FACTOR    0.99998570           0.99994070

US NATIONAL GRID DESIGNATOR: 18SUJ2086609990 (NAD 83)

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

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     0.14cm        NEU SIGMAS
SHIFTS N:   -0.002 m (0.000 m) E:   -0.001 m (0.000 m) H:    0.000 m (0.000 m)

REF FRAME:        NAD_83(2011) @ 2010.0000              ITRF2014 @ 2022.8000
X:                1069126.500 m    0.000 m          1069125.543 m    0.000 m
Y:               -4839600.096 m    0.000 m         -4839598.649 m    0.000 m
Z:                4001126.300 m    0.000 m          4001126.241 m    0.000 m
LAT:           39 06 05.71462      0.000 m       39 06 05.74625      0.000 m
E LON:        282 27 26.13248      0.000 m      282 27 26.10659      0.000 m
W LON:         77 32 33.86752      0.000 m       77 32 33.89341      0.000 m
EL HGT:               80.897 m    0.000 m              79.603 m    0.000 m
ORTHO HGT:           113.250 m    0.016 m  (= EL HGT - -32.353 GEOID18 HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (4501 VA N)
NORTHING (Y)      4331128.271 m         2159710.545 m
EASTING (X)        280119.881 m         3582802.375 m
CONVERGENCE       -1.60434167 deg       0.59744167 deg
POINT SCALE        1.00019535           0.99998402
COMBINED FACTOR    1.00018266           0.99997133

US NATIONAL GRID DESIGNATOR: 18STJ8012031128 (NAD 83)
```

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
Resource Assessment Service
Tawes State Office Building
580 Taylor Avenue
Annapolis, Maryland 21401
Toll free in Maryland: 877-620-8DNR
Out of State call: 410-260-8021
TTY users: Call via the Maryland Relay
dnr.Maryland.gov

MARYLAND GEOLOGICAL SURVEY
2300 St. Paul Street
Baltimore, Maryland 21218
Telephone Contact Information: 410-554-5500
mgs.md.gov

DNR Publication No. 12-122222-342