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ESTABLISHMENT OF A LAND SUBSIDENCE-MONITORING NETWORK TO ASSESS THE POTENTIAL EFFECTS OF GROUNDWATER WITHDRAWALS IN SOUTHERN MARYLAND

by

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Prepared in cooperation with the
Dominion Cove Point LNG, LP

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ABBREVIATIONS USED IN THIS REPORT

General

GPS	global positioning system
LNG	liquid natural gas
LP	limited partnership
MDE	Maryland Department of the Environment
MGS	Maryland Geological Survey
NGS	National Geodetic Survey
OPUS	Online Positioning User Service
PVC	polyvinyl chloride

Units of Measurement

ft	feet
in.	inch
mi	miles
cm	centimeter
m	meters
gal/d	gallons per day
%	percent
±	plus/minus
<	less than

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KEY RESULTS

A network consisting of four 3D rod survey marks was installed to monitor potential changes in land elevation as a result of groundwater withdrawals in Southern Maryland. Decades of groundwater use in Southern Maryland have caused groundwater levels to decline by as much as ~70 meters (230 feet), reducing interstitial hydrostatic pore pressures and raising the potential for compaction and land subsidence. While the magnitude of land subsidence will likely be small (millimeter per year scale) and therefore not pose major engineering problems, it could exacerbate the problem of tidal flooding in low-lying areas caused by sea-level rise. Three of the survey marks installed − Cove Point (COV-1) in Calvert County, Lexington Park (LEX-1) in St. Mary's County, and Waldorf (WAL-1) in Charles County − are located in areas of high groundwater withdrawals where relatively deep cones of depression have formed. For comparison, a fourth mark − Rosaryville State Park (ROS-1) in southern Prince George's County − was installed in an area of relatively low groundwater withdrawals. One set of 5-hour GPS occupations was made in the fall of 2015 and processed using the National Geodetic Survey's OPUS Projects online utility. Estimated vertical accuracy ranged from 0.002 to 0.003 meters for ellipsoid heights. Heights obtained by this survey provide an initial set of measurements to establish a baseline for future monitoring.

INTRODUCTION

Work performed for this project was initiated in response to a permit requirement by the Maryland Public Service Commission for expansion of the Dominion Cove Point Liquid Natural Gas (LNG) Terminal near Lusby, Maryland. As stated under condition J-2 of the Maryland Public Service Commission's final order (Order No. 86372, Case No. 9318, May 30, 2014; http://webapp.psc.state.md.us/Intranet/Casenum/CaseAction_new.cfm?CaseNumber=9318, accessed 4/4/2016):

> "(a) To confirm the findings of the Reviewing State Agencies that no statistically significant indication of subsidence is expected to occur as a result of the Project, DCP shall establish a trust or similar instrument in the amount of $190,000 for the Maryland Geological Survey (MGS) to conduct subsidence monitoring in and near Calvert County. The trust or similar instrument, which is a one-time contribution from DCP, must be established prior to the start of construction. The terms and conditions of the trust or similar instrument shall be mutually agreeable to both parties.
>
> (b) DCP shall allow authorized representatives of MGS reasonable access to the facility to conduct monitoring for the Calvert County subsidence study. DCP shall provide reasonable assistance as may be necessary to effectively and safely conduct such monitoring."

Sites "in and near" Calvert County were selected at (1) Cove Point Park adjacent to the LNG terminal in Calvert County (Cove Point [COV-1]), (2) Bank Square production well at Lexington Park in St. Mary's County (Lexington Park [LEX-1]), (3) Billingsley Road production well (Well 12) at Waldorf in Charles County (Waldorf [WAL-1]), and (4) Rosaryville State Park in southern Prince George's County (Rosaryville State Park [ROS-1]).

OBJECTIVE AND SCOPE OF WORK

The objective of this project is to establish a network of high-integrity survey marks to monitor potential land subsidence resulting from groundwater withdrawals in Southern Maryland. The marks are located in the center of the deepest cones of depression in Southern Maryland, and for comparison, at one site in an area of relatively low groundwater withdrawal in southern Prince George's County. Initial Global Positioning System (GPS) elevation surveys were conducted to establish a baseline for future elevation measurements. For comparison, a GPS-derived elevation of a benchmark located in the presumably more geologically stable Piedmont Physiographic Province (National Geodetic Survey reference mark GORF N) was also included. It is intended that GPS elevation surveys be conducted at yearly intervals (in the fall) at the established marks, in addition to the Piedmont benchmark, to monitor potential changes in height.

BACKGROUND

Decades of groundwater withdrawals from unconsolidated, confined (artesian) coastal plain aquifers in Southern Maryland have resulted in significant drawdown of groundwater levels (Staley and others, 2014). Withdrawing water from a confined aquifer reduces the hydrostatic pressure head in the pumped aquifer and in the adjacent confining layers (clay and silt). As withdrawals increase to supply a growing population, further drawdown can be expected. Reduction of hydrostatic pressure in the aquifer systems resulting from the drawdown increases the load on the sediment which may lead to compaction and land subsidence. Permanent reduction in reservoir capacity by irreversible compaction of sediments may also occur. Case histories of land subsidence in coastal plain settings related to groundwater withdrawals are well documented (Gabrysch, 1969; Davis and Rollo, 1969; Davis, 1987; Engi, 1985; Poland, 1984; Sun and others, 1999). 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). Land subsidence related to groundwater withdrawals in Southern Maryland, while not likely to cause major engineering problems, could exacerbate the problem of tidal flooding in low-lying areas caused by future sea-level rise.

In its earliest stages, subsidence of the land surface caused by groundwater withdrawals would be very slight because the sediments, in particular the older Lower Cretaceous Potomac Group deposits, were subjected to greater overburden pressures (preconsolidated) in their geologic past caused by the weight of younger sediments that have since been eroded away (Davis, 1987; Obermeier, 1984). Increasing grain-to-grain loads due to

declining water levels must exceed the preconsolidation stress before significant land subsidence occurs. Davis (1987) suggests that a head loss of about 20 meters (m) (66 feet [ft]) is necessary before land subsidence can occur in fine-grained sediments of the Atlantic Coastal Plain sediment.

In some areas of Southern Maryland, groundwater levels have declined by as much as ~70 m (230 ft) from estimated prepumping levels in response to water withdrawals (Andreasen and others, 2016). Given the wide areas in Southern Maryland coastal plain that have experienced more than 20 m (66 ft) of groundwater drawdown, there is a potential for land subsidence. Currently, there is no groundwater-related land-subsidence monitoring in Southern Maryland. The Maryland Geological Survey has been monitoring for land subsidence through yearly GPS surveys in three major well fields tapping the Patapsco and Patuxent aquifer systems (Potomac Group aquifer system) in central Anne Arundel County for the past 20 years (Mack, 1995). To date there has been no evidence of land subsidence (Sain, 2015). The potential for land subsidence in Southern Maryland, however, may be greater than in the area of Anne Arundel County currently being monitored. The occurrence of deep cones of depression in Southern Maryland (Staley and others, 2014), and younger, more compressible sediment, may result in a greater likelihood for compaction and land subsidence.

LOCATION OF STUDY AREA

The study area is located in Southern Maryland (Calvert, Charles, southern Prince George's and St. Mary's Counties) in the Coastal Plain Physiographic Province (fig. 1). All survey mark sites are located on public property (County or State-owned), with the exception of the Cove Point site which is owned by Dominion LNG, LP, and managed by Calvert County Department of Parks and Recreation. The National Geodetic Survey (NGS) GORF N reference site is located in the Piedmont Physiographic Region of Howard County, Maryland (fig. 1).

SITE SELECTION

The survey mark sites constructed for this project were selected to correspond to areas of the greatest amount of stress (declining water levels) resulting from groundwater withdrawals in Southern Maryland. For comparison, one of the four sites selected (Rosaryville State Park) is located in an area of relatively low groundwater withdrawals.

Many decades of groundwater withdrawals from the confined aquifers in Maryland's Coastal Plain Physiographic Province have caused groundwater levels to decline. Figure 2 shows composite heads in five major aquifers or aquifer systems during the fall of 2013. The aquifers include, from shallowest to deepest, the Aquia, Magothy, Upper Patapsco, Lower Patapsco, and Patuxent. Heads in the shallower Piney Point aquifer, and other minor aquifers including the water-table aquifer, are not included in the analysis shown in Figure 2. The composite heads were generated by kriging and rasterizing potentiometric-surface maps from Staley and others (2014), then summing the head altitudes. The map illustrates areas of greatest stress (declining water levels) resulting from groundwater withdrawals. Also shown on Figure 2 are the locations of appropriated groundwater use greater than 10,000 gallons per day (gal/d). The map shows three areas where composite groundwater levels are deeper than 250 ft below sea level. Those areas include central Charles County through central Calvert County, southeastern St. Mary's County, and central Talbot County. In all other areas, composite heads are less than about 150 ft below sea level. Three existing survey marks located at major well fields in central Anne Arundel County (Arnold [Arnold-1], Crofton Meadows [Crofton-1], and Broad Creek [Broad-1]) monitored yearly for land subsidence using GPS are also shown on Figure 2. While groundwater withdrawals in Anne Arundel County are significantly greater than in Southern Maryland (~47 versus ~24 million gal/d in 2010 [Maupin and others, 2014]), greater permeability of the aquifers in Anne Arundel County results in a lesser amount of drawdown. After 20 years of yearly GPS measurements, no apparent change in land-surface elevation has been determined at the marks in Anne Arundel County at the given measurement error level (average uncertainty of 1.35 centimeters [cm]). Given that level of accuracy, if land subsidence was occurring at all it would have to been less than approximately 11 cm over 20 years.

The Cove Point mark, while not in an area of greatest groundwater withdrawals, is located near (within about 0.5 mi) production wells at the Cove Point LNG Terminal. Production wells at the Cove Point LNG Terminal include one well screened in the Aquia aquifer and one well screened in the deeper Lower Patapsco aquifer system. Groundwater withdrawals may increase to as much as 233,000 gal/d on average at the Cove Point Terminal in future years (Robert Peoples, Maryland Department of the Environment, written commun., 2015).

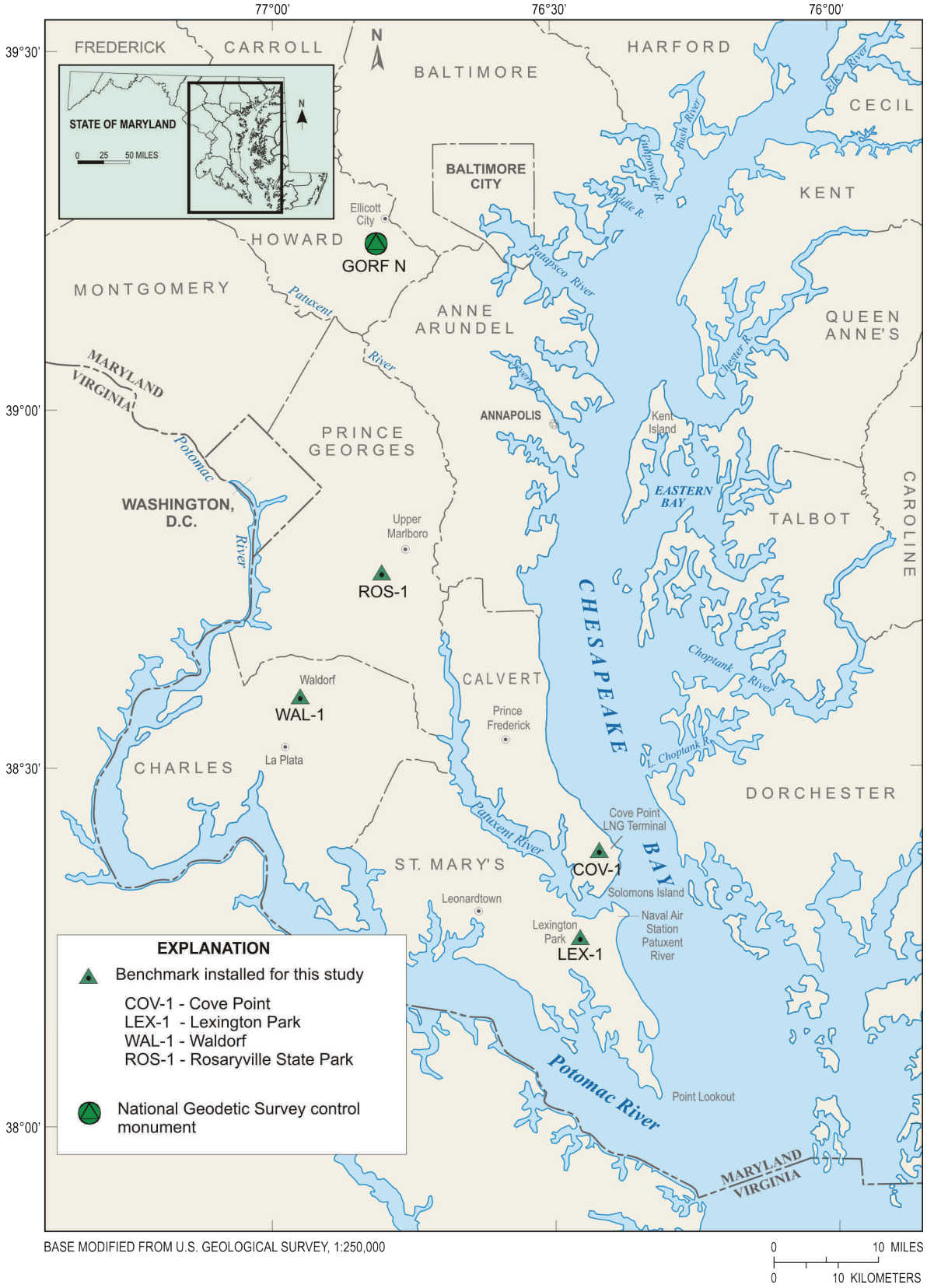


Figure 1. Location of study area.

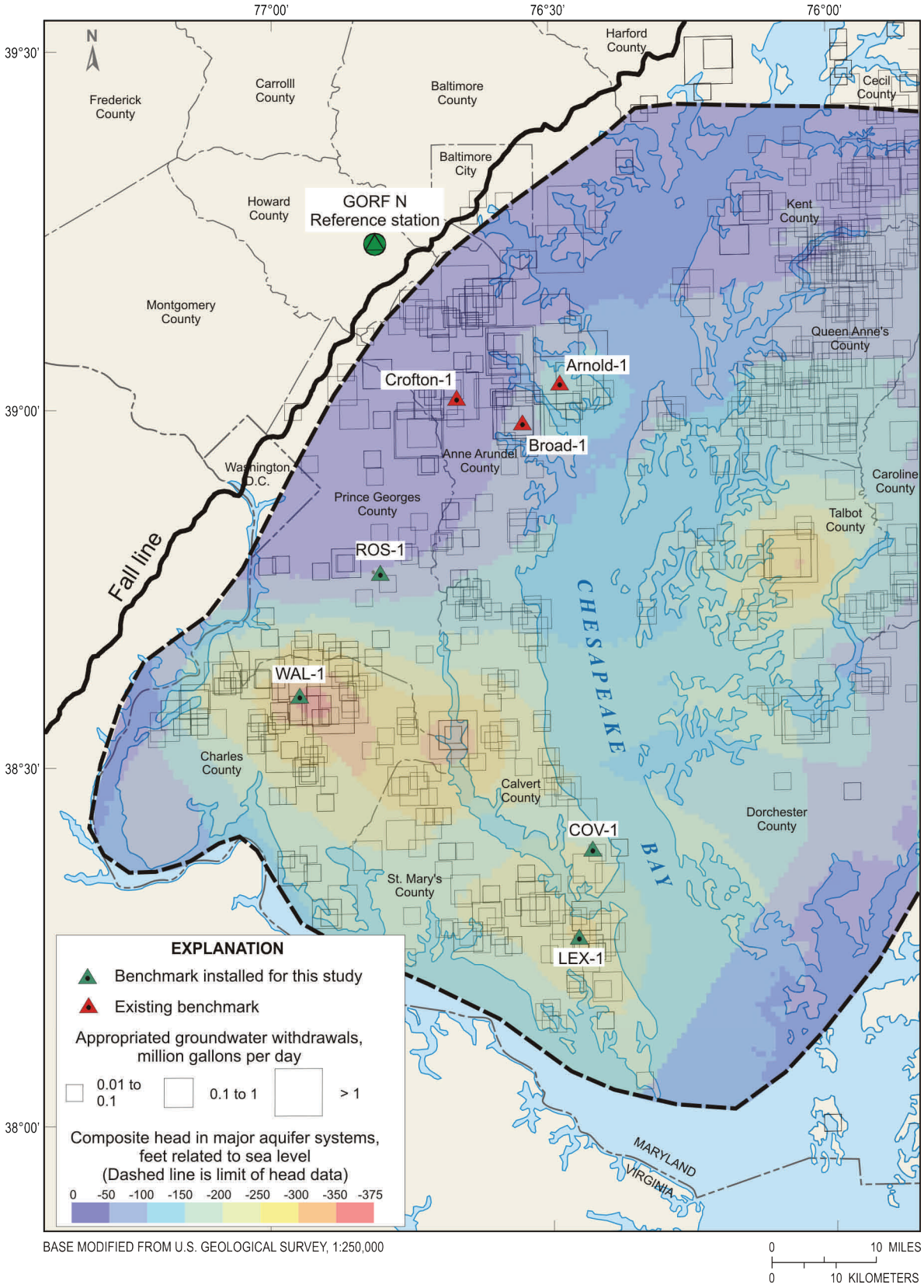


Figure 2. Composite heads in the major aquifers in Southern Maryland during the Fall of 2013.

DESCRIPTION OF SURVEY MARKS

The four survey marks installed for this project are all of the 3D rod type (fig. 3). The marks were installed using materials and methods according to National Geodetic Survey standards (Floyd, 1978). Prior to installing the mark rod, a 14-inch (in.) diameter hole was dug to a depth of 22 in. by hand spade and digging bar, then deepened to 44 in. using a 5-in. diameter hand auger. A 9/16-in. stainless steel rod with drive point was centered in the open hole and driven to refusal using a 70-pound electric percussion hammer delivering 950 blows per minute with 55 ft-pounds of impact energy (fig. 4). Refusal was reached when continuous hammering resulted in less than 1 ft of penetration over a 1-minute interval. The rod was cut or driven so that the top was approximately 3 in. below land surface. A greased plastic sleeve was installed over the rod and the hole was backfilled with clean, medium-grain sand to a depth of approximately 20 inches. A 6-in. PVC protective casing with weatherproof cap was installed over the rod/sleeve assembly and the annular space outside the PVC casing was filled with concrete. The inside of the PVC casing was filled to within approximately 6 in. of the top with sand. A domed bronze end cap was hammered and glued (epoxy) onto the stainless steel rod. A small

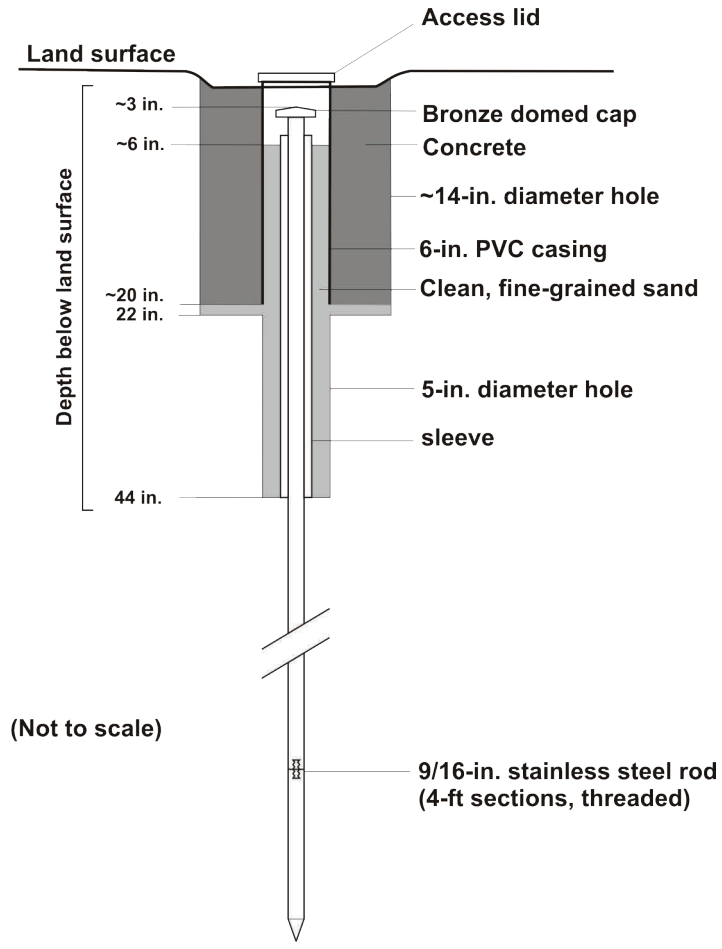


Figure 3. Schematic cross section of a 3D rod mark.

divot was drilled into the top of the domed bronze cap for placement of a survey range pole.

Cove Point

The Cove Point mark (designated COV-1), installed September 15, 2015, is located in Cove Point Park within approximately 0.5 mi of production wells at the Cove Point LNG Terminal in Calvert County (figs. 1 and 5; app. A). The property, owned by Dominion LNG, LP, is utilized by Calvert County for recreation. The mark is located near the park entrance adjacent to a sewage pumping station and electrical transformer (figs. 5 and 6). The surficial sediment encountered in the dug hole at the site consists of approximately 1 ft of soil (possibly fill), a hard, silty, loamy, sediment with occasional wood fragments to 2.5 ft, then a medium, well-sorted, tan sand to 4 ft. A county-scale (1:62,500) geologic map indicates that the Pleistocene-age Brandywine Formation is the outcropping unit at the site (Glaser, 1994). Refusal at the site was reached at 36.5 ft. Given that the thickness of the Brandywine Formation ranges from 3 to 40 ft in Calvert County, it is possible that the rod reached refusal in the Choptank and St. Mary's Formations (undivided) of Miocene age which underlies the Brandywine Formation at the site (Glaser, 1994). The Cove Point site has an unobstructed view of the sky, allowing for optimum satellite coverage.

Lexington Park

The Lexington Park mark (designated LEX-1), installed August 21, 2015, is located at the Bank Square production well site in Lexington Park, St. Mary's County (figs. 7 and 8; app. A). The property, owned by St. Mary's County, is the site of a municipal production well screened in the Aquia aquifer and operated by the St. Mary's Metropolitan Commission. The mark is located 27 ft from the production well (fig. 7). The surficial sediment encountered in the dug hole at the site consists entirely of fill. A county-scale (1:62,500) geologic map of St. Mary's County indicates that the site is underlain by the Upland Gravel of Pliocene age (McCartan, 1989b). Below the Upland Gravel lies the Chesapeake Group (undivided) of Miocene age as determined by geophysical and lithologic logs in a test well located within 100 ft from the mark (Hansen and Wilson, 1984). Refusal at the site was reached at 68 ft. Given that the thickness of the Upland Gravel at the site is approximately 66 ft below land surface in the test well, the rod likely reached refusal in the older Miocene-age deposits. The Lexington Park site has a relatively unobstructed view of the sky, with a few mature trees partially obstructing the western and southeastern horizons.

Waldorf

The Waldorf mark (designated WAL-1), installed October 7, 2015, is located at the Billingsley Road production well (Well 12) site in Waldorf, Charles County (figs. 9 and 10; app. A). The Billingsley Road production well, a municipal supply well operated by Charles County, is located approximately 50 ft from the mark (fig. 9). The surficial sediment encountered in the dug hole at the site consists of a thin layer of soil (less than 1 ft), then a silt-clay layer with occasional gravel to 4 ft. A county-scale (1:62,500) geologic map of Charles County indicates that the site is underlain by the Upland Gravel of Pliocene age (McCartan, 1989a). Refusal at the site was reached at 40 ft. The sky view at the site is partially obstructed to the east by mature trees, potentially constraining GPS satellite geometry.

Rosaryville State Park

The Rosaryville State Park mark (designated ROS-1), installed August 13, 2015, is located near the Mt. Airy mansion on the grounds of Rosaryville State Park in southern Prince George's County (figs. 11 and 12; app. A). The surficial sediment encountered in the dug hole at the site consists of a thin layer of soil (less than 1 ft), a gravelly layer to about 2 ft, then a fine-grained sandy, loamy sediment to 4 ft. A county-scale (1:62,500) geologic map of Prince George's County indicates that the site is underlain by Upland deposits of Upper Miocene to Pliocene age (Glaser, 2003). Refusal at the site was reached at 37.5 ft. The sky view at the site is partially obstructed to the south-southwest by mature trees, potentially constraining GPS satellite geometry.

(text continued on p. 17)

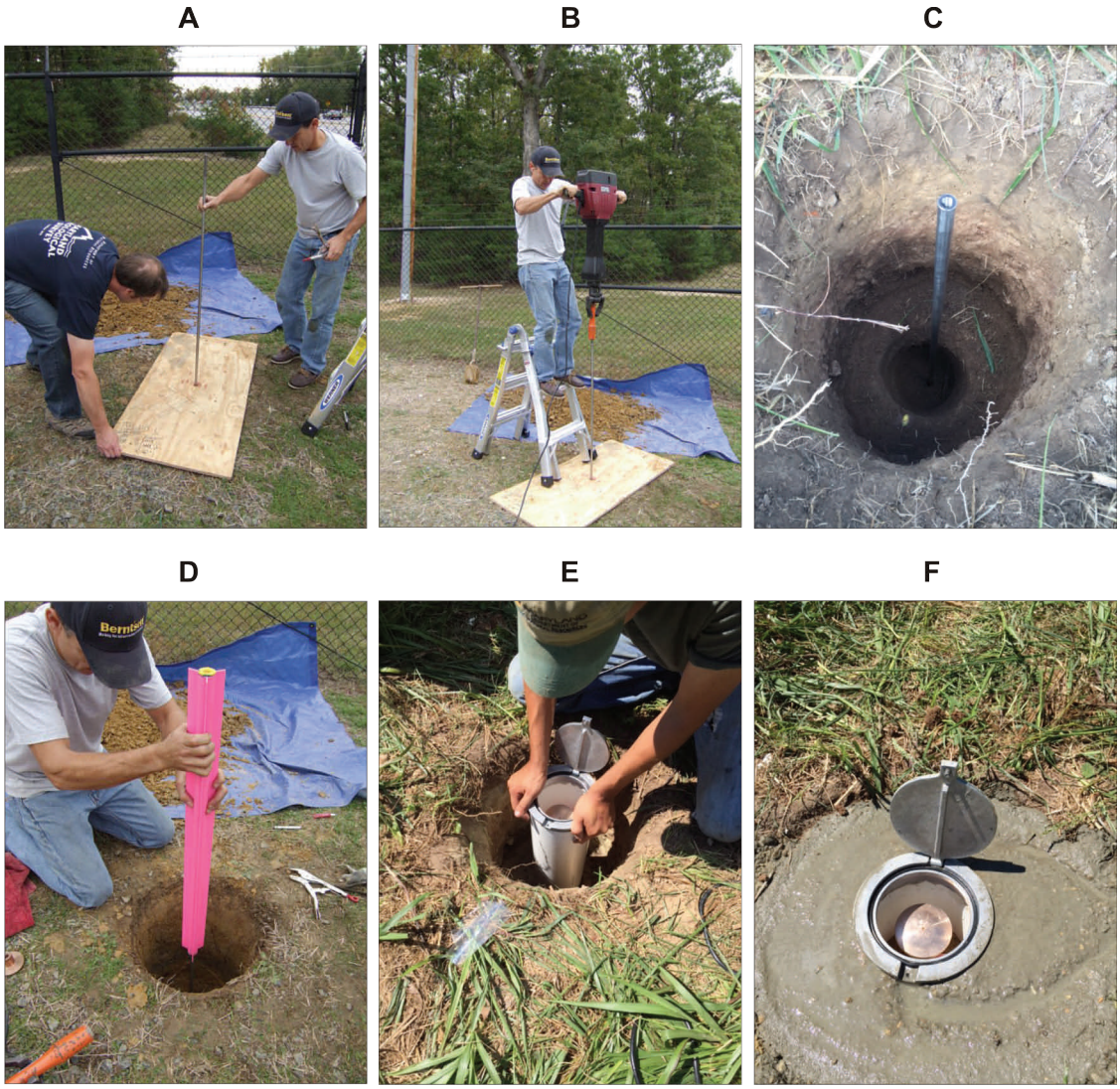


Figure 4. Photos showing construction of a 3D rod mark. [A - Insertion of stainless steel rod; B - Driving rod with electric-powered jack hammer; C - Finished rod driven in hole; D - Placement of sleeve; E - Installation of protective casing and access lid, and; F - Finished mark set in concrete with bronze domed survey cap]

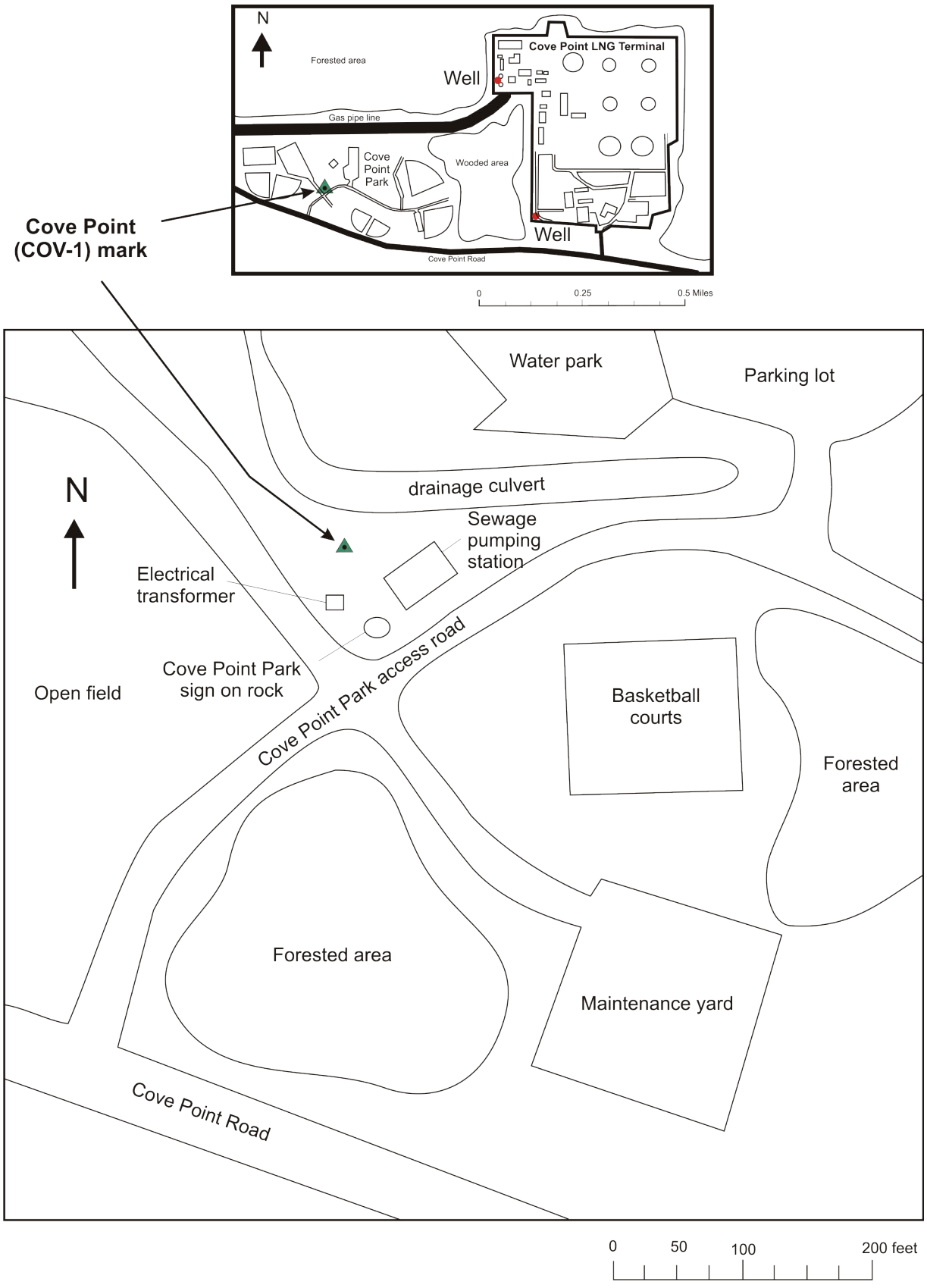


Figure 5. Location of the Cove Point mark. See Figure 1 for general location.

Horizon photo looking east

Close-up photo of COV-1

Figure 6. Photos showing the Cove Point mark.

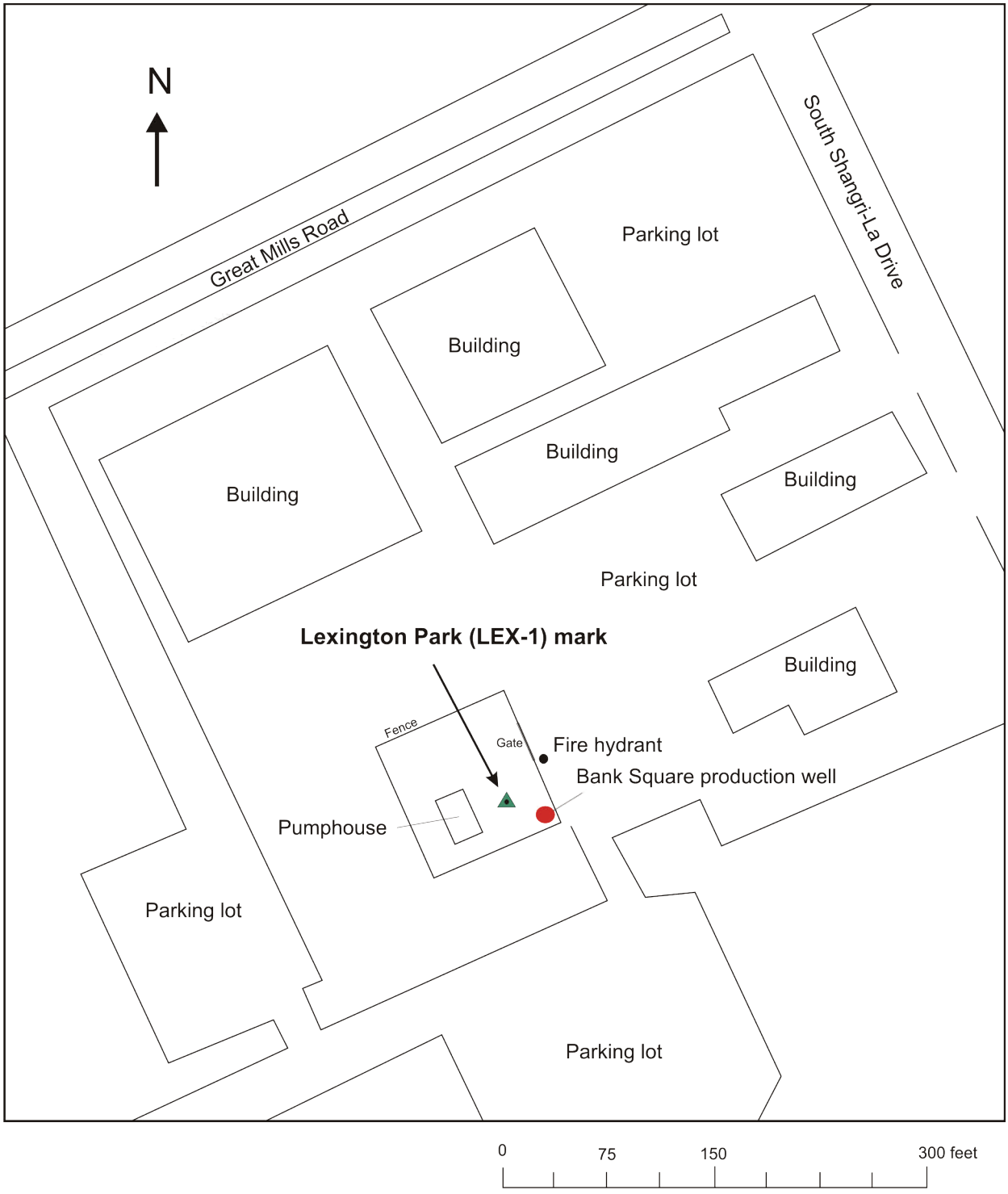
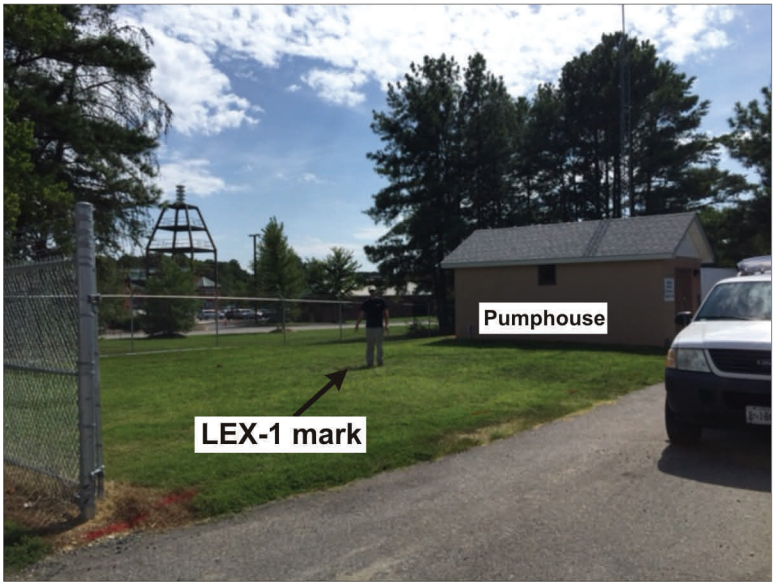


Figure 7. Location of the Lexington Park mark. See Figure 1 for general location.

Horizon photo looking south-southwest



Close-up photo of LEX-1

Figure 8. Photos showing the Lexington Park mark.

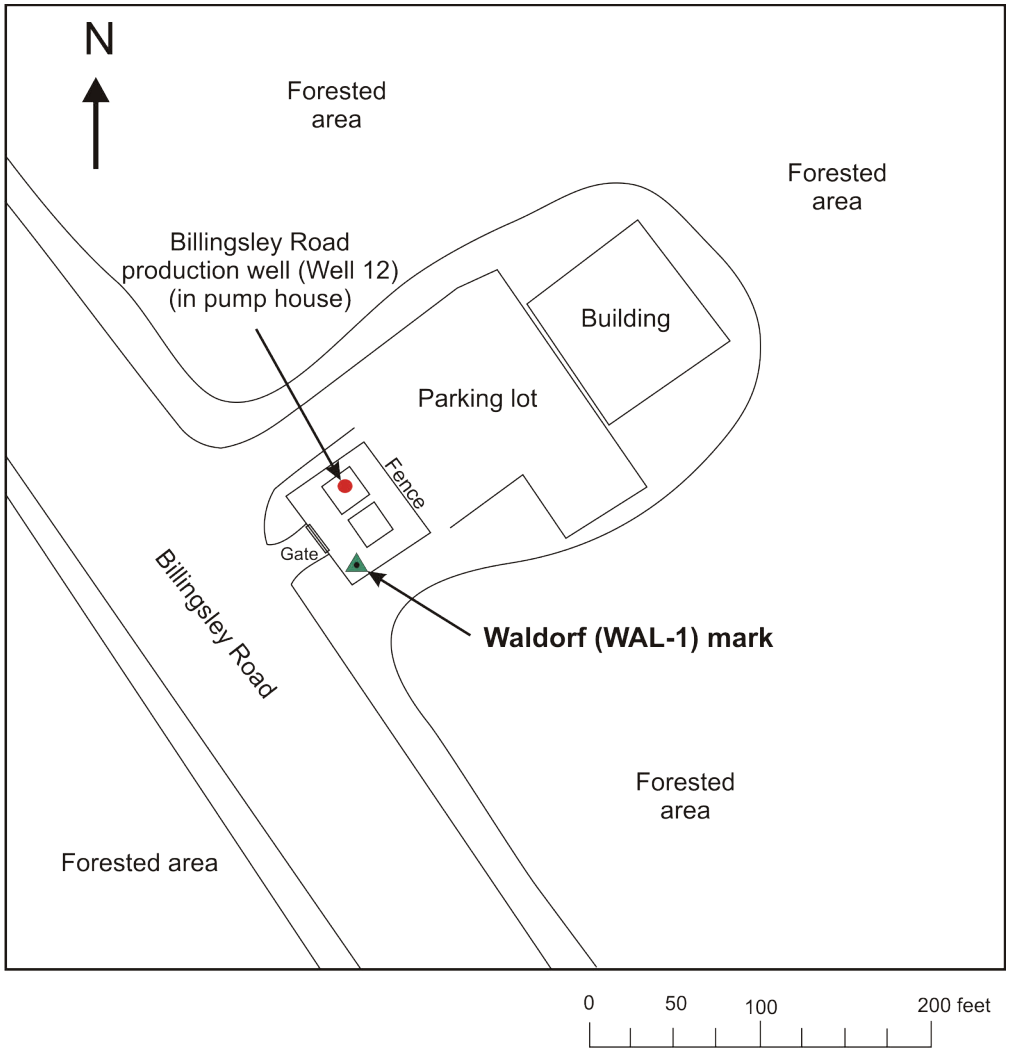
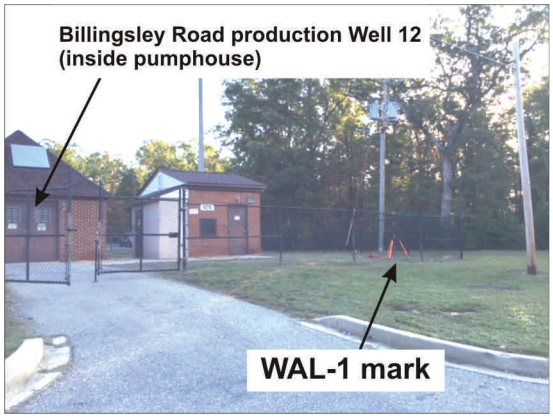


Figure 9. Location of the Waldorf mark. See Figure 1 for general location.

Horizon photo looking east



Close-up photo of WAL-1

Figure 10. Photos showing the Waldorf mark.

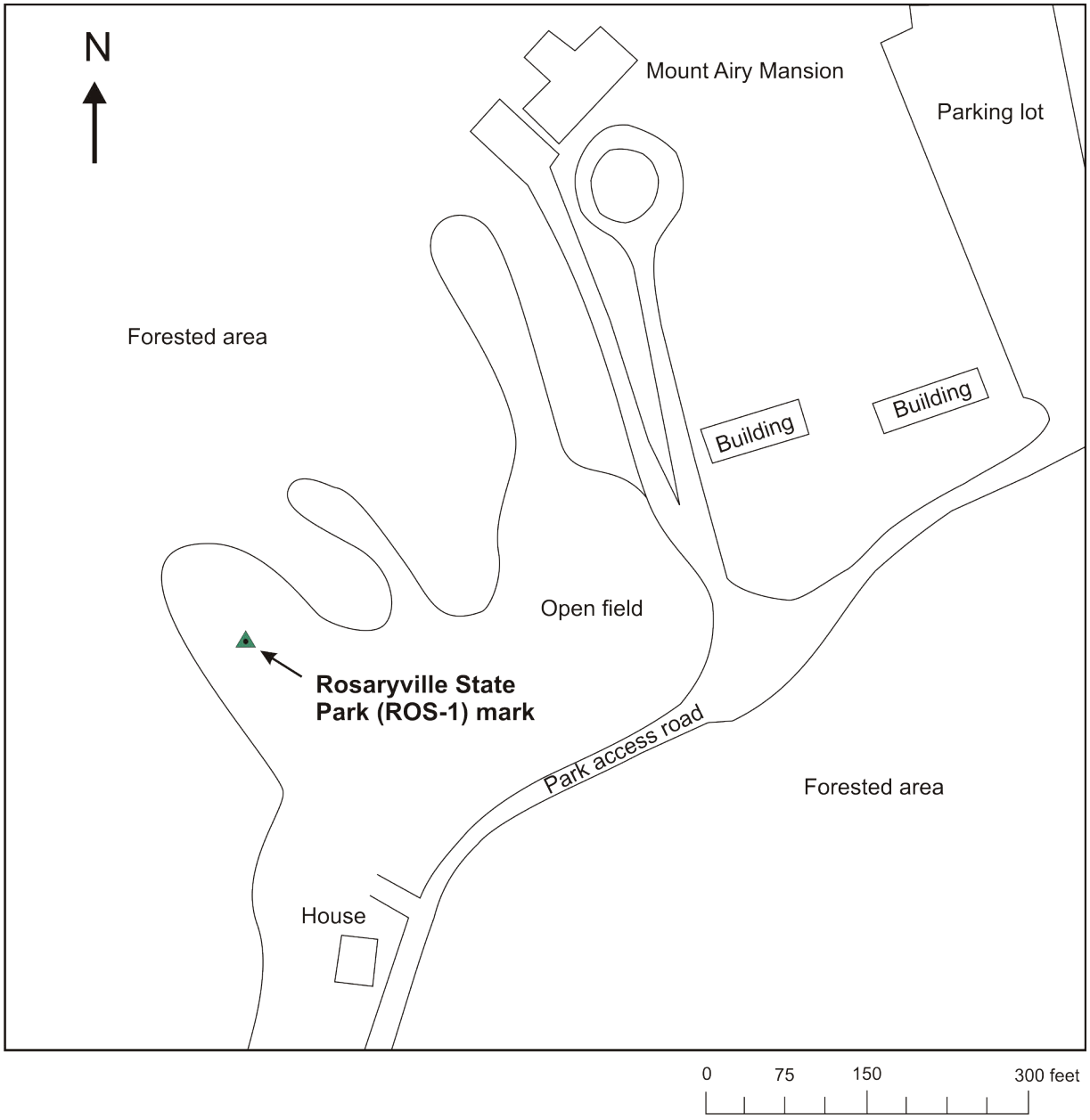


Figure 11. Location of the Rosaryville State Park mark. See Figure 1 for general location.

Horizon photo looking east-southeast

Close-up photo of ROS-1

Figure 12. Photos showing the Rosaryville State Park mark.

GPS SURVEYS AND DATA PROCESSING

A single occupation GPS survey was made at each mark installed for the project, and at the GORF N benchmark, between October 13-19, 2015. Each site was occupied for a period of five hours using a Topcon[1] Hiper SR dual frequency (L1/L2) receiver (serial number 1064-11667). The receiver was attached to a 2.0 m two-piece carbon fiber range pole and held in place by a carbon fiber surveying tripod with a 40-minute adjustable circular vial (leveling bubble) (fig. 13). The north arrow reference mark on the receiver was not aligned to geographic north. The survey point for each installed mark was a small divot in the top of the domed bronze cap affixed to the stainless steel rod. GPS readings were recorded and stored in the Topcon receiver, downloaded to a PC, then uploaded to the National Geodetic Survey's Online Positioning User Service (OPUS) for processing.

The raw GPS data were processed using the National Geodetic Survey's OPUS Projects (Armstrong, 2015). The data was processed after a minimum of 30 days from data collection to obtain "precise" satellite ephemeridae. In calculating orthometric heights, OPUS Projects selected the GEOID12B geoid model. Data processing defaults specified in the OPUS Project included a piecewise linear tropospheric model with an interval of 7,200 seconds, an elevation cutoff of 15.0 degrees, and normal constraint weights. Unconstrained marks include the four marks installed for this project (COV-1, LEX-1, WAL-1 and ROS-1) and GODE (GGAO[Greenbelt]) and NLIB (North Liberty VLBA site) CORS sites. GODE was designated as the hub for the project and NLIB served as the distant mark for stabilizing tropospheric corrections. NLIB is located 1,284 kilometers (km) from the hub. Constrained CORS stations used to process session network baselines and in network adjustment included: ANP5 (Annapolis 5), ANP6 (Annapolis 6), BACO (Baltimore County), CORB (Corbin), GODZ (GGAO), HNPT (Horn Point Environmental Lab.), LOYB (LOYOLLA B COOP), LOYF (Annapolis MD), LOYK (LOYOLLA LOYK), LOYM (LOYOLLA M), NRL1 (U.S. Naval Research Laboratory), and UMBC (U of Md Balt Coop). All of the CORS stations have a minimum of seven years of record with GODE (hub) and NLIB (distant mark) having 19 and 21 years, respectively. NRL1 and GODZ are IGS (International GNSS Service) stations that are part of the CORS network. Distances between the hub and all marks (with the exception of NLIB) are less

Figure 13. Photo showing GPS receiver.

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

than approximately 100 km. The session solutions were all within acceptable ranges for standard error of unit weight (0.1 to 1.1), overall and individual baseline root-mean-square error (<0.025 m), percentage of omitted observations (<20%), and percentage of fixed ambiguities (<20%). The OPUS Projects session solutions and network adjustment results are given in Appendixes B and C.

GPS-DERIVED HEIGHTS

Ellipsoid heights determined by OPUS Projects are given in Table 1. At the Cove Point mark (COV-1), the October 13, 2015 occupation resulted in an ellipsoid height of -1.481 m (+/- 0.002 m). At the Lexington Park mark (LEX-1), the October 14, 2015 occupation resulted in an ellipsoid height of -2.034 m (+/- 0.003 m). At the Waldorf mark (WAL-1), the October 16, 2015 occupation resulted in an ellipsoid height of 28.789 m (+/- 0.003 m). At the Rosaryville State Park mark (ROS-1), the October 15, 2015 occupation resulted in an ellipsoid height of 33.863 m (+/- 0.003 m). At the GORF N mark, the October 19, 2015 occupation resulted in an ellipsoid height of 123.355 m (+/- 0.003 m).

The relatively short occupation time (five hours) may possibly affect the accuracy of the height estimates, especially at sites with partial obstruction of the horizon (WAL-1 and ROS-1). In addition, the single occupation at each site prevented validation of the observations that multiple occupations over different days would provide. Future GPS surveys for this project will include both longer and multiple occupations.

SUMMARY

Four 3D rod marks were installed to establish a monitoring network for potential future land subsidence caused by groundwater withdrawals in Southern Maryland. Three of the marks (Cove Point [COV-1] in Calvert County, Lexington Park [LEX-1] in St. Mary's County, and Waldorf [WAL-1] in Charles County) are located in areas of high groundwater withdrawals where water levels have declined significantly. A fourth mark site − Rosaryville State Park in southern Prince George's County − is located in an area of relatively low groundwater withdrawals for comparison. GPS readings were made at each site in the fall of 2015 to obtain initial ellipsoid heights. The GPS data were processed using the National Geodetic Survey's OPUS Projects online utility. Ellipsoid height accuracy ranged from 0.002 to 0.003 m. Future GPS measurements will be made on a yearly interval to develop a record of land-surface-elevation change.

Table 1. Summary of 2015 GPS surveys.

Site	Date of occupation	Horizontal (IGS08 [2015.7825])		Vertical (IGS08 [2015.7825])		
		Latitude (dd:mm:ss)	Longitude (dd:mm:ss)	Ellipsoidal height (m)	Observations used, percent	Fixed ambiguities, percent
COV-1	10/13/15	N38:23: 11.19206	W076:25: 22.10071	-1.481 +/- 0.002	99.5	100
LEX-1	10/14/15	N38:15: 47.68768	W076:27: 20.53677	-2.034 +/- 0.003	94.0	93.5
WAL-1	10/16/15	N38:35: 56.66774	W076:56: 23.51268	28.789 +/- 0.003	83.7	95.5
ROS-1	10/15/15	N38:46: 27.64276	W076:49: 11.98694	33.863 +/- 0.003	86.2	93.3
GORF-N	10/19/15	N39:13: 34.27349	W076:48: 50.48427	123.355 +/- 0.003	94.8	92.3

ACKNOWLEDGMENTS

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APPENDIXES

Appendix A. Description of survey marks constructed for this study.

Cove Point mark

Designation: COV-1 State: Maryland
Latitude: 38 23 11.16127 NAD83 County: Calvert
Longitude: 76 25 22.08119 NAD83
Elevation: 34.219 m (112.267 ft) NAVD88
Stamping: COV-1 (ink mark)
Type: Flanged-encased rod (3D rod)
Surface mark: Domed, bronze cap
Setting: Driven into the ground to refusal at 36.5 ft
Set by Maryland Geological Survey 9/15/2015; chief of party DCA

The marker is located in Cove Point Park on property owned by Dominion LNG, LP, about 2 mi. north of Lusby and 1 mi. west of the entrance to the Cove Point Liquid Natural Gas Terminal.

To reach from a point where MD State Highway 4 intersects Cove Point Road (Rt. 497), go east on Cove Point Road for 0.72 mi. to the entrance of Cove Point Park. Turn left into the park and go 380 ft to the first park road intersection. Turn left and go 85 ft to mark on right.

The point is marked with a stainless steel rod driven to refusal. It is 30 ft N15E from an electrical transformer, 46 ft N20W from a rock with Cove Point Park sign, and 33 ft N75W from west corner of sewage pumping station. The rod is housed in a 6-in. protective casing with an aluminum access cap level with the surface of the ground.

Lexington Park mark

Designation: LEX-1 State: Maryland
Latitude: 38 15 47.65700 NAD83 County: St. Mary's
Longitude: 76 27 20.51730 NAD83
Elevation: 33.785 m (110.843 ft) NAVD88
Stamping: LEX-1 (ink mark)
Type: Flanged-encased rod (3D rod)
Surface mark: Domed, bronze cap
Setting: Driven into the ground to refusal at 68 ft
Set by Maryland Geological Survey 8/21/2015; chief of party DCA

The marker is located in Lexington Park at the Bank Square production well site property owned by the St. Mary's Metropolitan Commission.

To reach from a point where Three Notch Road (Rt. 235) and Great Mills Road (Rt. 246) intersect, go west on Great Mills Road 930 ft to Shangri-La Drive. Turn left on South Shangri-La Drive and go south 260 ft. Turn right in parking lot and go 350 ft southwest. Turn left and go 150 ft southeast to mark on right.

The point is marked with a stainless steel rod driven to refusal. It is 31 ft S52W from a fire hydrant, 27 ft N66W from a production well inside a cement ring, and 30 ft due east from the north-east corner of the well pumphouse. The rod is housed in a 6-in. protective casing with an aluminum access cap level with the surface of the ground.

Appendix A. Continued.

Waldorf mark

Designation: WAL-1
Latitude: 38 35 56.63699 NAD83
Longitude: 76 56 23.49246 NAD83
Elevation: 63.023 m (206.768 ft) NAVD88
Stamping: WAL-1 (ink mark)
Type: Flanged-encased rod (3D rod)
Surface mark: Domed, bronze cap
Setting: Driven into the ground to refusal at 40 ft
Set by Maryland Geological Survey 10/7/2015; chief of party DCA

State: Maryland
County: Charles

The marker is located about 3 mi. north of White Plains at the Billingsley Road production well site property owned by Charles County.

To reach from a point where Rt. 301 and Billingsley Road intersect, go west on Billingsley Road 1.0 mile to mark on right.

The point is marked with a stainless steel rod driven to refusal. It is 8.5 ft N2E from the south corner of the facility fence, 19 ft S25W from the nearest building, 44 ft S67W from a radio antenna pole, and 31 ft N65W from an electric utility pole (SMECO). The rod is housed in a 6-in. protective casing with an aluminum access cap level with the surface of the ground.

Rosaryville State Park mark

Designation: ROS-1
Latitude: 38 46 27.61185 NAD83
Longitude: 76 49 11.96673 NAD83
Elevation: 67.932 m (222.874 ft) NAVD88
Stamping: ROS-1 (ink mark)
Type: Flanged-encased rod (3D rod)
Surface mark: Domed, bronze cap
Setting: Driven into the ground to refusal at 37.5 ft
Set by Maryland Geological Survey 8/13/2015; chief of party DCA

State: Maryland
County: Prince George's

The marker is located in the Rosaryville State Park (Mount Airy Mansion) owned by the State of Maryland.

To reach from a point where Rt. 301 and Rosaryville Road intersect, go west on Rosaryville Road 3 mi.. Turn right at the entrance to Mount Airy Mansion and go 0.6 mi. Turn left at driveway and go 80 ft. Bear right at a heading of N26W and go about 80 ft across field to mark.

The point is marked with a stainless steel rod driven to refusal. It is 218 ft S2W from an electric utility pole (PEPCO 8513420291) and 112 ft N60E from an electric utility pole (PEPCO 8513420674). The rod is housed in a 6-in. protective casing with an aluminum access cap level with the surface of the ground.

Appendix B. OPUS Projects session solutions for the 2015 GPS surveys.

NGS OPUS-PROJECTS SESSION SOLUTION REPORT
==========

COV-1

```
SUBMITTED BY:                   david.andreasen
SOLUTION FILE NAME:             2015-286-opus-P.sum
SOLUTION SOFTWARE:              page5(1404.11)
SOLUTION DATE:                  2016-02-05T14:21:23 UTC
STANDARD ERROR OF UNIT WEIGHT: 0.877
TOTAL NUMBER OF OBSERVATIONS:  110462
TOTAL NUMBER OF MARKS:         8
NUMBER OF CONSTRAINED MARKS:   5

OVERALL RMS:                    1.5 cm
START TIME:                     2015-10-13T00:00:00 GPS
STOP TIME:                      2015-10-13T23:59:30 GPS
PROGRAM OPERATION:              FULL RUN
FREQUENCY:                      L1-ONLY TO ION-FREE [BY BASELINE LENGTH]
OBSERVATION INTERVAL:           30 s
ELEVATION CUTOFF:               15 deg
TROPO INTERVAL:                 7200 s [PIECE-WISE LINEAR PARAMETERIZATION]
DD CORRELATIONS:                ON
```

BASELINE	LENGTH	RMS	OBS	OMITTED	FIXED
anp5-gode	18.887 km	1.5 cm	17873	3.2%	96.5%
loyf-gode	26.907 km	1.5 cm	18511	0.5%	96.6%
nrl1-gode	28.131 km	1.6 cm	18504	0.7%	100.0%
hnpt-gode	77.261 km	1.4 cm	18301	1.0%	98.2%
gode-cov1	78.794 km	1.6 cm	3523	0.5%	100.0%
loym-gode	80.728 km	1.3 cm	18049	2.2%	94.8%
nlib-gode	1284.831 km	1.8 cm	15701	1.3%	68.4%

LEX-1

```
SUBMITTED BY:                   david.andreasen
SOLUTION FILE NAME:             2015-287-opus-P.sum
SOLUTION SOFTWARE:              page5(1404.11)
SOLUTION DATE:                  2016-02-05T14:39:25 UTC
STANDARD ERROR OF UNIT WEIGHT: 0.696
TOTAL NUMBER OF OBSERVATIONS:  110889
TOTAL NUMBER OF MARKS:         8
NUMBER OF CONSTRAINED MARKS:   5

OVERALL RMS:                    1.2 cm
START TIME:                     2015-10-14T00:00:00 GPS
STOP TIME:                      2015-10-14T23:59:30 GPS
PROGRAM OPERATION:              FULL RUN
FREQUENCY:                      L1-ONLY TO ION-FREE [BY BASELINE LENGTH]
OBSERVATION INTERVAL:           30 s
```

Appendix B. Continued.

```
ELEVATION CUTOFF:              15 deg
TROPO INTERVAL:                7200 s [PIECE-WISE LINEAR PARAMETERIZATION]
DD CORRELATIONS:               ON

  BASELINE      LENGTH       RMS       OBS   OMITTED    FIXED
-------------------------------------------------------------
 loyf-gode     26.907 km      1.2 cm    18550     0.2%   100.0%
 nrl1-gode     28.131 km      1.1 cm    18584     0.2%   100.0%
 hnpt-gode     77.261 km      1.1 cm    18363     0.7%   100.0%
 loym-gode     80.728 km      1.1 cm    18049     2.5%    95.2%
 gode-lex1     90.184 km      1.8 cm     3296     6.4%    93.5%
 corb-gode    102.681 km      1.1 cm    18450     0.2%    98.1%
 nlib-gode   1284.831 km      1.6 cm    15597     2.0%    66.7%
```

WAL-1

```
SUBMITTED BY:                  david.andreasen
SOLUTION FILE NAME:            2015-289-opus-P.sum
SOLUTION SOFTWARE:             page5(1404.11)
SOLUTION DATE:                 2016-02-05T14:42:29 UTC
STANDARD ERROR OF UNIT WEIGHT: 0.731
TOTAL NUMBER OF OBSERVATIONS:  110112
TOTAL NUMBER OF MARKS:         8
NUMBER OF CONSTRAINED MARKS:   5

OVERALL RMS:                   1.2 cm
START TIME:                    2015-10-16T00:00:00 GPS
STOP TIME:                     2015-10-16T23:59:30 GPS
PROGRAM OPERATION:             FULL RUN
FREQUENCY:                     L1-ONLY TO ION-FREE [BY BASELINE LENGTH]
OBSERVATION INTERVAL:          30 s
ELEVATION CUTOFF:              15 deg
TROPO INTERVAL:                7200 s [PIECE-WISE LINEAR PARAMETERIZATION]
DD CORRELATIONS:               ON

  BASELINE      LENGTH       RMS       OBS   OMITTED    FIXED
-------------------------------------------------------------
 godz-gode      0.000 km      0.2 cm    18516     0.2%   100.0%
 anp5-gode     18.887 km      1.3 cm    17993     2.4%   100.0%
 nrl1-gode     28.131 km      1.1 cm    18454     0.5%   100.0%
 loyb-gode     44.959 km      1.3 cm    18418     0.6%   100.0%
 gode-wal1     47.936 km      1.8 cm     2910    19.5%    95.5%
 loym-gode     80.728 km      1.0 cm    18073     2.3%    98.2%
 nlib-gode   1284.831 km      1.6 cm    15748     1.5%    67.9%
```

Appendix B. Continued.

ROS-1

```
SUBMITTED BY:                   david.andreasen
SOLUTION FILE NAME:             2015-288-opus-P.sum
SOLUTION SOFTWARE:              page5(1404.11)
SOLUTION DATE:                  2016-02-05T14:41:10 UTC
STANDARD ERROR OF UNIT WEIGHT: 0.684
TOTAL NUMBER OF OBSERVATIONS:  109358
TOTAL NUMBER OF MARKS:         8
NUMBER OF CONSTRAINED MARKS:   5

OVERALL RMS:                    1.1 cm
START TIME:                     2015-10-15T00:00:00 GPS
STOP TIME:                      2015-10-15T23:59:30 GPS
PROGRAM OPERATION:              FULL RUN
FREQUENCY:                      L1-ONLY TO ION-FREE [BY BASELINE LENGTH]
OBSERVATION INTERVAL:           30 s
ELEVATION CUTOFF:               15 deg
TROPO INTERVAL:                 7200 s [PIECE-WISE LINEAR PARAMETERIZATION]
DD CORRELATIONS:                ON
```

BASELINE	LENGTH	RMS	OBS	OMITTED	FIXED
godz-gode	0.000 km	0.2 cm	18473	0.2%	100.0%
anp5-gode	18.887 km	1.3 cm	17924	2.5%	98.8%
loyf-gode	26.907 km	1.1 cm	18487	0.3%	100.0%
gode-ros1	27.469 km	1.4 cm	2456	16.0%	93.3%
nrl1-gode	28.131 km	1.1 cm	17976	2.6%	98.2%
loyb-gode	44.959 km	1.2 cm	18393	0.6%	100.0%
nlib-gode	1284.831 km	1.5 cm	15649	1.5%	52.6%

GORF N

```
SUBMITTED BY:                   david.andreasen
SOLUTION FILE NAME:             2015-292-A.sum
SOLUTION SOFTWARE:              page5(1404.11)
SOLUTION DATE:                  2016-02-05T16:47:19 UTC
STANDARD ERROR OF UNIT WEIGHT: 0.611
TOTAL NUMBER OF OBSERVATIONS:  92488
TOTAL NUMBER OF MARKS:         7
NUMBER OF CONSTRAINED MARKS:   4

OVERALL RMS:                    1.0 cm
START TIME:                     2015-10-19T00:00:00 GPS
STOP TIME:                      2015-10-19T23:59:30 GPS
PROGRAM OPERATION:              FULL RUN
FREQUENCY:                      L1-ONLY TO ION-FREE [BY BASELINE LENGTH]
OBSERVATION INTERVAL:           30 s
ELEVATION CUTOFF:               15 deg
TROPO INTERVAL:                 7200 s [PIECE-WISE LINEAR PARAMETERIZATION]
DD CORRELATIONS:                ON
```

Appendix B. Continued.

BASELINE	LENGTH	RMS	OBS	OMITTED	FIXED
loyk-gode	12.538 km	0.9 cm	18371	1.0%	100.0%
anp6-gode	18.899 km	1.0 cm	18024	1.2%	100.0%
gode-gorf	22.726 km	1.2 cm	3252	5.5%	92.3%
umbc-gode	27.934 km	1.1 cm	18595	0.1%	100.0%
baco-gode	46.042 km	1.0 cm	18498	0.4%	100.0%
nlib-gode	1284.831 km	1.1 cm	15748	1.4%	76.9%

Note:
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.

Appendix C. OPUS Projects network adjustment for the 2015 GPS surveys.

NGS OPUS-PROJECTS NETWORK ADJUSTMENT REPORT
==========

SUBMITTED BY: david.andreasen
SOLUTION FILE NAME: network-final 2.sum
SOLUTION SOFTWARE: GPSCOM(1210.24)
SOLUTION DATE: 2016-02-24T10:42:49 UTC
STANDARD ERROR OF UNIT WEIGHT: 0.731
TOTAL NUMBER OF OBSERVATIONS: 533309
TOTAL NUMBER OF MARKS: 19
NUMBER OF CONSTRAINED MARKS: 12

START TIME: 2015-10-13T00:00:00 GPS
STOP TIME: 2015-10-19T23:59:30 GPS
FREQUENCY: L1-ONLY TO ION-FREE [BY BASELINE LENGTH]
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) 2015-286 opus-P	1.5 cm	page5(1404.11)	2016-02-05T14:21 UTC
2) 2015-287 opus-P	1.2 cm	page5(1404.11)	2016-02-05T14:39 UTC
3) 2015-288 opus-P	1.1 cm	page5(1404.11)	2016-02-05T14:41 UTC
4) 2015-289 opus-P	1.2 cm	page5(1404.11)	2016-02-05T14:42 UTC
5) 2015-292 opus-P	1.0 cm	page5(1404.11)	2016-02-05T16:47 UTC

BASELINE	LENGTH	RMS	OBS	OMITTED	FIXED	IN SOLUTION(S)
godz-gode	0.000 km	0.2 cm	36989	0.2%	100.0%	3, 4
loyk-gode	12.538 km	0.9 cm	18371	1.0%	100.0%	5
anp5-gode	18.887 km	1.4 cm	53790	2.7%	98.4%	1, 3, 4
anp6-gode	18.899 km	1.0 cm	18024	1.2%	100.0%	5
gode-gorf	22.726 km	1.2 cm	3252	5.5%	92.3%	5
loyf-gode	26.907 km	1.3 cm	55548	0.3%	98.8%	1, 2, 3
gode-ros1	27.469 km	1.4 cm	2456	16.0%	93.3%	3
umbc-gode	27.934 km	1.1 cm	18595	0.1%	100.0%	5
nrl1-gode	28.131 km	1.2 cm	73518	1.0%	99.5%	1, 2, 3, 4
loyb-gode	44.959 km	1.3 cm	36811	0.6%	100.0%	3, 4
baco-gode	46.042 km	1.0 cm	18498	0.4%	100.0%	5
gode-wal1	47.936 km	1.8 cm	2910	19.5%	95.5%	4
hnpt-gode	77.261 km	1.3 cm	36664	0.8%	99.1%	1, 2
gode-cov1	78.794 km	1.6 cm	3523	0.5%	100.0%	1
loym-gode	80.728 km	1.1 cm	54171	2.3%	96.0%	1, 2, 4
gode-lex1	90.184 km	1.8 cm	3296	6.4%	93.5%	2
corb-gode	102.681 km	1.1 cm	18450	0.2%	98.1%	2
nlib-gode	1284.831 km	1.5 cm	78443	1.5%	66.3%	1, 2, 3,...

Appendix C. Continued.

++
UNCONSTRAINED MARKS and CORS
++

MARK: COV-1

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2015.7825)	
X:	1175163.280 m	0.001 m	1175162.440 m	0.001 m
Y:	-4866014.502 m	0.002 m	-4866013.043 m	0.002 m
Z:	3939155.633 m	0.002 m	3939155.564 m	0.002 m
LAT:	38 23 11.16127	0.001 m	38 23 11.19206	0.001 m
E LON:	283 34 37.91881	0.001 m	283 34 37.89929	0.001 m
W LON:	76 25 22.08119	0.001 m	76 25 22.10071	0.001 m
EL HGT:	-0.173 m	0.002 m	-1.481 m	0.002 m
ORTHO HGT:	34.219 m	0.016 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4249650.235 m	80056.609 m
EASTING (X)	375737.326 m	450428.645 m
CONVERGENCE	-0.88361821 deg	0.36227021 deg
POINT SCALE	0.99979016	0.99998609
COMBINED FACTOR	0.99979019	0.99998612

US NATIONAL GRID DESIGNATOR: 18SUH7573749650 (NAD 83)

MARK: LEX-1

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2015.7852)	
X:	1174354.974 m	0.001 m	1174354.136 m	0.001 m
Y:	-4874932.364 m	0.002 m	-4874930.904 m	0.002 m
Z:	3928427.122 m	0.002 m	3928427.053 m	0.002 m
LAT:	38 15 47.65700	0.001 m	38 15 47.68768	0.001 m
E LON:	283 32 39.48270	0.001 m	283 32 39.46323	0.001 m
W LON:	76 27 20.51730	0.001 m	76 27 20.53677	0.001 m
EL HGT:	-0.722 m	0.003 m	-2.034 m	0.003 m
ORTHO HGT:	33.785 m	0.016 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4236024.466 m	66364.212 m
EASTING (X)	372648.473 m	447635.911 m
CONVERGENCE	-0.90159979 deg	0.34162173 deg
POINT SCALE	0.99979974	1.00000660
COMBINED FACTOR	0.99979985	1.00000671

US NATIONAL GRID DESIGNATOR: 18SUH7264836024 (NAD 83)

Appendix C. Continued.

MARK: WAL-1

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2015.7907)	
X:	1127888.815 m	0.001 m	1127887.975 m	0.001 m
Y:	-4862133.260 m	0.002 m	-4862131.806 m	0.002 m
Z:	3957648.577 m	0.002 m	3957648.508 m	0.002 m
LAT:	38 35 56.63699	0.001 m	38 35 56.66774	0.001 m
E LON:	283 03 36.50754	0.001 m	283 03 36.48732	0.001 m
W LON:	76 56 23.49246	0.001 m	76 56 23.51268	0.001 m
EL HGT:	30.087 m	0.003 m	28.789 m	0.003 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)	4274070.455 m	103501.669 m
EASTING (X)	331073.128 m	405238.868 m
CONVERGENCE	-1.21049974 deg	0.03774653 deg
POINT SCALE	0.99995142	0.99996145
COMBINED FACTOR	0.99994670	0.99995673

US NATIONAL GRID DESIGNATOR: 18SUH3107374070 (NAD 83)

MARK: ROS-1

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2015.7882)	
X:	1135286.285 m	0.001 m	1135285.444 m	0.001 m
Y:	-4847925.473 m	0.003 m	-4847924.021 m	0.003 m
Z:	3972839.261 m	0.002 m	3972839.194 m	0.002 m
LAT:	38 46 27.61185	0.001 m	38 46 27.64276	0.001 m
E LON:	283 10 48.03327	0.001 m	283 10 48.01306	0.001 m
W LON:	76 49 11.96673	0.001 m	76 49 11.98694	0.001 m
EL HGT:	35.157 m	0.003 m	33.863 m	0.003 m
ORTHO HGT:	67.932 m	0.016 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4293307.802 m	122971.227 m
EASTING (X)	341898.644 m	415642.194 m
CONVERGENCE	-1.14001363 deg	0.11297994 deg
POINT SCALE	0.99990781	0.99995141
COMBINED FACTOR	0.99990229	0.99994589

US NATIONAL GRID DESIGNATOR: 18SUH4189893307 (NAD 83)

Appendix C. Continued.

MARK: GORF N

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2015.7992)	
X:	1128606.448 m	0.001 m	1128605.605 m	0.001 m
Y:	-4817138.993 m	0.002 m	-4817137.546 m	0.002 m
Z:	4011878.573 m	0.002 m	4011878.510 m	0.002 m
LAT:	39 13 34.24225	0.001 m	39 13 34.27349	0.001 m
E LON:	283 11 09.53620	0.001 m	283 11 09.51573	0.001 m
W LON:	76 48 50.46380	0.001 m	76 48 50.48427	0.001 m
EL HGT:	124.635 m	0.003 m	123.355 m	0.003 m
ORTHO HGT:	156.878 m	0.016 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4343444.144 m	173131.331 m
EASTING (X)	343417.049 m	416059.040 m
CONVERGENCE	-1.14738738 deg	0.11672882 deg
POINT SCALE	0.99990189	0.99996850
COMBINED FACTOR	0.99988234	0.99994895

US NATIONAL GRID DESIGNATOR: 18SUJ4341743444 (NAD 83)

CORS: GODE (used as hub)

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2015.7884)	
X:	1130774.430 m	0.001 m	1130773.587 m	0.001 m
Y:	-4831255.018 m	0.001 m	-4831253.564 m	0.001 m
Z:	3994200.534 m	0.001 m	3994200.465 m	0.001 m
LAT:	39 01 18.19020	0.001 m	39 01 18.22131	0.001 m
E LON:	283 10 23.42544	0.001 m	283 10 23.40508	0.001 m
W LON:	76 49 36.57456	0.001 m	76 49 36.59492	0.001 m
EL HGT:	15.788 m	0.001 m	14.495 m	0.001 m
ORTHO HGT:	48.168 m	0.016 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 18)	SPC (1900 MD)
NORTHING (Y)	4320774.485 m	150431.523 m
EASTING (X)	341854.671 m	414996.118 m
CONVERGENCE	-1.15043529 deg	0.10868975 deg
POINT SCALE	0.99990796	0.99995308
COMBINED FACTOR	0.99990548	0.99995060

US NATIONAL GRID DESIGNATOR: 18SUJ4185420774 (NAD 83)

Appendix C. Continued.

MARK: NLIB (long-distance cors)

```
REF FRAME:        NAD_83(2011) (2010.0000)                IGS08 (2015.7888)
X:                 -130933.928 m    0.001 m          -130934.777 m    0.001 m
Y:                -4762293.057 m    0.001 m         -4762291.697 m    0.001 m
Z:                 4226854.724 m    0.001 m          4226854.638 m    0.001 m
LAT:           41 46 17.70092      0.001 m       41 46 17.72769      0.001 m
E LON:        268 25 30.40784      0.001 m      268 25 30.36946      0.001 m
W LON:         91 34 29.59216      0.001 m       91 34 29.63054      0.001 m
EL HGT:              208.055 m    0.001 m             207.001 m    0.001 m
ORTHO HGT:           240.608 m    0.009 m  (H = h - N WHERE N = GEOID12B HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 15)         SPC (1402 IA S)
NORTHING (Y)      4625397.325 m         198509.188 m
EASTING (X)        618447.032 m         660052.831 m
CONVERGENCE       0.94946740 deg       1.26807407 deg
POINT SCALE        0.99977264           0.99999793
COMBINED FACTOR    0.99974002           0.99996530

US NATIONAL GRID DESIGNATOR: 15TXG1844725397 (NAD 83)
```

++

CONSTRAINED MARKS

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CORS: ANP5

```
CONSTRAIN: 3-D NORMAL
ADJUST  X:   -0.003m (0.001m)   Y:    0.008m (0.001m)   Z:    0.010m (0.001m)
ADJUST  N:    0.013m (0.001m)   E:   -0.001m (0.001m)   H:   -0.000m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                IGS08 (2015.7867)
X:                 1149299.240 m    0.001 m          1149298.395 m    0.001 m
Y:                -4827708.339 m    0.001 m         -4827706.881 m    0.001 m
Z:                 3993217.447 m    0.001 m          3993217.375 m    0.001 m
LAT:           39 00 37.00478      0.001 m       39 00 37.03592      0.001 m
E LON:        283 23 26.71963      0.001 m      283 23 26.69951      0.001 m
W LON:         76 36 33.28037      0.001 m       76 36 33.30049      0.001 m
EL HGT:              21.694 m     0.001 m              20.395 m     0.001 m
ORTHO HGT:           54.691 m     0.016 m  (H = h - N WHERE N = GEOID12B HGT)

               UTM COORDINATES    STATE PLANE COORDINATES
                UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4319149.092 m         149219.727 m
EASTING (X)        360669.012 m         433843.134 m
CONVERGENCE       -1.01311757 deg       0.24525146 deg
POINT SCALE        0.99983904           0.99995259
COMBINED FACTOR    0.99983564           0.99994919

US NATIONAL GRID DESIGNATOR: 18SUJ6066919149 (NAD 83)
```

Appendix C. Continued.

CORS: ANP6

```
CONSTRAIN: 3-D NORMAL
ADJUST  X:   -0.002m (0.001m)   Y:    0.020m (0.001m)   Z:    0.004m (0.001m)
ADJUST  N:    0.016m (0.001m)   E:    0.003m (0.001m)   H:   -0.013m (0.002m)

REF FRAME:        NAD_83(2011) (2010.0000)                IGS08 (2015.7986)
X:                 1149309.163 m    0.001 m          1149308.315 m    0.001 m
Y:                -4827690.273 m    0.001 m         -4827688.817 m    0.001 m
Z:                 3993238.123 m    0.001 m          3993238.053 m    0.001 m
LAT:           39 00 37.83759      0.001 m       39 00 37.86874      0.001 m
E LON:        283 23 27.29475      0.001 m      283 23 27.27447      0.001 m
W LON:         76 36 32.70525      0.001 m       76 36 32.72553      0.001 m
EL HGT:               22.839 m    0.002 m              21.542 m    0.002 m
ORTHO HGT:            55.836 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4319174.521 m         149245.466 m
EASTING (X)        360683.299 m         433856.860 m
CONVERGENCE       -1.01302201 deg       0.24535173 deg
POINT SCALE        0.99983900           0.99995260
COMBINED FACTOR    0.99983542           0.99994902

US NATIONAL GRID DESIGNATOR: 18SUJ6068319174 (NAD 83)
```

CORS: BACO

```
CONSTRAIN: 3-D NORMAL
ADJUST  X:   -0.003m (0.001m)   Y:    0.007m (0.001m)   Z:    0.017m (0.001m)
ADJUST  N:    0.018m (0.001m)   E:   -0.001m (0.001m)   H:    0.004m (0.002m)

REF FRAME:        NAD_83(2011) (2010.0000)                IGS08 (2015.7986)
X:                 1143199.185 m    0.001 m          1143198.339 m    0.001 m
Y:                -4801171.602 m    0.001 m         -4801170.147 m    0.001 m
Z:                 4026765.158 m    0.001 m          4026765.080 m    0.001 m
LAT:           39 23 58.03806      0.001 m       39 23 58.06926      0.001 m
E LON:        283 23 35.55690      0.001 m      283 23 35.53656      0.001 m
W LON:         76 36 24.44310      0.001 m       76 36 24.46344      0.001 m
EL HGT:              128.313 m    0.002 m              127.018 m    0.002 m
ORTHO HGT:           160.876 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4362337.578 m         192424.940 m
EASTING (X)        361647.405 m         433869.644 m
CONVERGENCE       -1.02002827 deg       0.24679217 deg
POINT SCALE        0.99983568           0.99999155
COMBINED FACTOR    0.99981555           0.99997142

US NATIONAL GRID DESIGNATOR: 18SUJ6164762337 (NAD 83)
```

Appendix C. Continued.

CORS: CORB

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CONSTRAIN: 3-D NORMAL
ADJUST  X:   -0.002m (0.001m)   Y:    0.007m (0.001m)   Z:    0.017m (0.001m)
ADJUST  N:    0.018m (0.001m)   E:   -0.001m (0.001m)   H:    0.005m (0.002m)

REF FRAME:        NAD_83(2011) (2010.0000)                IGS08 (2015.7849)
X:                 1097041.998 m    0.001 m          1097041.160 m    0.001 m
Y:                -4897239.883 m    0.001 m         -4897238.422 m    0.001 m
Z:                 3923126.379 m    0.001 m          3923126.302 m    0.001 m
LAT:            38 12 07.82852      0.001 m       38 12 07.85882      0.001 m
E LON:         282 37 35.42973      0.001 m      282 37 35.40927      0.001 m
W LON:          77 22 24.57027      0.001 m       77 22 24.59073      0.001 m
EL HGT:                37.241 m    0.002 m              35.929 m    0.002 m
ORTHO HGT:             69.809 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)      4230910.110 m        2060045.543 m
EASTING (X)        292173.051 m        3598666.745 m
CONVERGENCE       -1.46838316 deg       0.70307393 deg
POINT SCALE        1.00013197           0.99997449
COMBINED FACTOR    1.00012613           0.99996865

US NATIONAL GRID DESIGNATOR: 18STH9217330910 (NAD 83)
```

CORS: GODZ

```
CONSTRAIN: 3-D NORMAL
ADJUST  X:    0.001m (0.001m)   Y:    0.007m (0.001m)   Z:    0.013m (0.001m)
ADJUST  N:    0.014m (0.001m)   E:    0.003m (0.001m)   H:    0.003m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                IGS08 (2015.7890)
X:                 1130774.430 m    0.001 m          1130773.587 m    0.001 m
Y:                -4831255.020 m    0.001 m         -4831253.566 m    0.001 m
Z:                 3994200.534 m    0.001 m          3994200.466 m    0.001 m
LAT:            39 01 18.19016      0.001 m       39 01 18.22129      0.001 m
E LON:         283 10 23.42542      0.001 m      283 10 23.40509      0.001 m
W LON:          76 49 36.57458      0.001 m       76 49 36.59491      0.001 m
EL HGT:                15.790 m    0.001 m              14.498 m    0.001 m
ORTHO HGT:             48.170 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4320774.484 m         150431.522 m
EASTING (X)        341854.670 m         414996.117 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)
```

Appendix C. Continued.

CORS: HNPT

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CONSTRAIN: 3-D NORMAL
ADJUST  X:   -0.003m (0.001m)   Y:    0.001m (0.001m)   Z:    0.020m (0.001m)
ADJUST  N:    0.017m (0.001m)   E:   -0.003m (0.001m)   H:    0.011m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2015.7835)
X:                 1196627.022 m    0.001 m          1196626.183 m    0.001 m
Y:                -4846359.957 m    0.001 m         -4846358.488 m    0.001 m
Z:                 3956723.227 m    0.001 m          3956723.153 m    0.001 m
LAT:           38 35 19.71057      0.001 m       38 35 19.74160      0.001 m
E LON:        283 52 10.66795      0.001 m      283 52 10.64885      0.001 m
W LON:         76 07 49.33205      0.001 m       76 07 49.35115      0.001 m
EL HGT:               -26.664 m    0.001 m             -27.981 m    0.001 m
ORTHO HGT:              8.232 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4271753.579 m         102722.211 m
EASTING (X)        401553.850 m         475762.992 m
CONVERGENCE       -0.70509880 deg       0.54580946 deg
POINT SCALE        0.99971935           0.99996232
COMBINED FACTOR    0.99972353           0.99996650

US NATIONAL GRID DESIGNATOR: 18SVH0155371753 (NAD 83)
```

CORS: LOYB

```
CONSTRAIN: 3-D NORMAL
ADJUST  X:    0.002m (0.001m)   Y:    0.012m (0.001m)   Z:    0.011m (0.001m)
ADJUST  N:    0.016m (0.001m)   E:    0.005m (0.001m)   H:   -0.002m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2015.7890)
X:                 1105168.966 m    0.001 m          1105168.126 m    0.001 m
Y:                -4858128.326 m    0.001 m         -4858126.875 m    0.001 m
Z:                 3968834.120 m    0.001 m          3968834.050 m    0.001 m
LAT:           38 43 42.02230      0.001 m       38 43 42.05303      0.001 m
E LON:        282 48 57.70206      0.001 m      282 48 57.68146      0.001 m
W LON:         77 11 02.29794      0.001 m       77 11 02.31854      0.001 m
EL HGT:               -1.557 m    0.001 m              -2.850 m    0.001 m
ORTHO HGT:            30.658 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)      4288895.099 m        2118664.857 m
EASTING (X)        310154.955 m        3614427.841 m
CONVERGENCE       -1.36676291 deg       0.82135680 deg
POINT SCALE        1.00004384           0.99995025
COMBINED FACTOR    1.00004408           0.99995049

US NATIONAL GRID DESIGNATOR: 18SUH1015488895 (NAD 83)
```

Appendix C. Continued.

CORS: LOYF

```
CONSTRAIN: 3-D NORMAL
ADJUST  X:   -0.007m (0.001m)   Y:    0.018m (0.001m)   Z:    0.006m (0.001m)
ADJUST  N:    0.017m (0.001m)   E:   -0.002m (0.001m)   H:   -0.011m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2015.7849)
X:                 1157209.558 m    0.001 m          1157208.716 m    0.001 m
Y:                -4828361.984 m    0.001 m         -4828360.533 m    0.001 m
Z:                 3990104.483 m    0.001 m          3990104.419 m    0.001 m
LAT:            38 58 28.07468      0.001 m       38 58 28.10584      0.001 m
E LON:         283 28 40.11483      0.001 m      283 28 40.09485      0.001 m
W LON:          76 31 19.88517      0.001 m       76 31 19.90515      0.001 m
EL HGT:               -14.508 m    0.001 m             -15.798 m    0.001 m
ORTHO HGT:             18.754 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4315044.803 m         145279.946 m
EASTING (X)        368140.232 m         441403.602 m
CONVERGENCE       -0.95755593 deg       0.29988966 deg
POINT SCALE        0.99981410           0.99995133
COMBINED FACTOR    0.99981638           0.99995361

US NATIONAL GRID DESIGNATOR: 18SUJ6814015044 (NAD 83)
```

CORS: LOYK

```
CONSTRAIN: 3-D NORMAL
ADJUST  X:   -0.003m (0.001m)   Y:    0.014m (0.001m)   Z:    0.004m (0.001m)
ADJUST  N:    0.012m (0.001m)   E:   -0.000m (0.001m)   H:   -0.008m (0.002m)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2015.7986)
X:                 1132081.305 m    0.001 m          1132080.462 m    0.001 m
Y:                -4823104.326 m    0.001 m         -4823102.878 m    0.001 m
Z:                 4003637.190 m    0.001 m          4003637.126 m    0.001 m
LAT:            39 07 51.85870      0.001 m       39 07 51.88990      0.001 m
E LON:         283 12 33.74079      0.001 m      283 12 33.72039      0.001 m
W LON:          76 47 26.25921      0.001 m       76 47 26.27961      0.001 m
EL HGT:               35.286 m     0.002 m              34.003 m     0.002 m
ORTHO HGT:            67.678 m     0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4332848.514 m         162577.490 m
EASTING (X)        345227.714 m         418102.927 m
CONVERGENCE       -1.13028302 deg       0.13140929 deg
POINT SCALE        0.99989496           0.99995975
COMBINED FACTOR    0.99988942           0.99995421

US NATIONAL GRID DESIGNATOR: 18SUJ4522732848 (NAD 83)
```

Appendix C. Continued.

CORS: LOYM

```
CONSTRAIN: 3-D NORMAL
ADJUST  X:   -0.002m (0.001m)   Y:    0.018m (0.001m)   Z:    0.007m (0.001m)
ADJUST  N:    0.017m (0.001m)   E:    0.002m (0.001m)   H:   -0.010m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2015.7858)
X:                 1158531.860 m    0.001 m          1158531.022 m    0.001 m
Y:                -4875375.204 m    0.001 m         -4875373.745 m    0.001 m
Z:                 3932556.892 m    0.001 m          3932556.822 m    0.001 m
LAT:           38 18 38.11945      0.001 m       38 18 38.15011      0.001 m
E LON:        283 22 02.02619      0.001 m      283 22 02.00650      0.001 m
W LON:         76 37 57.97381      0.001 m       76 37 57.99350      0.001 m
EL HGT:                6.100 m    0.001 m               4.791 m    0.001 m
ORTHO HGT:            39.973 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4241537.516 m          71542.829 m
EASTING (X)        357249.301 m         432118.015 m
CONVERGENCE       -1.01236454 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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CORS: NRL1

```
CONSTRAIN: 3-D NORMAL
ADJUST  X:    0.003m (0.001m)   Y:    0.006m (0.001m)   Z:    0.002m (0.001m)
ADJUST  N:    0.005m (0.001m)   E:    0.004m (0.001m)   H:   -0.003m (0.001m)

REF FRAME:        NAD_83(2011) (2010.0000)                 IGS08 (2015.7863)
X:                 1117249.854 m    0.001 m          1117249.014 m    0.001 m
Y:                -4848760.132 m    0.001 m         -4848758.679 m    0.001 m
Z:                 3976821.293 m    0.001 m          3976821.227 m    0.001 m
LAT:           38 49 14.65988      0.001 m       38 49 14.69085      0.001 m
E LON:        282 58 32.16457      0.001 m      282 58 32.14416      0.001 m
W LON:         77 01 27.83543      0.001 m       77 01 27.85584      0.001 m
EL HGT:              -16.916 m    0.001 m             -18.208 m    0.001 m
ORTHO HGT:            15.309 m    0.016 m  (H = h - N WHERE N = GEOID12B HGT)

                UTM COORDINATES    STATE PLANE COORDINATES
                 UTM (Zone 18)         SPC (1900 MD)
NORTHING (Y)      4298830.869 m          128107.022 m
EASTING (X)        324254.390 m          397881.208 m
CONVERGENCE       -1.26939151 deg       -0.01531348 deg
POINT SCALE        0.99998035           0.99995031
COMBINED FACTOR    0.99998300           0.99995296

US NATIONAL GRID DESIGNATOR: 18SUH2425498830 (NAD 83)
```

Appendix C. Continued.

CORS: UMBC

CONSTRAIN: 3-D NORMAL
ADJUST X: -0.016m (0.001m) Y: 0.021m (0.001m) Z: 0.009m (0.001m)
ADJUST N: 0.022m (0.001m) E: -0.011m (0.001m) H: -0.013m (0.002m)

REF FRAME:	NAD_83(2011) (2010.0000)		IGS08 (2015.7986)	
X:	1136717.965 m	0.001 m	1136717.121 m	0.001 m
Y:	-4812977.269 m	0.001 m	-4812975.822 m	0.001 m
Z:	4014471.593 m	0.001 m	4014471.530 m	0.001 m
LAT:	39 15 24.36126	0.001 m	39 15 24.39255	0.001 m
E LON:	283 17 18.53140	0.001 m	283 17 18.51103	0.001 m
W LON:	76 42 41.46860	0.001 m	76 42 41.48897	0.001 m
EL HGT:	65.927 m	0.002 m	64.647 m	0.002 m
ORTHO HGT:	98.393 m	0.016 m	(H = h - N WHERE N = GEOID12B HGT)	

	UTM COORDINATES UTM (Zone 18)	STATE PLANE COORDINATES SPC (1900 MD)
NORTHING (Y)	4346666.840 m	176550.163 m
EASTING (X)	352329.281 m	424898.753 m
CONVERGENCE	-1.08323927 deg	0.18106049 deg
POINT SCALE	0.99986850	0.99997190
COMBINED FACTOR	0.99985816	0.99996156

US NATIONAL GRID DESIGNATOR: 18SUJ5232946666 (NAD 83)

Note:
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.

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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