CHAPTER 5

GNSS & Control

Chapter Contents

Sec. 5.01 General

The Global Positioning System (GPS) technology is the system created and maintained by the United States. More specifically, the current American satellite-based radio navigation system was originally known as NAVSTAR GPS which stood for navigation satellite timing and ranging global positioning system. GLONASS is the Russian counterpart to America's GPS. Galileo is the European Union system and BeiDou is the Chinese counterpart system. There are other more regional systems such as IRNSS operated by India and QZSS which is a Japanese system. These systems combined are now referred to as Global Navigational Satellite System (GNSS) and it continues to advance and improve in its capabilities. GNSS has become a common tool for surveying that is not only "smaller, lighter and faster" but has the ability to perform geodetic control surveying in a fraction of the time as compared to classical terrestrial survey methods with a total station as an example. GNSS has enabled surveyors the ability to establish control for a project from known existing control that may be miles away. VDOT utilizes GNSS for securing control values for primary control as well as photo control for aerial surveys. VDOT allows other uses of GNSS in addition to traditional static operations, specifically, the use of Real-Time Kinematic (RTK) GNSS surveying for photo control, right of way and corridor baseline stakeout, and also topographic collection when standard industry guidelines are followed. Other divisions within VDOT are also utilizing GNSS in one form or another to collect data for their specific needs.

As with any surveying tool, certain guidelines, specifications and methodologies must be adhered to. The intent of this chapter of the survey manual is to assist the surveyor in the mission planning, collection and processing of GNSS data for VDOT survey projects. The surveyor should consult the publications, "**Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques, Version 5.0: May 11, 1988**" Reprinted with corrections: August 1, 1989, published by the Federal Geodetic Control Committee (FGCC) and also the "**Standards and Specifications for Geodetic Control Networks**" as published by the Federal Geodetic Control Committee (FGCC), Rockville MD, September 1984. Additionally a number of memoranda from the National Geodetic Survey should be followed as a guide when establishing new survey control. Specifically NOAA Technical Memorandum NOS NGS 58, Guidelines for establishing Ellipsoid Heights, and NOAA Technical Memorandum NOS NGS 59, Guidelines for establishing GPS-Derived Orthometric Heights. This chapter was prepared heavily in parts, from these NGS publications. VDOT will continue its procedures to generate, via GNSS survey techniques, state plane coordinates and orthometric heights in U.S. Survey Feet for its Route Survey projects. These values shall be converted to the VDOT Project Coordinates, which are also given in the U.S. Survey foot. For more on Project coordinates, see Section 5.07 regarding LD-200 cards in this chapter. It is important to remember however that legacy projects, projects started or completed before 2014, will reflect a variety of coordinate configurations and VDOT survey control from older projects should be used with this understanding.

Sec. 5.02 GNSS Equipment

The GNSS geodetic receivers used for static survey operations shall receive both the L1 and L2 carrier frequencies transmitted by the current constellation of GNSS satellites and shall have the capability of tracking a minimum of eight GNSS satellites simultaneously. The receivers shall have the capability to receive and decode the C/A (Coarse Acquisition) code and the P-code (Precise-code) data on the L1 frequency and the P-code in the L2 frequency. The receivers should have the means to use the encrypted P-code *(sometimes called the Y-code when encrypted)*.

Dual frequency receivers are required for precision surveys to correct for the effects of ionospheric refraction where the magnitude of the error may range from 1 to 10 ppm. The receivers must record the phase of the satellite signals, the receiver clock times and the signal strength or quality of the signal. The phase center of the antenna, which is constant and unique to the antenna model, should be known from the manufacturer. It is best not to use different antenna models during a survey, as the phase center may create a bias in the elevations of survey points. If the receiver does not have a known phase center database relating to antenna type, the user should have the ability to enter the measurement components for the phase center height of the antenna. The measurement components are a measured height above a survey point to a mark on an adapter (or to a corner of the antenna) and the fixed constant distance from an adapter mark to the phase center of the antenna (provided by the manufacturer). Figure 5-A, is an example from the NGS illustrating the different antenna measurements required for different antenna types. **Fixed Height Tripods are recommended for use during GNSS missions to avoid measurement or transcription errors.** It is also best practice to orient each antenna in the same geographic direction. Most antennae have a north mark which should be aimed in the direction of true north, however, this not so critical a factor as to justify undue or time consuming efforts. The GNSS receivers should be programmable and have several I/O ports. The software should be able to convert the data to RINEX-3 format for use with other GNSS systems and software. It is permissible to use third party software to convert a proprietary formats to the RINEX (receiver independent exchange) format.

Sec. 5.03 GNSS Networks and Accuracy Standards

In general, the GNSS Network will consist of known points and all points to be surveyed, allowing "loop closures" to be calculated from processing procedures utilizing data from a minimum of two sessions that allow the calculated vectors between stations to form a loop. Since each GNSS derived position is a "relative position" determined by analyzing signals from the satellite array to the occupied point only, and since no GNSS data directly between independent antenna positions is available, it is important to process the GNSS session(s) as a whole to ensure all the point positions have been derived from the same satellite data and control restraints. This allows the baseline vectors, direction and distance between the occupied points to be drawn and computed both as loop as well as a "spider web" of independent baselines creating redundancy for precision/accuracy purposes.

A known point would be a point that has a known position and/or elevation. A HARN (high accuracy reference network including the high precision geodetic network) Station, a CORS (continuously operating reference station) site, a NGS vertical station, a USGS monument tied to NAVD88 datum or, especially in VDOT's case, an existing survey station from an existing project, would be considered a known point. A minimum of three known points shall be included in the observing scheme. The three known points should be based on or originate from a common datum. In some cases, it is acceptable to use available software to convert elevations to the NAVD88 datum. The location of the new control points shall depend on the optimum layout to carry out the required needs of the survey.

The "**Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques, Version 5.0**", by the Federal Geodetic Control Committee (FGCC), is VDOT's source for the definition of accuracy standards and the specifications and procedures to achieve those standards. When requested, any surveyor performing a GNSS survey for VDOT that must comply with an accuracy standard, shall adhere to the standards and specifications as published by the FGCC, being a subcommittee of the Federal Geographic Data Committee.

The accuracy standard for the survey will depend on several factors.
These factors include, but are not limited to:

- number of receivers available for the project
- the "mission plan" or observation scheme
- quality and/or precision of the control points
- satellite availability and geometry
- signal strength
- network geometry
- observation duration

Sec. 5.04 General Specifications for GNSS Surveys

In general, this section is intended to be a guide for any surveyor who is providing VDOT with GNSS data. These procedures are general minimum requirements that must be met by the surveyor in order for the GNSS survey data to be accepted by VDOT. These procedures are for static and rapid static GNSS observations and techniques. Please refer to "**Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques**" for more specific criteria not covered here. When experience and field conditions allow for alternative procedures, at the discretion of the licensed surveyor in charge, then documentation will be provided demonstrating the accuracy obtained and the procedures followed.

1. **GNSS Survey Project Datum.** Unless otherwise instructed, **ALL VDOT GNSS CONTROL SURVEYS SHALL BE REFERENCED TO THE CURRENT PUBLISHED NATIONAL SPATIAL REFERENCE SYSTEM (NSRS) ADJUSTMENT AND THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88) SHALL BE THE ELEVATION DATUM.** Only horizontal NAD 83 coordinates and control data observed by GNSS methods from reference stations included in the NSRS will be accepted by VDOT. The NSRS contains GNSS stations and data published from the following network observations: Continuously Operating Reference Stations (CORS), NOAA CORS Network (NCN), Federal Base Network (FBN) surveys, Cooperative Base Network (CBN) surveys, Area Navigation Approach (ANA) airport surveys, and "Blue-booked" User Densification Network (UDN) GNSS surveys.

2. **GNSS Network Control Procedures.** All GNSS Network Control and Field Survey procedures will conform to the standards as defined in this section, for routine VDOT surveys, shown hereon as **2a** through **2o**. The intent of these procedures is to produce GNSS surveys and data for the **Project Control Monumentation** that meets a geometric accuracy of 1:100,000 at the 68% confidence interval. A list of specifications is included as Figure 5-M, for easy reference.

2a A minimum of three (3) GNSS receivers shall be used simultaneously during all Static & Rapid Static GNSS sessions.

2b Existing or known points that will be used to control the survey shall be occupied simultaneously during the initial observation sessions. This is a check to ensure that existing, known or network control has not been disturbed and that the published values are, indeed correct. This is an integral part of the mission plan.

2c Horizontal networks shall be connected to a minimum of two (2) NSRS (NGS) 1st-order (or higher) stations (see #1 of this section). At least one benchmark shall be used and held fixed for surveys where horizontal values will be paramount. The use of eccentric horizontal stations is not permitted.

2d Vertical networks shall be connected to a minimum of three (3) third-order (or higher) bench marks. At least two of the benchmarks shall be near the project boundary to help determine the geoid separation of the project area.

2e Sight (or station) pairs that are to be established by GNSS methods to provide azimuths for the survey shall be inter-visible stations and spaced no less than 600 feet apart and no more than 1450 feet apart. Azimuth pairs that are to be established by GNSS methods should be spaced approximately one mile apart but no more than 3 miles apart. Each sight (or station) pair and each azimuth pair shall be occupied at least **twice** simultaneously and separated by a minimum of one-half hour to create a redundant, direct connection between project control points. A sample network scheme is included as Figure 5-B.

2f During each session, a minimum of 5 satellites shall be observed simultaneously. The Geometric Dilution of Precision (GDOP) shall never be greater than six (6) at any time during the observation session. The Position (3D) Dilution Precision (PDOP) shall never be greater than four (4) at any time during the observation session. Acceptable GDOP & PDOP values can be achieved through good mission planning practices and utilization of mission planning software. *(Types of Dilution of Precision for GNSS; HDOP for horizontal, VDOP for vertical, PDOP is 3D, TDOP for time, and GDOP is geometrical)*

2g Each session's, data sampling shall have an epoch (minimum) time interval of 5 seconds for Rapid Static survey procedures and 15 seconds for Static survey procedures. Satellite signals shall be observed from a minimum of 2 quadrants that are diagonally opposite from each other during Rapid Static survey missions. Satellite signals shall be observed from a minimum of 3 quadrants during a Static survey mission. This requirement shall be met while monitoring data collection in the field. It will also be verified by the GDOP value.

2h Satellite receivers and processing software shall be programmed such that any satellite data below an elevation mask of 15 degrees shall not be used in the processing of baseline vectors. Any data below the 15 degree elevation mask would be questionable due to effects of atmospheric refraction.

2i During reconnaissance and each observation session, careful notes or obstruction diagrams (see Figure 5-C) shall be recorded for any obstructions that are 20 degrees or higher above the horizon. Proper mission planning can minimize the effects of any obstructions and maximize the opportunity for a productive observation session.

2j The geoid model to be used shall either be the **2012A Geoid Model or the 2012B Geoid Model**. Either of these versions may be used as the model for determining the geoid separation for each project control point and subsequent elevation.

2k The ellipsoid model to be used for determining elevation of the ellipsoid, shall be the **GRS 80** ellipsoid model which is the reference ellipsoid for NAD 1983.

2l VDOT requires that the final adjusted coordinates for the GNSS project shall be the product of a three-dimensional least squares adjustment software package.

2m Static observation procedures shall be required for all baselines with a length of 20 kilometers (km) or longer. For a baseline length between 20 and 50 kilometers, observation sessions shall be at a minimum, 2.5 hours plus one minute per kilometer of the longest baseline length for that session. For a baseline length between 50 and 100 kilometers, observation sessions shall be at a minimum, 3.5 hours plus one minute per kilometer of baseline length for that session. Proper mission planning and point site selections are vital to the success of the observing session.

2n Rapid Static observation procedures may be used for all baselines shorter than 20 kilometers (km) in length. Observation sessions shall be at a minimum, 20 minutes plus one minute per kilometer of the longest baseline length for that session. Proper mission planning and point site selections are vital to the success of the observing session. From a conservative standpoint, it is strongly recommended to add additional time to minimize the effect of solar activity, atmospheric refraction and unhealthy satellites.

2o The determination of observation duration is ultimately the responsibility of the Licensed Surveyor in responsible charge, and will be a function of the spacing of known control, distance of known control to survey project control, and the length of the project corridor among other factors. Again, if control is farther than 20 kilometers from the project, static observation procedures will be used.

3. **Securing Photogrammetry Control.** Securing control for photogrammetry will also follow the same guidelines as listed above. If control is nearby, the photogrammetry mission can be accomplished with rapid static observation procedures using “leap-frog” or traversing techniques through the control such that direct measurements are made between consecutive targets. Intermittent ties to the existing, known control and/or the monumented project control should be made during the mission. Proper mission planning techniques will develop the best results and checks for the mission. **The adjustment of photogrammetry control should be independent of the VDOT Project Control Monumentation adjustment.**

4. **Utilizing RTK GNSS on VDOT Projects.** At the time of this revision to the Survey manual, VDOT is currently allowing the use of Real-Time Kinematic (RTK) GNSS

surveying equipment and procedures capable of achieving a 2-cm positional accuracy. RTK GNSS surveying techniques utilizing a base station on established control such as a VDOT project control point, a HARN point, or dialing into a subscription RTK service for corrections for securing photo control and topography will be acceptable to VDOT when measures are taken to ensure similar accuracy results as would be achieved by using Static or Rapid-Static procedures outlined in this manual. Prior to securing photo control, the surveyor shall have a base unit set on known control and shall check the values at another control point with the roving unit.

The surveyor must provide proof of photo control points being measured at least twice by RTK methods, spot-checked by conventional survey methods, and that the positional differences are insignificant. The surveyor shall verify that the positional accuracy meets or exceeds the survey specifications. It is incumbent on, and the responsibility of, the surveyor with responsible charge providing data to VDOT to secure results that would meet similar accuracy standards as other methods outlined herein. It is also required that documentation demonstrating the method of collection, status of base station control, ties to the CORS or HARN, if used, as well as the accuracy acquired, shall be provided along with the deliverable survey data. Any questions regarding field procedures may be directed to VDOT’s GeoSpatial Survey Support group at GeoSpatial-info@VDOT.virginia.gov.

5. Utilizing OPUS on VDOT Projects:

This **Online Positioning User Service (OPUS)** provides simple access to high-accuracy National Spatial Reference System (NSRS) coordinates. By uploading a data file collected with a survey-grade GPS receiver you can obtain an NSRS position via email.

OPUS requires minimal user input and uses software which computes coordinates for NGS' Continuously Operating Reference Station (CORS) network. The resulting positions are accurate and consistent with other NSRS users. Static and/or Rapid Static GNSS observations should be input and computed using OPUS Projects rather than using only the basic OPUS solution. OPUS Projects allows all of the observed points to be computed simultaneously in session(s) ensuring better local network accuracies.

Your solution is sent privately via email, and, if you choose, can also be shared publicly via the NGS website. To use properly, please familiarize yourself with all the information provided on the National Geodetic Survey website http://www.ngs.noaa.gov/OPUS/.

As with RTK GNSS procedures outlined above, it is permissible to use OPUS for establishing data for VDOT Projects as long as measures and care are taken to achieve similar accuracy results that meet or exceed the accuracy results that would otherwise be achieved by using Static or Rapid-Static procedures outlined in this manual.

The responsible charge surveyor shall verify that the positional accuracy meets or exceeds the required survey specifications. OPUS Projects GNSS solution techniques are being improved almost daily and are too numerous to outline in this manual. Therefore it is incumbent on, and the responsibility of, the licensed surveyor in responsible charge who is providing data to VDOT to secure results that would meet similar accuracy standards as other methods outlined herein. It is also required that documentation demonstrating the method of collection, status of base station control used, ties to the CORS or HARN, as well as the accuracy acquired, shall be provided along with the deliverable survey data. OPUS provides an adjustment report and this report shall be include in the documentation provided to VDOT. Any questions regarding field procedures may be directed to VDOT's GeoSpatial Survey Support group at GeoSpatial-info@VDOT.virginia.gov.

Data File of dual-frequency GPS (L1/L2) full-wavelength carrier observables:

- Static data only; the antenna must remain unmoved throughout the observing session. 20-minutes of data or more, up to 48-hours, but not crossing UTC midnight more than once.
- Files under 2 hours, processed as rapid-static, must include the P2 and either P1 or C1 observables.
- GLONASS or Galileo observables may be included; though only the GPS may be available for use depending on when the data files are submitted.
- Any elevation cut-off or mask angle; though only satellites more than 15° above the horizon may be used (check the OPUS Projects default settings prior to processing data).
- Recording (epoch) rates of 1, 2, 3, 5, 10, 15, or 30 seconds; though all data file are decimated to 30 seconds.
- RINEX 2 or RINEX 3 data format, though some other raw data formats may be submitted and automatically converted by OPUS' internal software (check for compatibility)
- Compressed UNIX, gzip, pkzip, or Hatanaka formats are allowed though all data files in compressed formats must have the same type of antenna and the same antenna height

Antenna

Selecting your antenna will engage the appropriate antenna calibration model, to counter the unique measurement biases inherent in each antenna's design. Take care! Choosing an incorrect antenna may result in a height error as large as 80 cm vertical, 1 cm horizontal. Tip: Use antenna calibration to find an exact match.

Antenna Height

Enter the vertical height in meters of your Antenna Reference Point (ARP) above the mark you are positioning, as shown in the image at right. The ARP for your antenna, usually the center of the base or tripod mount, is illustrated in antenna calibration images under the pull down menu for antenna brand and model. If you enter a 0.0 antenna height, your ARP position will be returned.

Sec. 5.05 Quality Control Procedures

This section of the Survey Manual will assist the surveyor with the minimum field practices to ensure quality GNSS survey data for VDOT. As with any high-tech measuring device, certain standards of care should be followed in the use and maintenance of the equipment. The following are a few of the procedures that are followed by VDOT surveyors to help minimize positioning and field errors and ensure a good quality with the field collected data.

a. The tribrach, for each unit, should periodically be checked so that the antenna is being centered accurately over the point. This can usually involve adjustment of the optical or laser plummet and perhaps the spirit level. It is important to ensure the antenna tribrach is centered directly above an occupied point at the beginning and end of each session; the antenna should also be checked for level at either end of the session.

b. Care should be taken when setting a control monument or station, (see Figure 5-D) so that the effect of obstructions or canopy can be minimized (see Figure 5-C). The monument and disk, or iron pin should be set according to normal VDOT procedures.

c. A site log form (see Figure 5-E) has been developed by VDOT for VDOT surveyors to corroborate data entered into the receiver. One site-log form shall be filled out for each receiver for each occupation. The pertinent data includes: the date, observer, receiver #, station occupied (name), beginning antenna height, the antenna offset, session start time, start intermediate and end minimum QI & satellite number, end session time, end antenna height and comments. The form is self-explanatory. It is the responsibility of the surveyor operating the receiver to complete each form. The QI is the Quality Index of the satellite signal being received from each satellite. Regarding some of VDOT's equipment as an example, Leica System 300, a value of 99 is best, Leica's System 500, a QI of 99 is best and anything below 92 is unacceptable. VDOT requires knowledge of which value is lowest and from which satellite. This knowledge will assist with processing baselines later on. The comment section is for the surveyor operating the receiver to describe any problems affecting the satellite data or satellite signal received.

d. The antenna height will be measured in meters (and feet). Measurements for antenna height shall be taken at the beginning and end of each session. If a station is to be occupied simultaneously through more than one session, the antenna will be reset over the station and a new antenna height at the beginning and end of each session will be measured. **It is the responsibility of the surveyor to ensure that the antenna height measured in the field is recorded correctly on the site log form and entered correctly into the software. Site log forms should be filled out in the field during the session.** Please refer to Figure 5-A, for assistance with the components of the antenna height measurements.

e. Prior to every new project, the memory card of the receiver should be formatted (or cleared) once it has been definitely proven that the data has been downloaded and saved. It shall be a priority of the person who downloads the mission data to clear the cards of data only after a successful download and back up has been verified. Verification of a successful download will consist of examining mission data for session times, antenna height, and baseline quality and saving the data to another source or location.

f. Two-way radios shall not be used within 25 feet of the GNSS receiver. Vehicles will be parked a minimum of 50 feet away from the GNSS receiver.

g. Every member of the GNSS survey mission should know their responsibilities, session starting and ending times, station locations and basic operation of the GNSS equipment.

Sec. 5.06 Deliverables

All GNSS "subject data" for VDOT contracted surveys (either primary control or photogrammetric control) whether they are performed by VDOT staff or Consultants, shall be delivered to, or at least copied to VDOT's Central Office personnel for a quality control check and evaluation. This information will be delivered to VDOT's Central Office GeoSpatial Survey Support group at GeoSpatial-info@VDOT.virginia.gov **before** the entire VDOT survey is due.

The subject data that is to be delivered to the GeoSpatial Survey Support group shall include, at a minimum, every item on the list depicted below.

a. A sketch, on 8 ½" X 11" sheet of paper, containing the known network control points (NGS, USGS, etc.) and the project control, with ID's.

b. A copy of data sheets published for each known network control point used in the adjustment. This data sheet shall include station name, Geographic Coordinates, ellipsoidal heights, orthometric heights, published state plane coordinates, "how to reach" descriptions and point description. A copy of an NGS data sheet is acceptable for the known control points. The same format is acceptable for the project control points. Photogrammetric control points shall be identified on the project control sketch **only**. Descriptions or measured swing-ties for photo control **shall not** be included or delivered to the GeoSpatial Survey Support group.

c. A constrained three-dimensional adjustment report showing the latitude and longitude of all horizontal points, all benchmarks, and all ellipsoidal heights held fixed shall be delivered to VDOT's GeoSpatial Survey Support group. The report should depict how the adjustment affects each point and the residuals of each baseline vector.

d. A listing of final adjusted geographic coordinates, ellipsoidal heights, and geoid separations for each station, including stations held fixed. The final adjusted geographic coordinates shall be listed with their respective positional error.

e. A listing of the final adjusted state plane coordinates with orthometric heights in U.S. Survey feet, including stations held fixed.

f. All copies of site log forms, either VDOT's **OR** a similar form, as prepared by field surveyors.

g. All copies of any obstruction diagrams (Figure 5-C), if not included with site logs.

h. A copy of the mission plan. This mission plan will include session times, occupation duration and types of receivers used with manufacturer's standard antenna phase-center offset included.

i. A one-page summary of the GNSS mission. The report should include:

- Reasons for fixing and floating stations,
- Evaluation of adjustment results,
- Total man-hours spent by crew and processor and overall assessment of the mission and performance of equipment.

j. All completed LD-200 cards (latest version, see Figure 5-F).

k. One digital copy of original GNSS raw data in Leica, Trimble, Topcon, or RINEX-3 format. This data can be delivered on a CD or via FTP server if the client has an existing FTP account with VDOT.

Sec. 5.07 LD-200 Card (Rev. 10/2014)

Required information includes: Latitude and Longitude (out to 5 decimal places), the Geoid Separation and Ellipsoidal Height, Horizontal and Vertical Datums, NAD 83 State Plane Coordinates, NAVD 88 Orthometric (Height) Elevation, control station or VDOT project station that adjusted values are based on and more. Space is provided for a horizontal closure report, the sketch and detailed description (on back of printed version, below on electronic version). The LD-200 Horizontal Control card (see Figure 5-F) will help the surveyor by giving more background knowledge of the coordinate origin and inspire more surveyors to turn in an electronic version of the card and data. The card is a cell in the MicroStation cell library (see VDOT CADD Manual and OpenRoads Standards).

Sec. 5.08 Basis of the State Plane Coordinate System

To make full use of the State Plane Coordinate System, one must understand how the plane coordinates of any given point are directly related to the geodetic coordinates (latitude and longitude) of that point. First, it should be understood that the latitude of a point is the angular difference between that point and the equator as measured in a north-south direction from the center of the earth. The longitude of a point is the east-west angular difference between that point and the zero or prime meridian, which passes through Greenwich, England. Use of a latitude and longitude system, though very precise, would be too cumbersome for most mapping applications. Furthermore, since the shape of the earth approximates a spheroid, steps must be taken to project the rounded surface of the earth onto a flat, rectangular map. This map projection is accomplished through the use of a plane coordinate system that uses scale and elevation factors to project (or map) the earth’s surface onto an imaginary plane and/or from the plane to the earth’s surface.

Virginia is divided into two (2) Lambert Conformal Conic Projection zones, North and South. The dividing line runs along latitude of North 38˚ and the Code of Virginia in § 1-601 further describes the zones along the county lines. A point is positioned using GNSS methods and the position is referenced to a geodetic coordinate system, latitude and longitude. The Geodetic Coordinates are directly related to the Virginia State Plane Coordinate System as described in The Code of Virginia § 1-605.

For example, if we need to define a point in Louisa, Virginia, the latitude can be defined as the angular difference between that point and the equator as shown in Figure 5-G. Similarly, the longitude can be defined as the angular difference from Greenwich, England, as shown in Figure 5-H. This point would be defined as 38^{O} North latitude and 78^{O} West longitude. This would relate our point in Louisa, Virginia to any other point on the surface of the earth. This is a very precise and universally accepted method of defining positions on the surface of the earth. However, while geodetic coordinates are precise, the computations associated with them are unnecessarily complex when one is dealing with a relatively small area on the face of the earth, and it becomes expedient to establish a simpler model of the earth while still maintaining acceptable accuracy. This can be accomplished by utilizing the VDOT State Plane Coordinate System, which is based on NAD83 coordinate values.

This plane coordinate system allows the use of relatively simple theories and formulae of plane geometry and trigonometry used by surveyors since the beginning of history for the measurement of land and structures on the earth's surface.

The interstate highway system that we enjoy today is one of the prime contributing factors to the establishment of the Virginia State Plane Coordinate System and similar systems employed by all the other states in the United States. State and Federal engineers agreed that plane coordinate systems would be established to allow accurate surveys to be performed, which with the proper corrections applied, would be accurate, nationwide. In addition, the various zones in these systems would be small enough so that if no corrections were applied, positional accuracy within the respective zones would exceed 1 part in 10,000.

Sec. 5.09 Depiction of Two Coordinate Zones

Figure 5-I is a graphic representation of the State of Virginia showing the two coordinate systems. Refer to the Virginia South Zone and note that the line intersects the surface of the earth at two points similar to the way the long chord of a curve intersects the P. C. and P. T. of that curve. Likewise, the distance along the line from 36^{O} 46' to Point A would be shorter than the distance along the arc from 36^{O} 46' to Point A. The relationship between these two distances would give us a scale factor to apply to distances measured along the arc to reduce them to distances along the line. At 36^{O} 46' and 37^{O} 58' these corrections would be expressed as 1.0000000 multiplied by the distance measured. As you move to the center of the zone; this factor decreased to 0.9999454. As you proceed South from 36^{O} 46' to the North Carolina line, the correction increased to about 1.0000464. You will note that this variation from high to low gives a possible difference in 1000 feet of 0.10 feet, which was the required accuracy for the coordinate system. This basic idea holds true for the Virginia North Zone.

Sec. 5.10 Relation of Grid North and True North

All lines or meridians of longitude run through the North and South Pole. Therefore, they cannot be parallel since they all converge on the poles. The central meridian for the State of Virginia is 78° 30' West longitude for both the North and South Zones. This means that throughout both zones grid north is exactly parallel to the 78° 30' West longitude, central meridian. The angular difference between the true north and grid north is called the θ (theta) angle or convergence angle. Figure 5-J shows this graphically.

Sec. 5.11 The VDOT Project Coordinate System

Beginning June 1, 2014 all new VDOT Projects will be based on the new VDOT Project Coordinate System outlined below (Now known as "VDOT Project Coordinates-2014"). To convert Virginia State Plane Coordinates (based on the US Survey Foot) to VDOT Project Coordinates-2014, the coordinates will need to be multiplied by the combined Scale & Elevation Factor for each specific project. One method of obtaining the scale factor for each project will be to submit GNSS data to OPUS (NGS utility) for each primary control point on the project. Submitting "Static" data to OPUS (minimum 2- hour occupations per point) will be required. Once the OPUS results are obtained, take the average of the combined factors under the State Plane Coordinates for the primary control points. Once this step is done, the inverse function (1/x) should be applied, resulting in the Combined Scale Factor for the project (9 decimal places- Example= 1.000000009).

This is only one method of obtaining the scale factor for a project. Regardless of the method used, the procedure shall be described in detail in the project notes as well in the Project Deliverables (Sec. 5.06).

Special Note on Projects that predate June 1, 2014:

Projects completed or started prior to January 1, 2014 should continue to use the former language below.

The VDOT Coordinate System is based on NAD83 METRIC values as defined in The Code of Virginia § 1-605. To convert NAD83 METRIC to VDOT Project coordinates (Imperial Units), first depending on the zone you are working in, subtract 1,000,000 meters from the South Zone Northing value (or 2,000,000 meters from the North Zone Northing value). Next, subtract 2,500,000 meters from the Easting value. Next, multiply the Northing and Easting values by 3.28083333333 (the conversion for the U. S. Survey Foot as defined in The Code of Virginia **§** 1-603. Last, multiply the Northing and Easting values by the Combined County Scale & Elevation Factor. Figure 5-K is a list of the approximate combined scale and elevation factor for the counties. This produces VDOT Project Coordinates (in Imperial Units) for a given project. A reverse of this procedure will transform VDOT Project Coordinates back the original NAD83 METRIC values. See Figure 5-F**,** showing the use of the above procedures as depicted on a LD-200 Horizontal Control Station Reference Card.

Sec. 5.12 Airborne GNSS

1. Airborne GNSS (A-GNSS) techniques can be used to acquire supplemental control for use on photogrammetric and/or Airborne LiDAR (A-LiDAR) projects.
2. It is important to maintain a minimum of two (2) Reference Base Stations over known control points during the duration of the flight.
3. These Reference Stations should be spaced 10 to 25 kilometers from the project. The entire project should be reachable within this range.
4. The range of 10 to 25 kilometers should be scrutinized keeping in mind the accuracy needs of the project. A general rule of thumb, under optimal conditions, would be about 1 cm of residual per 10 kilometers of baseline distance. Bear in mind, there usually are other factors involved that could result in an increase in your residual values. i.e. a poor GDOP value
5. When multiple Reference Stations are required, no part of the project should be farther than 25 kilometers from at least one of the Reference Stations.
6. Reference Stations as well as Rovers should be set to collect one second epoch data.

Sec. 5.13 Horizontal and Vertical Control **<sctl(UPC#)>**

Horizontal

Permanent Horizontal Control Monuments shall be set on all surveys for highways for all systems, including closed surveys. Data available for setting horizontal control will be sent with the survey authorization, or as schedules permit the Global Positioning System (GPS) will be initiated by the GeoSpatial Program Manager with the authorization memorandum. The Survey Manager will ensure that the Land Surveyor Supervisor has sufficient data for control.

A **minimum** of four (**4**) monuments shall be set on each project greater than 1 mile in length, the amount of control shall be discussed with District Survey Manager prior to field work commencing. Standard VDOT disks may be set in concrete with re-bar or other metal added to assist in relocation with a metal detector. Rod & control disk caps may also be used if approved by the District Survey Manager or GeoSpatial Program Manager.

A **minimum** of three (**3**) monuments shall be set on projects less than 1 mile in length. Rod & Caps may be used on projects less than 1 mile in length if approved by the District Survey Manager or GeoSpatial Program Manager and control is placed outside the limits of construction.

Rod & cap shall be used to set all traverse points, unless ground conditions are not suitable. Swing ties to other objects should be obtained as evidence for re-establishment of all monumentation set.

Any new survey that will not be tied into any existing VDOT survey projects, shall be tied to the appropriate system as outlined in the Code of Virginia Section § 1-600 and into the most current NGS vertical datum**.** The **Global Navigation Satellite System (GNSS)** should be utilized whenever it is practical to do so. Unless specifically directed by the GeoSpatial Program Manager, any survey that is an extension of, or will tie into, an existing VDOT survey project will be constrained to the datum of the existing survey project.

Monuments should be tied to State plane and project coordinate values shown to the nearest one thousandth foot **(0.001-ft)** and vertical control to the nearest one hundredth foot **(0.01-ft)**.

Form LD-200 (Horizontal Control Reference Card) (Figure 5-F**)** shall be completed for all permanent monuments set for horizontal control, for referencing purposes. When the cards have been completed by VDOT personnel or consultants, the original copy will be uploaded into ProjectWise and an email sent to the GeoSpatial Survey Support group at GeoSpatial-info@vdot.virginia.gov and the appropriate District immediately upon completion of the control with a link to the ProjectWise folder. Control will not be considered complete until all deliverables outlined herein are provided.

Vertical - Leveling and Securing Elevations <sctl(UPC#)>

All location survey leveling will be secured by the use of Total Station methods and procedures or differential leveling as applicable. Elevations for all location surveys shall be based on GPS, U.S.G.S. or N.G.S. **U.S. Survey Feet** datum. ***The use of an assumed vertical datum is not acceptable.*** This is important, and no departure from this rule is authorized. The kind and source of datum should always be included in the Survey Report. When a survey is authorized, the Survey Manager or Land Survey Supervisor or Consultant shall be responsible for finding the location, description and elevation of any available government benchmarks.

A series of benchmarks must be established throughout the project at intervals of approximately one thousand feet **(1000 ft.)**. A benchmark should also be established near all future structures (bridges, box culverts) and at all road intersections. These benchmarks must be as permanent as possible, located on solid structure bases or in the bases of trees not likely to be disturbed by construction. **A benchmark will never be set in a utility pole**.

A complete description, including project coordinates and station plus and offset distance from the construction centerline (if available) as well as accurate description of the object on which the benchmark is located, must be given. In all cases, any benchmark established must be turned on, in order to be properly tied to the line of levels. Check levels must be run unless a previously established, permanent benchmark is convenient to both ends of the project. If a government benchmark is found near each end of the job and intermediate benchmarks are tied in by reason of turns, then a tie-in with the permanent benchmarks near each end of the project could serve as an adequate check. This is known as a "single run" level line because the leveling was performed in a single direction between established benchmarks.

The maximum error in differential leveling when establishing elevations for benchmarks or any primary project control points shall in no case be greater than five-hundredths **(±0.05')** of a foot times the square root of the length of the level run in miles **(±0.05 ft. X √M)**, where **M** is the leveling loop length in miles. If previously established, permanent benchmarks are not convenient to both ends of the project, it will be necessary to perform a "double run" closed leveling loop. This is accomplished by running the levels in both a forward and backward direction, beginning and ending on the same benchmark. Elevations on VDOT Control Monuments should also be read when benchmark levels are being run. For shorter level runs, the benchmark leveling standard of **(±0.05 ft. X √M)** translates to approximately **(±0.0069 ft. X √Sta)** where **√Sta** represents 100 foot stations, or the total level run distance divided by one hundred (100).

The maximum error in leveling when establishing elevations for secondary project controls and photogrammetric ground control points shall in no case be greater than seven-hundredths **(±0.07')** of a foot times the square root of the length of the level run in miles **(±0.07 ft. X √M)**. These may be a combination of single run level lines when between benchmarks, or double run level loops when they lie outside of the established controls. For shorter level runs, this leveling standard of **(±0.07 ft. X √M)** translates to approximately **(±0.0096 ft. X √Sta)** where **√Sta** represents 100 foot stations, or the total level run distance divided by one hundred (100).

For profile leveling, the maximum mis-closure allowable at a benchmark elevation previously established shall be no greater than plus or minus fourteen-thousandths of a foot **(±0.014 ft.)** times the square root of the distance expressed in one hundred foot (100) stations from the preceding benchmark. Thus a leveling distance of 850 feet would be 8.5 stations, or the leveling distance divided by one hundred provides the distance in stations (Sta). This profile leveling standard of (**0.014 ft x √Sta)** translates to approximately (**±0.10 ft. X √M)** when compared to the benchmark leveling standard stated above.

Sec. 5.14 Traverse Baselines **<sctl(UPC#)>**

The traverse baselines should be established to be functional relative to the safety and geometric alignment of the survey corridor of the project.

Traverse baselines will be included in a VDOT Survey control file. All traverse closures will be reported in the survey location report. Traverse baseline will only show bearing and distance. To help eliminate confusion, no stationing shall be shown. All plus and offsets will be referenced from the construction centerline. Horizontal and vertical control points shall be shown on the plan sheets.

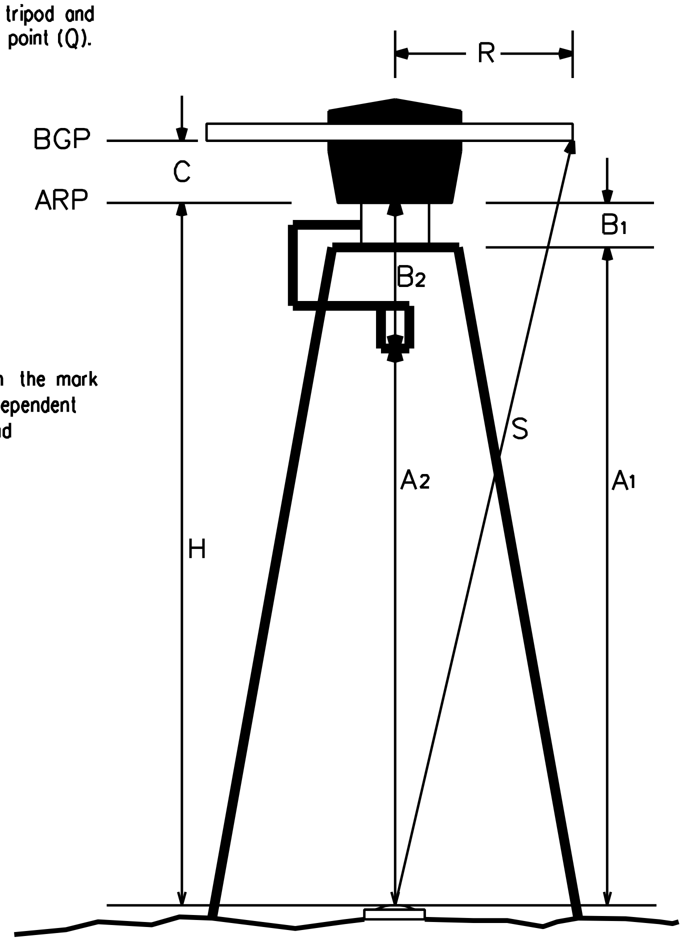
Figure 5-A

ILLUSTRATION FOR ANTENNA HEIGHT MEASUREMENTS:

I. Instructions for Fixed-Height Tripods:

Measure & record the length (A) and other offsets, if any, between the tripod and Antenna Reference Point (ARP) (B) and/or between the tripod and datum point (Q).

Antenna Height = $H = A_1 + B_1 - Q$



II. Instructions for Slip-Leg Tripod:

NOTE: For Leica measuring hooks, use the instructions below.

Leica Measuring Hook = $H = A_2 + B_2$

1. Measure the Slant Height

Before and after the observation session, measure the slope distance from the mark at least three notches on the Bottom of Ground Plane (BGP) using two independent rulers (e.g. metric and imperial). Record measurments in the table below, and compute the average.

Measure S	Notch #_	Notch #_	Notch #_	Average
Before, cm				
Before, inch				
After, cm				
After, inch				
Note: cm = 1nch x (2.54)		Overall average, cm		

S = ______________ cm

2. Record the Antenna Radius (R) and the Antenna Constant (C)

The antenna radius is the horizontal distance from the Antenna Reference Point (ARP) to the measurment notch. The antenna constant is the vertical distance from the ARP to the BGP. See your Antenna specification manual for exact measurments.

R = ______________ cm

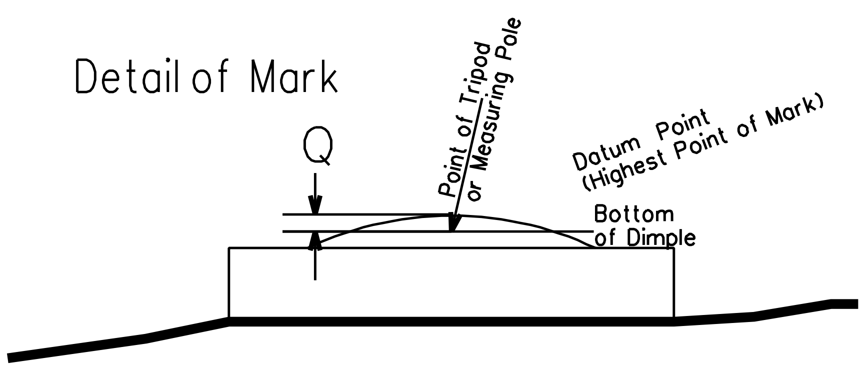
C = ______________ cm

3. Compute Antenna Height (H)

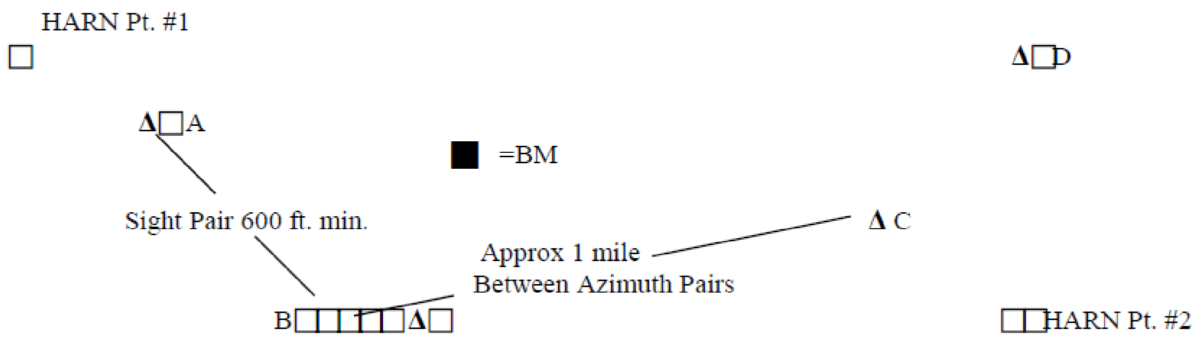
Use the following Pythagorean formula:

Antenna Height $H = ((\sqrt{S^2 - R^2}) - C) - Q$

Detail of Mark



<u>Figure 5-B</u>



A,B,C,D = VDOT Route Survey Control Points; Coordinates to be Determined
HARN #1 to HARN #2 = 17 km ■ = BM on NAVD88 datum; GDOP = 2.5; 6 Satellites
HARN Points Have Known X, Y & Z Values

Observation Session #1, 4 Receivers, Duration 30 Minutes Minimum, Use Rapid Static Procedures, Occupy HARN #1, HARN#2, BM & A.

Observation Session #2, 4 Receivers, A-C = 3 km, Duration 15 Minutes Minimum, Use Rapid Static Procedures, Occupy BM, A, B & C.

Observation Session #3, 4 Receivers, B-D = 3 km, Duration 15 Minutes Minimum, Use Rapid Static Procedures, Occupy B, C, D & BM.

Observation Session #4, 4 Receivers, Duration 30 Minutes Minimum, Use Rapid Static Procedures, Occupy HARN #1, HARN#2, BM & D.

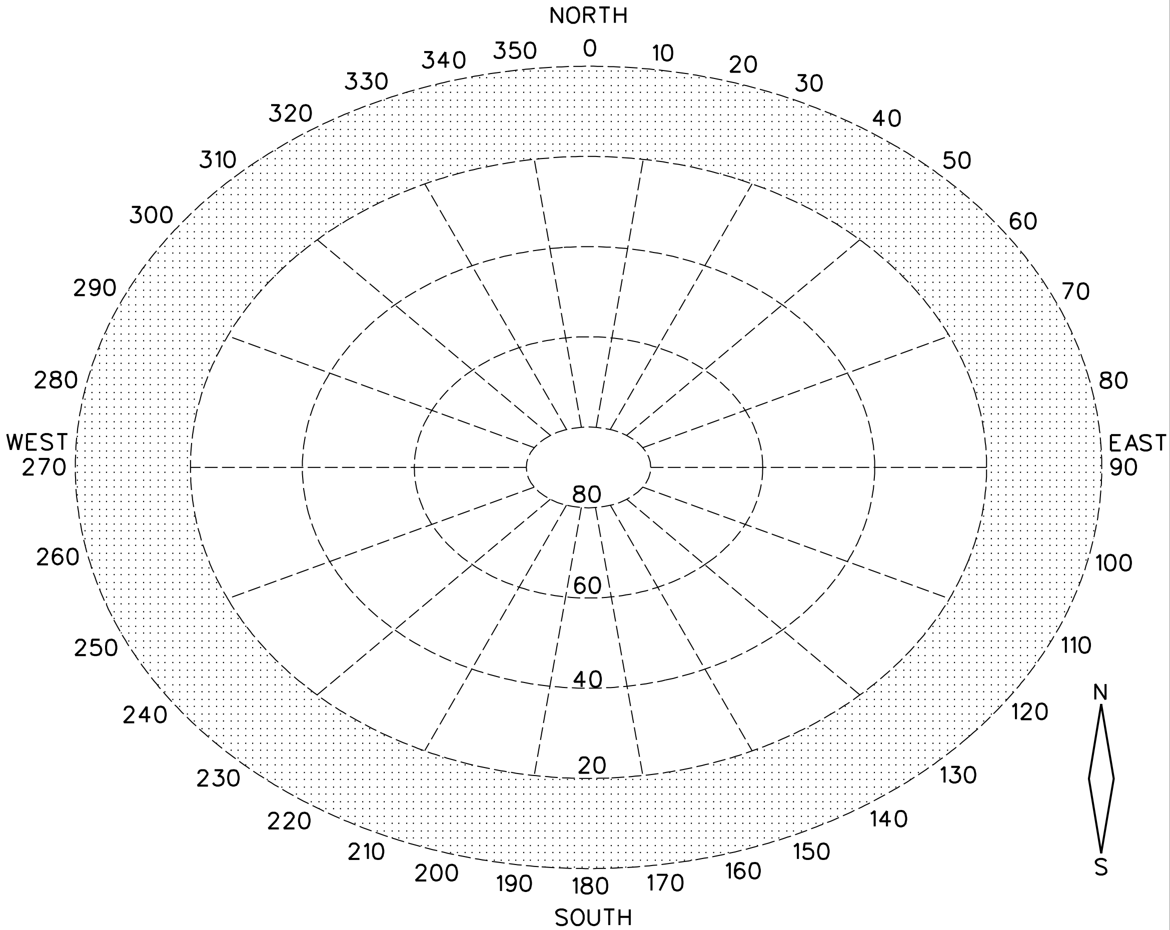
Observation Session #5, 4 Receivers, Duration 15 Minutes Minimum, Use Rapid Static Procedures, Occupy A, B, C & D.

Figure 5-B is an example of one observing session scheme. This illustrates one way to design a mission, but a mission is not limited to one scheme to accomplish the same results. An observing scheme should be developed to meet your specific accuracy standard criteria. The best source of information to develop observing session scheme or mission plan is "**Geometric Geodetic Accuracy Standard and Specifications for Using GNSS Relative Positioning Techniques**". FGCC ver. 5.0 8/19/89.

Figure 5-C

GPS 610

GPS SATELLITE VISIBILITY OBSTRUCTION DATA SHEET



ACRN ____________________

OLD\OSN ____________________

ELEVATION ____________________ (m) / f

LATITUDE ____________________ (N) / S NAD27

LONGITUDE ____________________ E / (W) (NAD83)

STATION NAME ____________________

____________________ DATE

____________________ ORGANIZATION

____________________ MAP SCALE

____________________ MAP SHEET

____________________ OBSERVER

Observer's height at time of observation ________ ft. / in. / m

NOTES:

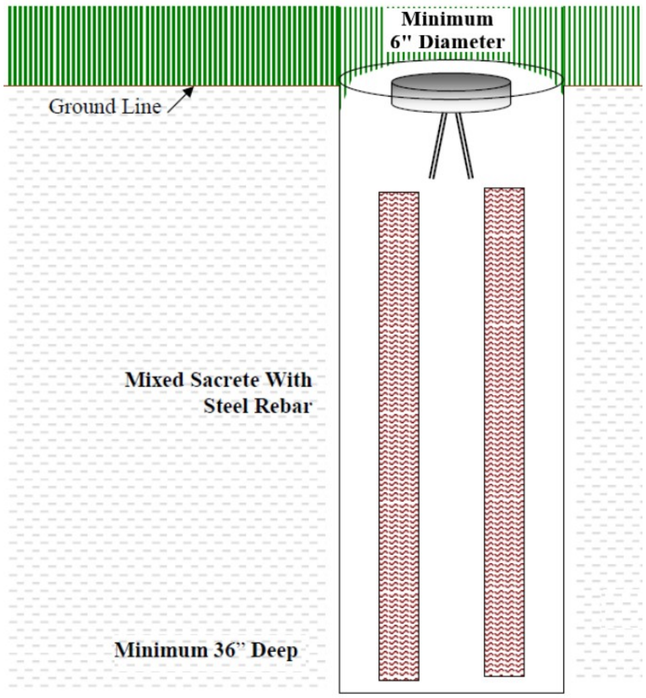
Indicate distance, direction, frequency, and power of known RF sources.

Show peripheral marks and required ties.

Show the distance to the nearest edge of all obstructions over 20° and\or indicate antenna height needed to clear obstructions at 20°.

Figure 5-D

**Stamped VDOT Disk Set In Concrete,
Disk to be Flush With the Ground Line**



**Stamped VDOT Control Disk
Domed, Minimum 3.25" Diameter**

**Stamped VDOT Disk Set on 5/8" Rebar,
Disk to be Flush With the Ground Line**

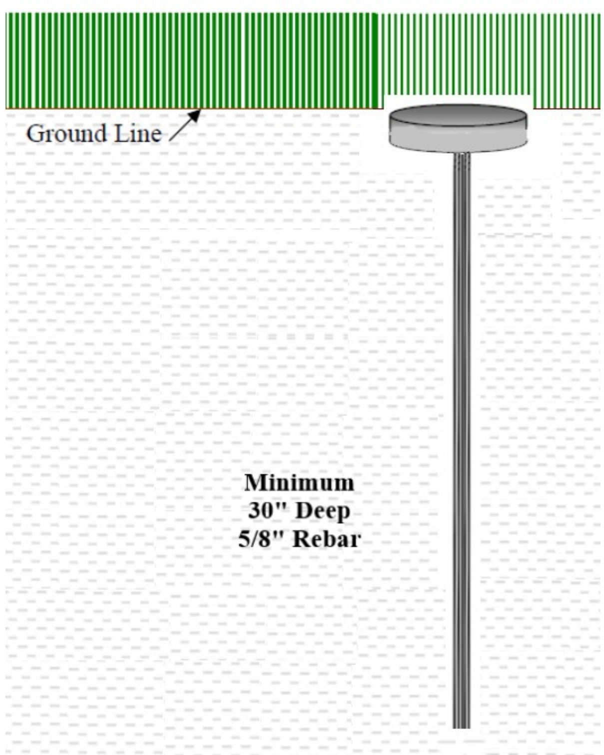


Figure 5-E
VDOT GNSS OBSERVATION SITE LOG

DATE: ________________ **OBSERVER:** _____________________

RECEIVER NUMBER: BASE _____ R1 _____ R2 _____ (______)

SERIAL NUMBER (LAST 4 DIGITS): ___________

STATION NUMBER (NAME): ______________ **SESSION NUMBER:** ______

BEGIN ANTENNA HEIGHT: ________ m CHECK: ________ ft.

MEASUREMENT TAKEN TO: ___ BOTTOM OF MOUNT
(Check One) ___ ANTENNA PHASE CENTER
___ BUMPER ___ HEIGHT HOOK

ANTENNA OFFSET: _________ m (Leica: 0.441m)

START SESSION TIME: ______________

START MINIMUN Q.I. READING: _______ SAT NUMBER: _______

INTERMEDIATE MINIMUM Q.I. READING: _______ SAT NUMBER: _______

END MINIMUN Q.I. READING: _______ SAT NUMBER: _______

END SESSION TIME: ______________

ENDING ANTENNA HEIGHT: _______ m CHECK: _______ ft.

COMMENTS AND SPECIAL NOTES

Figure 5-F

LD-200 (REV. 10/2014)

Virginia Department of Transportation Horizontal Control

Control Station I.D. : _-___ Date : _-_-_

VDOT Project Coordinates (2014)	VA State Plane Coordinates : NAD 83- U.S. Survey Feet
East (X) : ______ ft. North (Y) : ______ ft. Elevation : ___ ft.	East (X) : ______ ft. North (Y) : ______ ft. Ortho. Elevation (H) : ____ ft. Zone : North_ South_ (place an 'X' beside one)
Project Specific Combined Scale Factor: 1._______ (8 Decimal Places)	Project Information Project Number : __________ Route : __ City/County : _____ Established By : ________
Latitude : _° _' ___" N (5 Decimal Places) Longitude : _° _' ___" W (5 Decimal Places) Geoid Separation (N) : _____ Ellipsoid Height (h) : ______ Horizontal Datum : _____ Year : ___ Vertical Datum : _____ Geoid : ___ Azimuth to Station : ____ is ___° _' _" Control Based On: Station (Name/PID) _______ or Project (Monument No.) : _____	To convert Virginia State Plane Coordinates to VDOT Project Coordinates, use the following formula : • Multiply the Easting And Northing Values (For Both Zones) by the Project Specific Combined Scale Factor. (Located above left) • Reverse this Procedure to convert VDOT Project Coordinates (2014) to NAD 83 - U.S. Survey Feet

DETAILED SKETCH (Not to Scale)

LD-200 (REV. 10/2014)

Sample Horizontal Control Card "LD-200"

Figure 5-G

VERTICAL PLANE THROUGH THE CENTER OF THE EARTH
LATITUDE

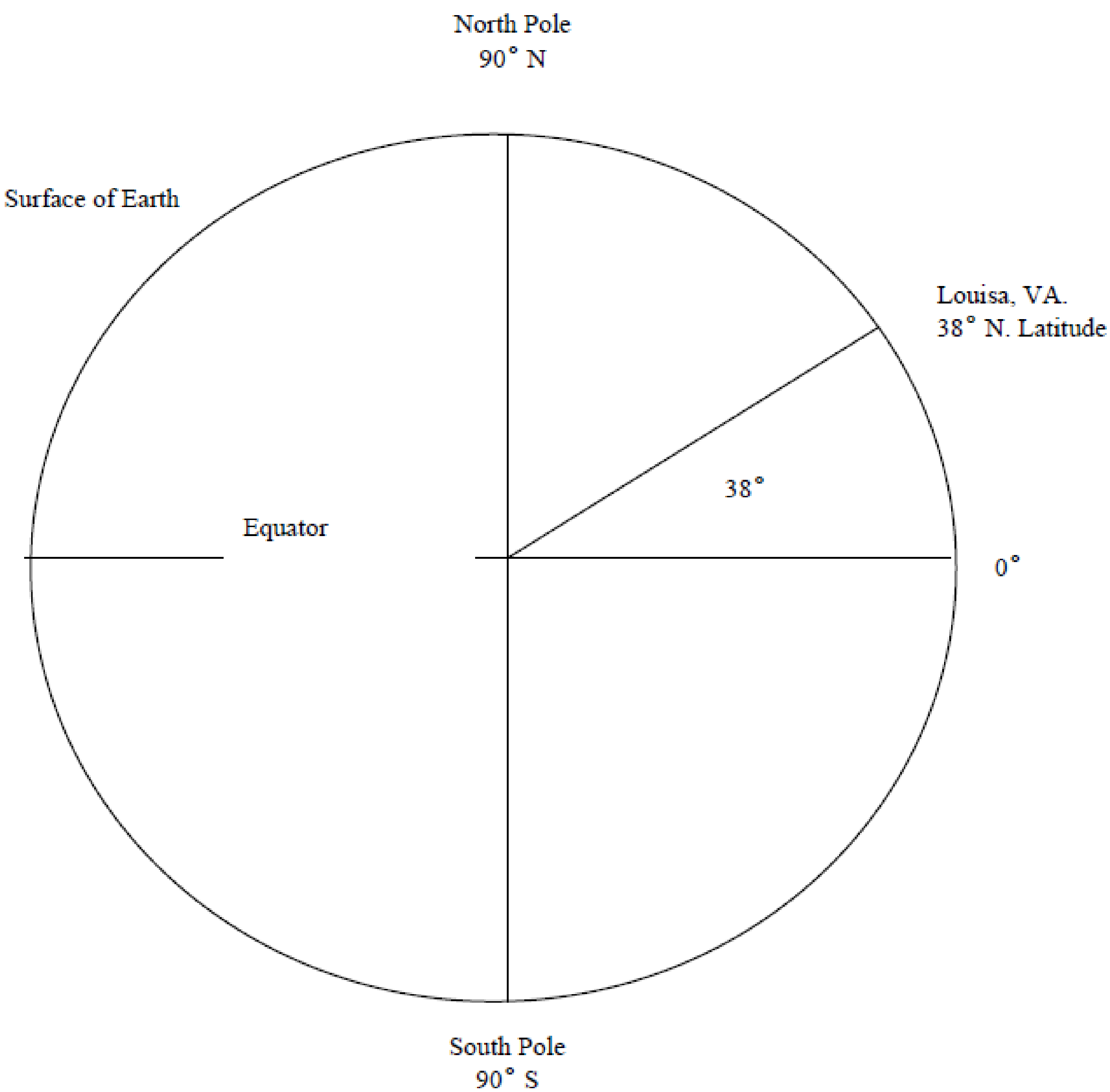


Figure 5-H

HORIZONTAL PLANE THROUGH THE CENTER OF THE EARTH
LONGITUDE

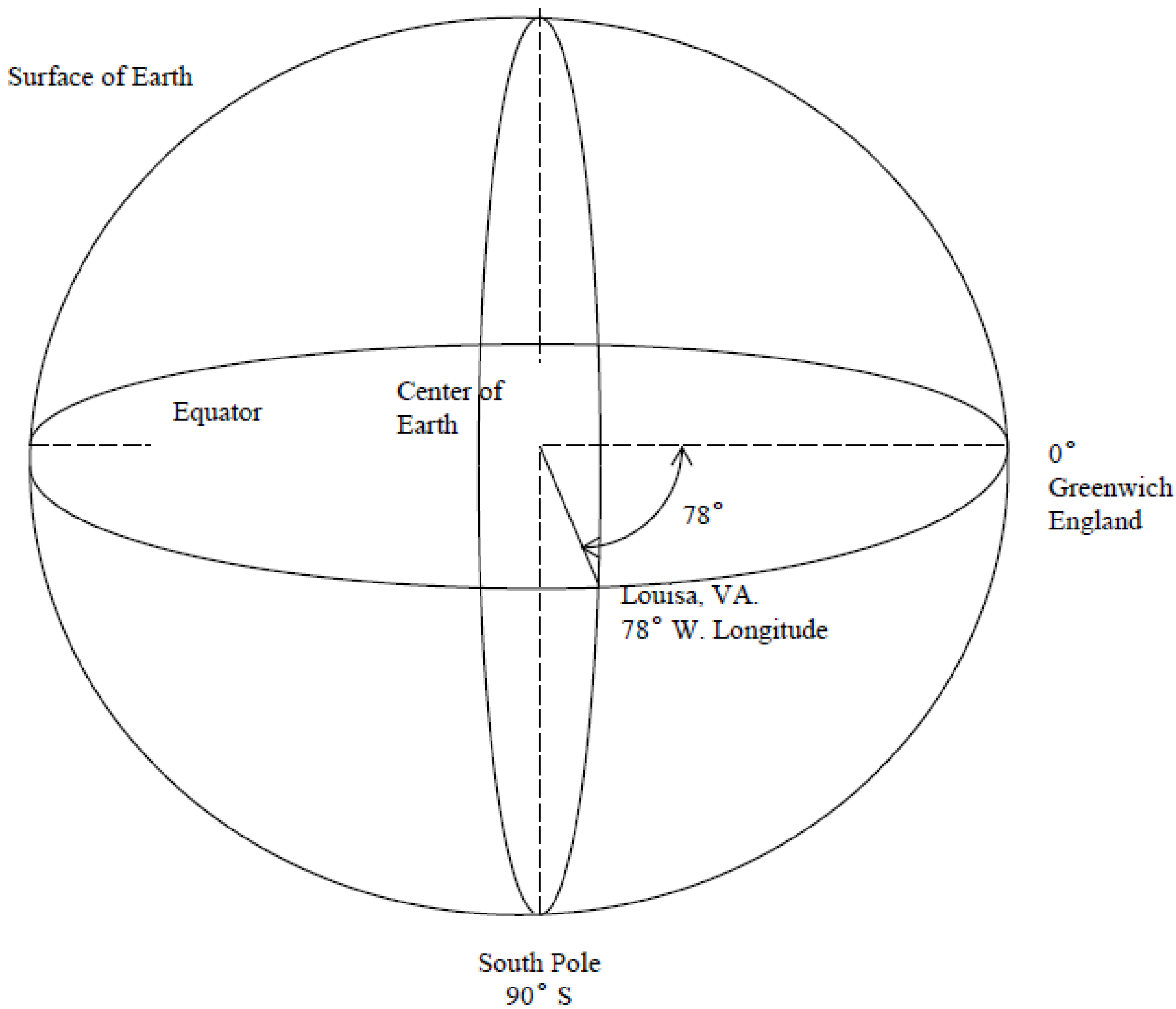


Figure 5-I

PROFILE VIEW
VIRGINIA STATE PLANE COORDINATE SYSTEM

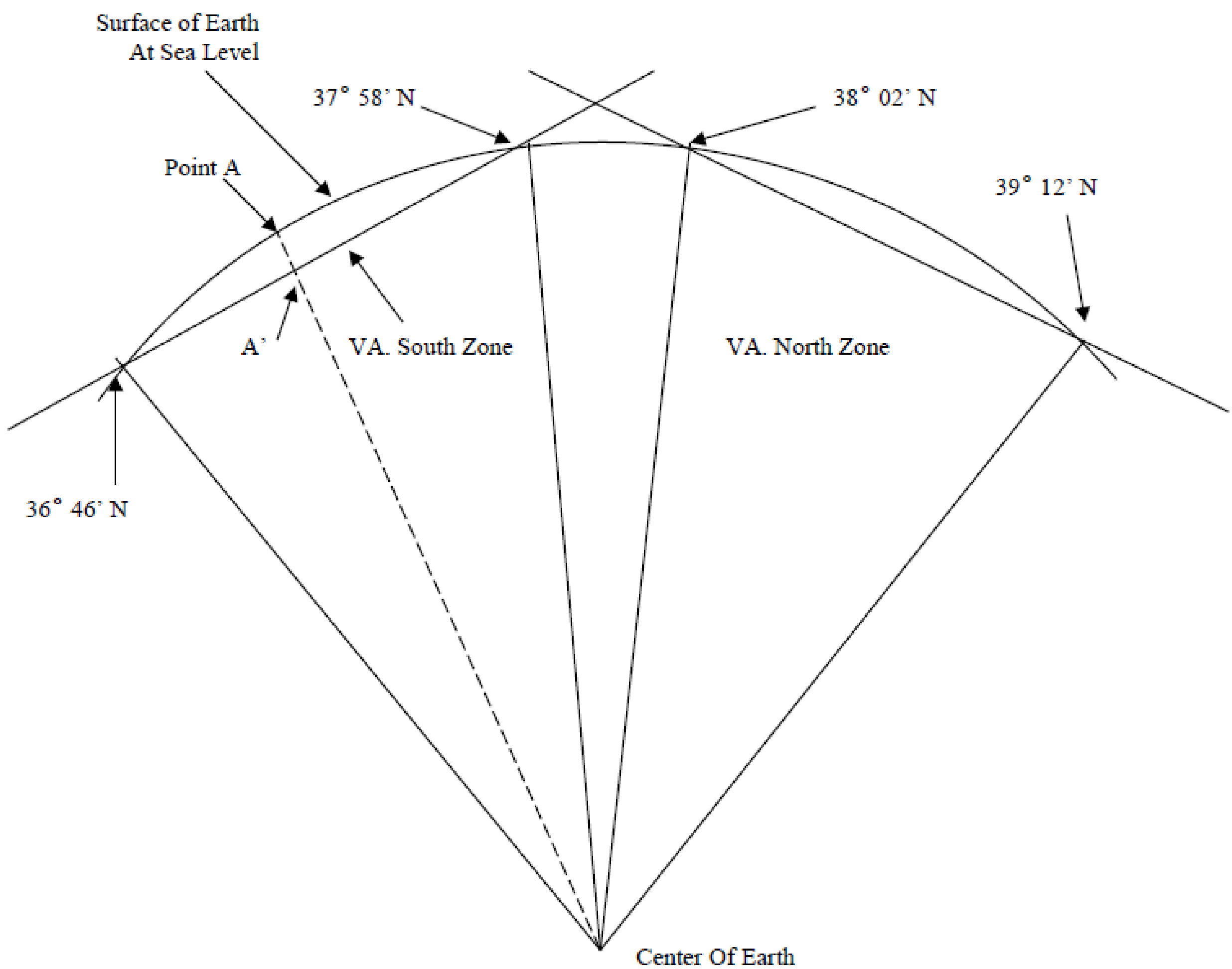


Figure 5-J

RELATIONSHIP BETWEEN TRUE NORTH & GRID NORTH

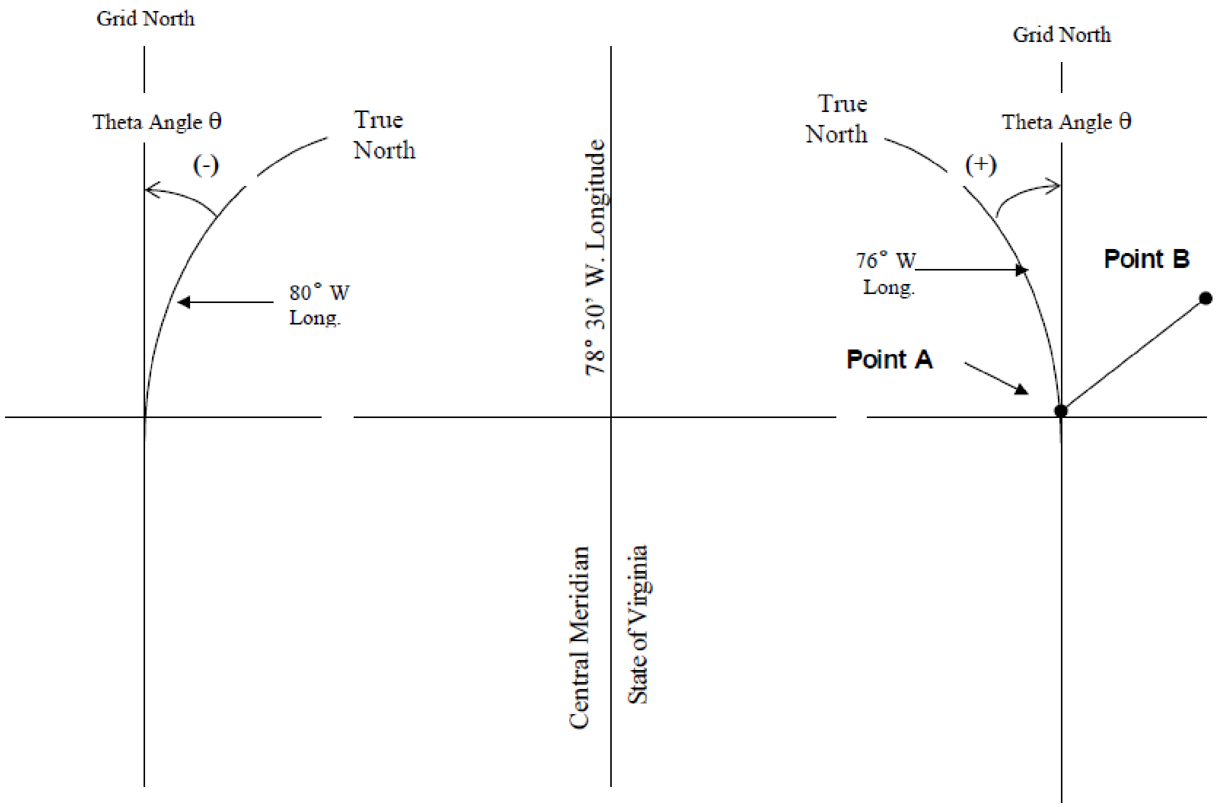


Figure 5-K

COMBINED SCALE AND ELEVATION FACTOR FOR THE COUNTY

(Legacy Data for Informational Purposes Only)

(Not to be used unless authorized by the District Survey Manager or State GeoSpatial Program Manager)

000	1.00006	Arlington
001	1.00004	Accomack
002	1.00002	Albemarle
003	1.00015	Alleghany
004	1.00007	Amelia
005	1.00009	Amherst
006	1.00008	Appomattox
007	1.00009	Augusta
008	1.00012	Bath
009	1.00009	Bedford
010	1.00017	Bland
011	1.00011	Botetourt
012	1.00001	Brunswick
013	1.00015	Buchanan
014	1.00007	Buckingham
015	1.00007	Campbell
016	1.00001	Caroline
017	1.00011	Carroll
018	1.00006	Charles City
019	1.00006	Charlotte
020	1.00006	Chesterfield
021	1.00004	Clarke
022	1.00017	Craig
023	1.00007	Culpeper
024	1.00007	Cumberland
025	1.00014	Dickenson
026	1.00005	Dinwiddie
027	1.00004	City of Hampton
028	1.00001	Essex
029	1.00006	Fairfax
030	1.00008	Fauquier
031	1.00012	Floyd
032	1.00004	Fluvanna
033	1.00009	Franklin
034	1.00004	Frederick
035	1.00017	Giles
036	1.00005	Gloucester
037	1.00005	Goochland
038	1.00011	Grayson
039	1.00007	Greene
040	1.00000	Greensville
041	1.00002	Halifax
042	1.00004	Hanover
043	1.00006	Henrico
044	1.00003	Henry
045	1.00016	Highland
046	1.00002	Isle of Wight
047	1.00005	James City
048	1.00004	King George
049	1.00004	King & Queen
050	1.00004	King William
051	1.00003	Lancaster
052	1.00006	Lee
053	1.00005	Loudoun
054	1.00002	Louisa
055	1.00005	Lunenburg
056	1.00007	Madison
057	1.00005	Mathews
058	1.00000	Mecklenburg
059	1.00005	Middlesex
060	1.00015	Montgomery
061	1.00000	City of HR
062	1.00007	Nelson
063	1.00005	New Kent
064	1.00000	Nor. Ches. Ports.
065	1.00004	Northampton
066	1.00002	Northumberland
067	1.00007	Nottoway
068	1.00006	Orange
069	1.00010	Page
070	1.00004	Patrick
071	1.00002	Pittsylvania
072	1.00006	Powhatan
073	1.00007	Prince Edward
074	1.00006	Prince George
075	1.00000	City of VA Beach
076	1.00006	Prince William
077	1.00014	Pulaski
078	1.00009	Rappahannock
079	1.00001	Richmond
080	1.00013	Roanoke
081	1.00008	Rockbridge
082	1.00011	Rockingham
083	1.00012	Russell
084	1.00011	Scott
085	1.00009	Shenandoah
086	1.00015	Smyth
087	1.00000	Southampton
088	1.00004	Spotsylvania
089	1.00006	Stafford
090	1.00005	Surry
091	1.00003	Sussex
092	1.00019	Tazewell
093	1.00007	Warren
094	1.00004	City of Newport News
095	1.00009	Washington
096	1.00002	Westmoreland
097	1.00015	Wise
098	1.00014	Wythe
099	1.00005	York

Figure 5-L

COUNTY CODE NUMBER REFERENCE FOR CITIES AND TOWNS

City or Town Code				County Location	District
100	Alexandria	C	000	Arlington	Nova
101	Big Stone Gap	T	097	Wise	Bristol
102	Bristol	C	095	Washington	Bristol
103	Buena Vista	C	081	Rockbridge	Staunton
104	Charlottesville	C	002	Albemarle	Culpeper
105	Clifton Forge	C	003	Alleghany	Staunton
106	Colonial Heights	C	020	Chesterfield	Richmond
107	Covington	C	003	Alleghany	Staunton
108	Danville	C	071	Pittsylvania	Lynchburg
109	Emporia	C	040	Greensville	HR
110	Falls Church	C	029	Fairfax	NOVA
111	Fredericksburg	C	088	Spotsylvania	Fredericksburg
112	Front Royal	T	093	Warren	Staunton
113	Galax	C	017	Carroll	Salem
114	Hampton	C	027	City of Hampton	HR
115	Harrisonburg	C	082	Rockingham	Staunton
116	Hopewell	C	074	Prince George	Richmond
117	Lexington	C	081	Rockbridge	Staunton
118	Lynchburg	C	015	Campbell	Lynchburg
119	Marion	T	086	Smyth	Bristol
120	Martinsville	C	044	Henry	Salem
121	Newport News	C	094	City of Newport News	HR
122	Norfolk	C	064	City of Norfolk	HR
123	Petersburg	C	026	Dinwiddie	Richmond
124	Portsmouth	C	064	City of Portsmouth	HR
125	Pulaski	T	077	Pulaski	Salem
126	Radford	C	060	Montgomery	Salem
127	Richmond	C	020	Chesterfield	Richmond
128	Roanoke	C	080	Roanoke	Salem
129	Salem	C	080	Roanoke	Salem
130	South Boston	C (T)	041	Halifax	Lynchburg
131	Chesapeake	C	064	City of Chesapeake	HR
132	Staunton	C	007	Augusta	Staunton
133	HR	C	061	Nansemond	HR
134	Virginia Beach	C	075	City of Virginia Beach	HR
135					
136	Waynesboro	C	007	Augusta	Staunton
137	Williamsburg	C	047	James City	HR
138	Winchester	C	034	Frederick	Staunton
139	Wytheville	T	098	Wythe	Bristol
140	Abingdon	T	095	Washington	Bristol
141	Bedford	C	009	Bedford	Salem

142	Blackstone	T	067	Nottoway	Richmond
143	Bluefield	T	092	Tazewell	Bristol
144	Farmville	T	073	Prince Edward	Lynchburg
145	Franklin	C	087	Southampton	HR
146	Norton	C	097	Wise	Bristol
147	Poquoson	C	099	York	HR
148	Richlands	T	092	Tazewell	Bristol
149	Vinton	T	080	Roanoke	Salem
150	Blacksburg	T	060	Montgomery	Salem
151	Fairfax	C	029	Fairfax	NOVA
152	Manassas Park	C	076	Prince William	NOVA
153	Vienna	T	029	Fairfax	NOVA
154	Christiansburg	T	060	Montgomery	Salem
155	Manassas	C	076	Prince William	NOVA
156	Warrenton	T	030	Fauquier	Culpeper
157	Rocky Mount	T	033	Franklin	Salem
158	Tazewell	T	092	Tazewell	Bristol
159	Luray	T	069	Page	Staunton
160	Accomack	T	001	Accomack	HR
161	Alberta	T	012	Brunswick	Richmond
162	Altavista	T	015	Campbell	Lynchburg
163	Amherst	T	005	Amherst	Lynchburg
164	Appalachia	T	097	Wise	Bristol
165	Appomattox	T	006	Appomattox	Lynchburg
166	Ashland	T	042	Hanover	Richmond
167	Belle Haven	T	001	Accomack	HR
168	Berryville	T	021	Clarke	Staunton
169	Bloxom	T	001	Accomack	HR
170	Boones Mill	T	033	Franklin	Salem
171	Bowling Green	T	016	Caroline	Fredericksburg
172	Boyce	T	021	Clarke	Staunton
173	Boydton	T	058	Mecklenburg	Richmond
174	Boykins	T	087	Southampton	HR
175	Branchville	T	087	Southampton	HR
176	Bridgewater	T	082	Rockingham	Staunton
177	Broadway	T	082	Rockingham	Staunton
178	Brodnax	T	012	Brunswick	Richmond
178	Brodnax	T	058	Mecklenburg	Richmond
179	Brookneal	T	015	Campbell	Lynchburg
180	Buchanan	T	011	Botetourt	Salem
181	Burkeville	T	067	Nottoway	Richmond
182	Cape Charles	T	065	Northampton	HR
183	Capron	T	087	Southampton	HR
184	Cedar Bluff	T	092	Tazewell	Bristol
185	Charlotte C. H.	T	019	Charlotte	Lynchburg
186	Chase City	T	058	Mecklenburg	Richmond
187	Chatham	T	071	Pittsylvania	Lynchburg

188	Cheriton	T	065	Northampton	HR
189	Chilhowie	T	086	Smyth	Bristol
190	Chincoteague	T	001	Accomack	HR
191	Claremont	T	090	Surry	HR
192	Clarksville	T	058	Mecklenburg	Richmond
193	Cleveland	T	083	Russell	Bristol
194	Clifton	T	029	Fairfax	NOVA
195	Clinchport	T	084	Scott	Bristol
196	Clintwood	T	025	Dickenson	Bristol
197	Clover	T	041	Halifax	Lynchburg
198	Coeburn	T	097	Wise	Bristol
199	Colonial Beach	T	096	Westmoreland	Fredericksburg
200	Columbia	T	032	Fluvanna	Culpeper
201	Courtland	T	087	Southampton	HR
202	Craigsville	T	007	Augusta	Staunton
203	Crewe	T	067	Nottoway	Richmond
204	Culpeper	T	023	Culpeper	Culpeper
205	Damascus	T	095	Washington	Bristol
206	Dayton	T	082	Rockingham	Staunton
207	Dendron	T	090	Surry	HR
208	Dillwyn	T	014	Buckingham	Lynchburg
209	Drakes Branch	T	019	Charlotte	Lynchburg
210	Dublin	T	077	Pulaski	Salem
211	Duffield	T	084	Scott	Bristol
212	Dumfries	T	076	Prince William	NOVA
213	Dungannon	T	084	Scott	Bristol
214	Eastville	T	065	Northampton	HR
215	Edinburg	T	085	Shenandoah	Staunton
216	Elkton	T	082	Rockingham	Staunton
217	Exmore	T	065	Northampton	HR
218	Fincastle	T	011	Botetourt	Salem
219	Floyd	T	031	Floyd	Salem
220	Fries	T	038	Grayson	Bristol
221	Gate City	T	084	Scott	Bristol
222	Glade Spring	T	095	Washington	Bristol
223	Glasgow	T	081	Rockbridge	Staunton
224	Glen Lyn	T	035	Giles	Salem
225	Gordonsville	T	068	Orange	Culpeper
226	Goshen	T	081	Rockbridge	Staunton
227	Gretna	T	071	Pittsylvania	Lynchburg
228	Grottoes	T	082	Rockingham	Staunton
228	Grottoes	T	007	Augusta	Staunton
229	Grundy	T	013	Buchanan	Bristol
230	Halifax	T	041	Halifax	Lynchburg
231	Hallwood	T	001	Accomack	HR
232	Hamilton	T	053	Loudoun	NOVA
233	Haymarket	T	076	Prince William	NOVA

234	Haysi	T	025	Dickenson	Bristol
235	Herndon	T	029	Fairfax	NOVA
236	Hillsboro	T	053	Loudoun	NOVA
237	Hillsville	T	017	Carroll	Salem
238	Holland	T	061	Nansemond	HR
239	Honaker	T	083	Russell	Bristol
240	Independence	T	038	Grayson	Bristol
241	Iron Gate	T	003	Alleghany	Staunton
242	Irvington	T	051	Lancaster	Fredericksburg
243	Ivor	T	087	Southampton	HR
244	Jarratt	T	091	Sussex	HR
244	Jarratt	T	040	Greensville	HR
245	Jonesville	T	052	Lee	Bristol
246	Keller	T	001	Accomack	HR
247	Kenbridge	T	055	Lunenburg	Richmond
248	Keysville	T	019	Charlotte	Lynchburg
249	Kilmarnock	T	051	Lancaster	Fredericksburg
249	Kilmarnock	T	066	Northumberland	Fredericksburg
250	LaCrosse	T	058	Mecklenburg	Richmond
251	Lawrenceville	T	012	Brunswick	Richmond
252	Lebanon	T	083	Russell	Bristol
253	Leesburg	T	053	Loudoun	NOVA
254	Louisa	T	054	Louisa	Culpeper
255	Lovettsville	T	053	Loudoun	NOVA
256	Madison	T	056	Madison	Culpeper
257	McKenney	T	026	Dinwiddie	Richmond
258	Melfa	T	001	Accomack	HR
259	Middleburg	T	053	Loudoun	NOVA
260	Middletown	T	034	Frederick	Staunton
261	Mineral	T	054	Louisa	Culpeper
262	Monterey	T	045	Highland	Staunton
263	Montross	T	096	Westmoreland	Fredericksburg
264	Mt. Crawford	T	082	Rockingham	Staunton
265	Mt. Jackson	T	085	Shenandoah	Staunton
266	Narrows	T	035	Giles	Salem
267	Nassawadow	T	065	Northampton	HR
268	New Castle	T	022	Craig	Salem
269	New Market	T	085	Shenandoah	Staunton
270	Newsoms	T	087	Southampton	HR
271	Nicklesville	T	084	Scott	Bristol
272	Occoquan	T	076	Prince William	NOVA
273	Onancock	T	001	Accomack	HR
274	Onley	T	001	Accomack	HR
275	Orange	T	068	Orange	Culpeper
276	Painter	T	001	Accomack	HR
277	Pamplin City	T	006	Appomattox	Lynchburg
277	Pamplin City	T	073	Prince Edward	Lynchburg

278	Parksley	T	001	Accomack	HR
279	Pearisburg	T	035	Giles	Salem
280	Pembroke	T	035	Giles	Salem
281	Pennington Gap	T	052	Lee	Bristol
282	Phenix	T	019	Charlotte	Lynchburg
283	Pocahontas	T	092	Tazewell	Bristol
284	Port Royal	T	016	Caroline	Fredericksburg
285	Pound	T	097	Wise	Bristol
286	Purcellville	T	053	Loudoun	NOVA
287	Quantico	T	076	Prince William	NOVA
288	Remington	T	030	Fauquier	Culpeper
289	Rich Creek	T	035	Giles	Salem
290	Ridgeway	T	044	Henry	Salem
291	Round Hill	T	053	Loudoun	NOVA
292	Rural Retreat	T	098	Wythe	Bristol
293	Saint Charles	T	052	Lee	Bristol
294	Saint Paul	T	097	Wise	Bristol
295	Saltville	T	086	Smyth	Bristol
296	Saxis	T	001	Accomack	HR
297	Scottsburg	T	041	Halifax	Lynchburg
298	Scottsville	T	002	Albemarle	Culpeper
298	Scottsville	T	032	Fluvanna	Culpeper
299	Shenandoah	T	069	Page	Staunton
300	Smithfield	T	046	Isle of Wight	HR
301	South Hill	T	058	Mecklenburg	Richmond
302	Stanardsville	T	039	Greene	Culpeper
303	Stanley	T	069	Page	Staunton
304	Stephens City	T	034	Frederick	Staunton
305	Stony Creek	T	091	Sussex	HR
306	Strasburg	T	085	Shenandoah	Staunton
307	Stuart	T	070	Patrick	Salem
308	Surry	T	090	Surry	HR
309	Tangier	T	001	Accomack	HR
310	Tappahannock	T	028	Essex	Fredericksburg
311	The Plains	T	030	Fauquier	Culpeper
312	Timberville	T	082	Rockingham	Staunton
313	Toms Brook	T	085	Shenandoah	Staunton
314	Troutdale	T	038	Grayson	Bristol
315	Troutville	T	011	Botetourt	Salem
316	Urbanna	T	059	Middlesex	Fredericksburg
317	Victoria	T	055	Lunenburg	Richmond
318	Virgilina	T	041	Halifax	Lynchburg
319	Wachapreague	T	001	Accomack	HR
320	Wakefield	T	091	Sussex	HR
321	Warsaw	T	079	Richmond	Fredericksburg
322	Washington	T	078	Rappahannock	Culpeper
323	Waverly	T	091	Sussex	HR
324	Weber City	T	084	Scott	Bristol

325	West Point	T	050	King William	Fredericksburg
326	Whaleyville	T	061	Nansemond	HR
327	White Stone	T	051	Lancaster	Fredericksburg
328	Windsor	T	046	Isle of Wight	HR
329	Wise	T	097	Wise	Bristol
330	Woodstock	T	085	Shenandoah	Staunton
331	Hurt	T	071	Pittsylvania	Lynchburg
			044	Henry	Salem
333	Collinsville	UUP	076	Prince William	NOVA
			076	Prince William	NOVA
335	Quantico Station	UUP	025	Dickenson	Bristol
			004	Amelia	Richmond
			010	Bland	Bristol
338	West Gate	UUP	018	Charles City	Richmond
339	Clinchco	T	024	Cumberland	Lynchburg
			036	Gloucester	Fredericksburg
			037	Goochland	Richmond
			048	King George	Fredericksburg
UUP	Uninc. Urb. Place		049	King and Queen	Fredericksburg
			057	Mathews	Fredericksburg
			062	Nelson	Lynchburg
			063	New Kent	Richmond
			072	Powhatan	Richmond
			089	Stafford	Fredericksburg

Figure 5-M

GNSS Survey Specifications for Project Monumentation

Specification	Static	Rapid (or Fast) Static
General Specifications		
Minimum number of reference stations used to control the survey - Minimum Order of station	Horz. - 2 NSRS 1st-order Vert. - 3 NSRS 3rd-order	Horz. - 2 NSRS 1st-order Vert. - 3 NSRS 3rd-order
Maximum distance from survey boundary to reference stations	50 km or ± 31 miles	20 km or ± 12.5 miles
Minimum number of dual frequency GNSS receivers used simultaneously	3	3
Mission Planning & Field Observation Specifications		
Minimum number of satellites observed simultaneously at all stations	5	5
Maximum GDOP / PDOP during observation session	6 / 4	6 / 4
Minimum number of simultaneous occupations of reference stations	2	2
Minimum number of simultaneous occupations of sight or azimuth pairs	2	2
Minimum time between sight and azimuth pair repeat observations	30 minutes	30 minutes
Minimum Spacing of Sight Pairs / Azimuth Pairs	600 ft. / 1 mile	600 ft. / 1 mile
Epoch interval for data sampling during observation session	15 seconds (maximum)	5 seconds (maximum)
Minimum satellite mask angle above the horizon for collection and processing	15 degrees	15 degrees
Satellite signals received from minimum number of quadrants	3	2 diagonally opposite
Obstruction diagrams completed for obstructions higher than	20 deg. above horizon	20 deg. above horizon
Minimum observation time at station	2.5 hours + 1min per km	20 minutes + 1 min per km
Antenna height measurement in meters (and feet) at beginning and end of session?	YES	YES
Processing and Adjustment Specifications		
Fixed Integer solution required for all baselines?	YES	YES
Ephemeris used for processing	Broadcast or Precise	Broadcast or Precise
Maximum misclosure per loop in any one component (x,y,z) not to exceed	5 cm	5 cm
Maximum misclosure per loop in terms of loop length not to exceed	20 ppm	20 ppm
Maximum allowable residual in any one component (x,y,z) in a properly constrained least squares network adjustment not to exceed	3 cm	3 cm
Maximum baseline length misclosure allowable in a properly constrained least squares network adjustment	20 ppm	20 ppm