6 Global Positioning System (GPS) Survey Guidelines

Survey Guidelines describe recommended methods and procedures needed to attain a desired survey accuracy standard. The guidelines in this section are based upon several sources of information as well as practical experience. The following sources were utilized in preparing these guidelines:

- *"Geometric Geodetic Accuracy Standards and Specifications for using GPS Relative Positioning Techniques"* by the Federal Geodetic Control Committee dated August 1, 1989. Available at no charge from North Carolina Geodetic Surveys.
- NOAA Technical Memorandum NOS NGS-58 titled *"Guidelines for establishing GPS-derived Ellipsoid Heights"* dated November 1997. Available for download from NOAA Web site, http://www.ngs.noaa.gov:80/PUBS_LIB/NGS-58.html
- CalTrans Survey Manual Chapter 6 titled *"Global Positioning System (GPS) Survey Specifications"* dated June 1997. Available for download from CalTrans Web site, http://www.dot.ca.gov/hq/esc/geometronics/SurveysManual/Manual%20TOC.html

Location and Surveys GPS Survey Guidelines are to be used for all NCDOT-involved transportation improvement projects, including special-funded projects.

Global Positioning System surveying is an evolving technology. As GPS hardware and processing software are improved, new guidelines will be developed and existing guidelines will be changed. The guidelines described in this section are not intended to discourage the development of new GPS procedures and techniques.

Note: Newly developed GPS procedures and techniques, which do not conform to the guidelines in this section, may be employed for production surveys if approved by the Location and Surveys Unit. Newly developed procedures shall be submitted to the Location and Surveys Unit for review and distribution.

6.1 Equipment

GPS surveying equipment generally consists of two major components: the receiver and the antenna.

6.1-1 Receiver Requirements

First-order, second-order, and third-order GPS surveys require GPS receivers that are capable of recording data for post processing. When performing specific types of GPS surveys, (i.e., static, fast-static, kinematic, and real-time kinematic) receivers and software must be suitable for the specific survey, as specified by the manufacturer.

Dual frequency receivers are required for observing baselines over 15 km in length and are suggested for all measurements. During periods of intense solar activity, dual frequency receivers should be used for observing baselines over 10 km in length.

6.1-2 Antennas

Whenever feasible, all antennas used for a project should be identical. For vertical control surveys, identical antennas must be used unless software is available to accommodate the use of different antennas, including Continuous Operating Reference Stations (CORS) antennas.

For Primary GPS Control Surveys, antennas with a ground plane attached must be used, and the antennas should be mounted on a tripod or a stable-supporting tower. Fixed-height tripods are required unless the station is not accessible by this means. When tripods or towers are used, optical plummets or collimators are required to ensure accurate centering over marks.

The use of range poles and/or stakeout poles to support GPS antennas should only be employed for General-order GPS surveys.

6.1-3 <u>Miscellaneous Equipment Requirements</u>

All equipment must be properly maintained and regularly checked for accuracy. Errors due to poorly maintained equipment must be eliminated to ensure valid survey results. Level vials, optical plummets, and collimators should be calibrated at the beginning and the end of each GPS survey. If the survey duration exceeds a week, these calibrations should be repeated weekly for the duration of the survey.

6.2 Methods

6.2-1 Static GPS Surveys

Static GPS survey procedures allow various systematic errors to be resolved when high accuracy positioning is required. Static procedures are used to measure baselines between stationary GPS receivers by recording data over an extended period of time during which the satellite geometry changes.

6.2-2 Fast-static GPS Surveys

Fast-static GPS surveys are similar to static GPS surveys, but with shorter observation periods. Fast-static GPS survey procedures require more advanced equipment and data reduction techniques than static GPS methods. Typically, the fast-static GPS method should not be used for requiring horizontal accuracy greater than 1: 100,000.

6.2-3 Kinematic GPS Surveys

Kinematic GPS surveys make use of two or more GPS receivers. At least one receiver is set up over a known (reference) point and remains stationary, while another (rover) receiver is moved from point to point. All baselines are measured from the reference receiver to the roving receiver. Kinematic GPS surveys can be either continuous or stop and go." Stop and go station observation periods are of short duration, typically under two minutes. Kinematic GPS surveys are employed where third-order or lower accuracy standards are applicable.

6.2-4 Real-Time GPS Surveys (Real-Time Kinematic)

Real-time GPS surveys are kinematic GPS surveys that are performed with a radio data link between a reference receiver and the roving receiver. The field survey is conducted like a kinematic survey, except measurement data from the reference receiver is transmitted to the roving receiver, enabling the rover to compute it's position in real time. The distance between the reference receiver and the rover is largely a function of your radio link. However, the distance between the reference receiver and the rover should not exceed 10 km. See section 6.4-4 and section 6.4-5 for more detailed information on RTK.

6.2-5 NGS's OPUS Utility

For small standalone projects such as Bridge jobs it is acceptable to use NGS's Online User Positioning Service (OPUS) in conjunction with other techniques to establish initial control. However, this should be decided on a case by case basis. For more information regarding OPUS go to:

http://www.ngs.noaa.gov

For more information on how OPUS can be utilized for controlling small standalone projects go to:

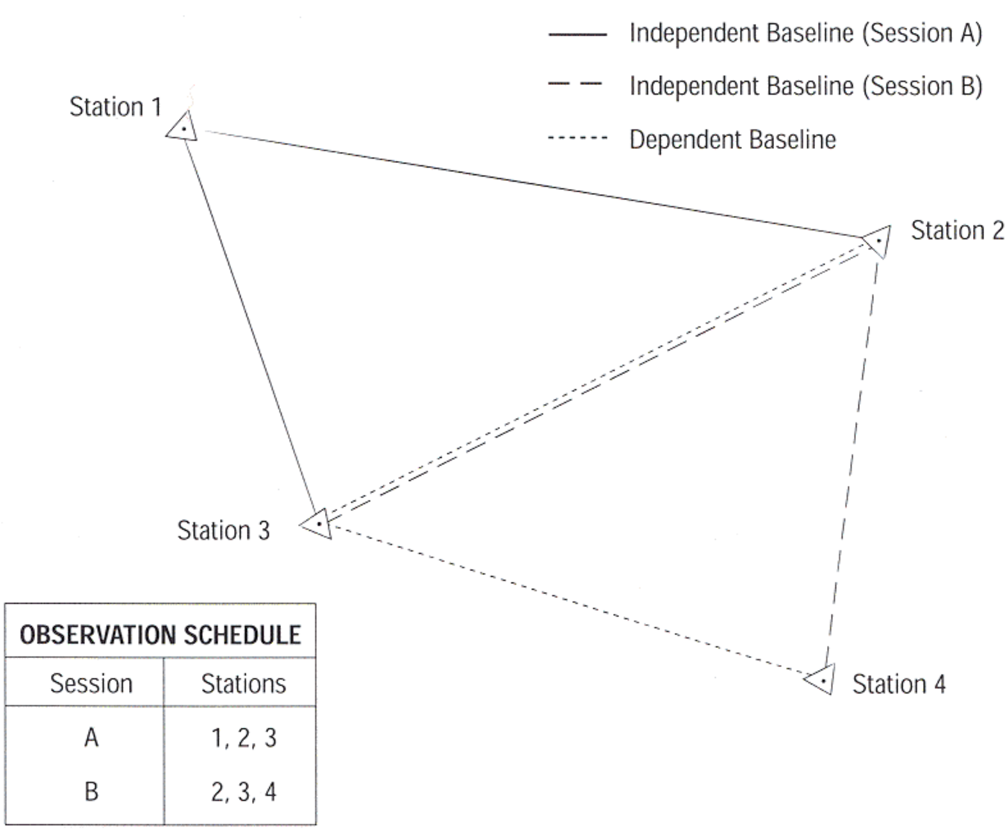
http://www.doh.dot.state.nc.us/preconstruct/highway/location/support/gpslinks.htm

6.3 General GPS Survey Guidelines

6.3-1 Network Design

Baselines (Vectors)

Baselines are developed by processing data collected simultaneously by GPS receivers at each end of a line. For each observation session, there is one less independent (non-trivial) baseline than the number of receivers collecting data simultaneously during the session. Notice in Figure 6-1 that three receivers placed on stations 1, 2, and 3 for Session "A" yield two independent baselines and one dependent (trivial) baseline. Magnitude (distance) and direction for dependent baselines are obtained by separate processing, but use the same data used to compute the independent baselines. Therefore, the errors are correlated. Dependent baselines are not to be used to compute or adjust the position of points.



OBSERVATION SCHEDULE	
Session	Stations
A	1, 2, 3
B	2, 3, 4

Figure 6-1

Loops

A loop is defined as a series of at least three independent, connecting baselines which start and end at the same station. Each loop must have at least one baseline in common with another loop. Each loop must contain baselines collected from a minimum of two sessions.

Networks

Networks should only contain closed loops. Each station in a network must be connected ,with at least two different independent baselines. Avoid connecting stations to a network by multiple baselines to only one other network station. First-order and second-order GPS control networks should consist of a series of interconnecting, closed loop, geometric figures.

Redundancy

First-order, second-order, and third-order GPS control networks are designed with sufficient redundancy to detect and isolate blunders and/or systematic errors. Redundancy of network design is achieved by:

- Connecting each network station with at least two independent baselines
- Series of interconnecting, closed loops
- Repeat baseline measurements

Refer to table 6-1 for the maximum number of baselines per loop, the number of required repeat independent baseline measurements, and least squares network adjustment guidelines.

Any GPS survey that lacks sufficient network or station redundancy to detect misclosures in an unconstrained (free) least squares network adjustment must be considered a general order GPS survey.

Reference Stations

The reference (controlling) stations for a GPS survey must meet the following requirements:

- Same or higher order of accuracy as that intended for the project
- All included in, or adjusted to, the High Accuracy Reference Network (HARN) with coordinate values that are current and meet reference network accuracy standards
- The Horizontal Datum for the HARN network is NAD 1983/95 and the Vertical Datum is NAVD88. Although these will be the preferred datums, it may be necessary to use existing monumentation with NAD83 and/or NGVD29 in order to keep consistency with previously controlled Projects or with Standalone Projects such as Bridge jobs. It will be the responsibility of the Location and Surveys Unit to determine the datum(s) to be utilized on a case by case basis.
- Evenly spaced throughout the survey project and in a manner that no project station is outside the area encompassed by the exterior reference stations

Refer to table 6-1 for the number of controlling stations, and distances between stations.

Adjacent Station Rule (20 Percent Rule)

For first-order and second-order GPS surveys, an independent baseline should be measured between points that are closer than 20 percent of the total distance between those points traced along existing or new connections. For example, in Figure 6-2, if the distance between Station 5 and Station 1 is less than 20 percent of the distance between Station 1 and Station 3 plus the distance between Station 3 and Station 5, an independent baseline should be measured between Station 1 and Station 5. If the application of the adjacent station rule is not practical, an explanation should be included in the survey notes and/or project report.

Direct connections should also be made between adjacent intervisible stations if they are being utilized as azimuth pairs. Whenever possible actual ground distances should be utilized along with the GPS measurement.

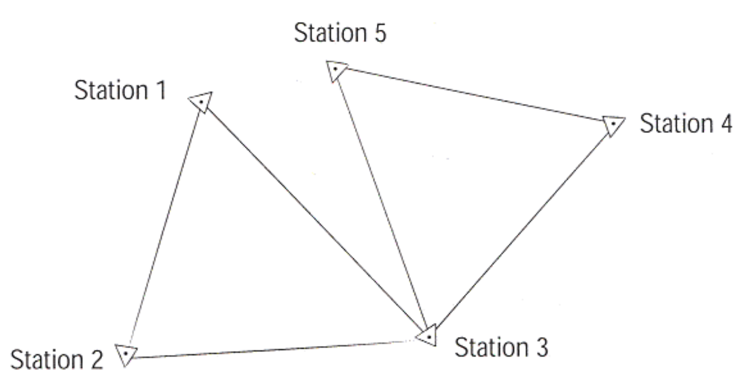


Figure 6-2

6.3-2 Satellite Geometry

Satellite geometry factors which must be considered when planning a GPS survey are:

- Number of satellites available
- Minimum elevation angle for satellites (elevation mask)
- Obstructions limiting satellite visibility
- Position Dilution of Precision (PDOP)

Refer to table 6-1 for specific requirements.

6.3-3 Field Procedures

Reconnaissance

Proper field reconnaissance is essential to the execution of efficient, effective GPS surveys. Reconnaissance should include:

- Station setting or recovery
- Checks for obstructions and multipath potential
- Preparation of station descriptions (monument description, to-reach descriptions for azimuth pairs, etc.)
- Development of a realistic observation schedule

Station Site Selection

The most important factor for determining GPS station location is the project's requirements (needs). After project requirements, consideration must be given to the following limitations of GPS:

- Stations should be situated in locations that are relatively free from horizontal obstructions. In general, a clear view of the sky is required. Satellite signals do not penetrate metal, buildings, or trees and are susceptible to signal delay errors when passing through leaves, glass, plastic and other materials.

- Locations near strong radio transmissions should be avoided because radio frequency transmitters, including cellular phone equipment, may disturb satellite signal reception.

- Avoid locating stations near large flat surfaces such as buildings, large signs, fences, etc., as satellite signals may be reflected off these surfaces causing multipath errors.

With proper planning, some obstructions near a GPS station may be acceptable. For example, station occupation times may be extended to compensate for obstructions.

Weather Conditions

Generally weather conditions do not affect GPS survey procedures with the following exceptions:

- GPS observations should never be conducted during electrical storms.
- Significant changes in weather or unusual weather conditions should be noted in the observation log (field notes). Horizontal GPS surveys should generally be avoided during periods of significant weather changes. Vertical GPS surveys should not be attempted during these periods.

Antenna Height Measurements

Blunders in antenna height measurements are the most common source of error in GPS surveys because all GPS surveys are three dimensional whether the vertical component will be used or not. Antenna height measurements determine the height from the survey monument mark to the phase center of the GPS antenna. With the exception of fixed-height tripods and permanently mounted GPS antennas, independent antenna heights should be measured in both feet and meters at the beginning and end of each observation session. A height hook or slant rod shall be used to make these measurements. All antenna height measurements should be recorded and entered in the receiver data file. Antenna height measurements in both feet and meters should check to within +/- 3 mm.

When a station is occupied during two or more observation sessions back to back, the antenna/tripod should be broken down, reset, and replumbed between sessions.

When adjustable antenna staffs are used (e.g., kinematic surveys), they must be adjusted so that the body of the person holding the staff does not act as an obstruction. The antenna height for staffs in extended positions must be checked continually throughout each day.

When fixed-height tripods are used, verify the height of the tripod and components (antenna) at the beginning of the project.

-

Documentation

The final GPS survey project report should include the following information:

- The existing control monuments used in the transfer
- An explanation of how adjustments were performed
- A printout of the Initial Analysis Worksheet as produced from the most current version of GPSPrj.XLT
- Project Sketch Map
- A listing of map projection transformation
- A listing of loop closures
- Location sketches and descriptions of all azimuth control pairs on control data sheets to include their X,Y,Z coordinate values, scale factor and GEOID separation
- GPS vector map as required by North Carolina Administrative Code, Title 21, Chapter 56, Section .1607
- An electronic MS-Excel spreadsheet file with all Project data utilizing the most current version of GPSPrj.XLT.

6.3-4 Office Procedures

General

For Primary GPS Control surveys, raw GPS observation (tracking) data must be collected and post processed for results and analysis. Post processing and analysis are required for first-order and second-order GPS surveys. The primary post processed results that are analyzed are:

- Baseline processing results
- Loop closures
- Repeat baseline differences
- Results from least squares network adjustments

Post processing software must be capable of producing relative-position coordinates and corresponding statistics which can be used in a three-dimensional least squares network adjustment. This software should also allow analysis of loop closures and repeat baseline observations.

.ssf Solution Retriever

A database of GPS vectors has been made available. This database has vectors including HARN monuments, which have been previously processed and can be incorporated into your "new" network. This will increase redundancy whenever possible without increasing field time. This database which is named .ssf solution retriever can be found on the web at:

http://www.doh.dot.state.nc.us/preconstruct/highway/location/project/

Loop Closure and Repeat Baseline Analysis

Loop closures and differences in repeat baseline measurements are computed to check for blunders and to obtain initial estimates of the internal consistency of the GPS network. Tabulate and include loop closures and the differences in repeat baseline measurements in the project documentation. Failure of a baseline in a loop closure does not automatically mean that the baseline in question should be rejected but is an indication that a portion of the network requires additional analysis.

Least Squares Network Adjustment

An unconstrained (free) adjustment is performed, after blunders are removed from the network, to verify the baseline measurements of the network. After a satisfactory standard deviation of unit weight is achieved using realistic a priori error estimates, a constrained adjustment is performed.

The constrained network adjustment fixes the coordinates of the known control points, thereby adjusting the network to the datum of the control points. A consistent control reference network (datum) must be used for the constrained adjustment.

6-4 Primary GPS Control Surveys

6.4-1 Applications

Primary GPS Control Surveys are utilized for the following typical Location and Surveys survey operations:

Supplemental control for engineering and construction surveys

Project Controls for Baselines
Photogrammetry control

6.4-2 Guidelines

Methods

- Static
- Fast-static
- RTK

Table 6-1 lists the guidelines for Primary GPS Control using static, fast-static, and RTK GPS procedures.

6.4-3 Geoid Modeling

Because of distortions in vertical control networks and systematic errors in geoid height models, results can be difficult to validate; however, results comparable to those obtained using differential leveling techniques are obtainable.

GPS-derived orthometric heights (elevations) are compiled from ellipsoid heights (determined by GPS observations) and modeled geoid heights (using an acceptable geoid height model such as Geoid96). See Figure 6-3

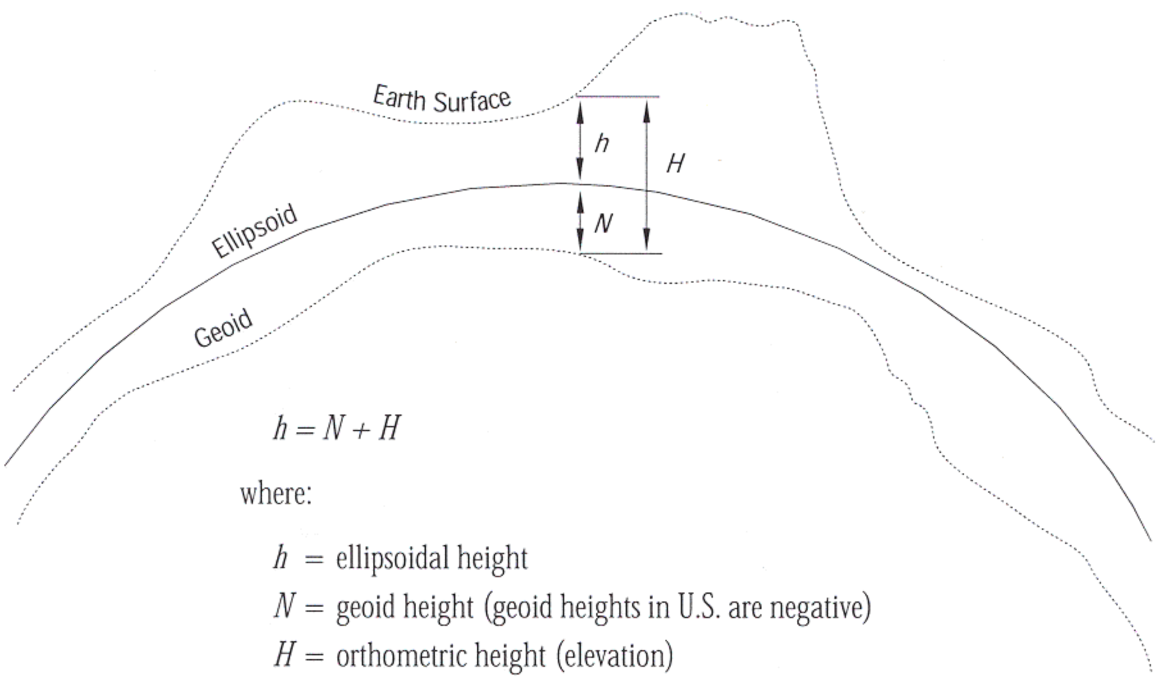


Figure 6-3

6.4-4 RTK Initialization

The initialization of the RTK equipment is the most important aspect of this type of surveying. Care should be taken to insure that the equipment is initialized correctly before collecting data.

On the Trimble Survey Controller, there are four very important bits of information that can identify whether or not you are properly initialized before you take your shot. These are the horizontal precision estimate, the vertical precision estimate, the type of solution being generated, and the rms. Other manufacturers use similar indicators to suggest whether the initialization is good or not.

No measurements should be performed until the system is using a fixed solution. Precision estimates are not accurate until the solution is fixed. Once the system reports a fixed solution, the rms should be under a value of 30.

When using RTK, you are looking at a distance-distance intersection, satellites to receiver. The Horizontal and Vertical precision estimates show how far the worst distance measured lies from the center of the solution. When that distance is less than L1/4, the initialization is probably good. When it's over L1/2, it's probably bad.

The L1 wavelength is 19 cm, so L1/4 is 4.75 cm or ~0.15'. L1/2 is 9.5 cm or ~0.30'. The hypotenuse of the Horizontal and Vertical precision estimates is how far the worst distance comes from meeting where the others intersect. This hypotenuse should clearly be less than 0.0475 m or larger than 0.0950 m.

As you see the estimates that are reported on the controller are not how good the actual X, Y, Z position is that you have collected but how good the GPS measurements are agreeing. Therefore critical measurements must be collected with multiple occupations to ensure consistent results.

6.4-5 <u>Initialization Guidelines</u>

The following procedures are recommended for ensuring satisfactory results.

1.) Initialize the survey using the On the Fly (OTF) method of initialization.
2.) Conduct a static point measurement over the mark noting that the solution is fixed and that the precision estimates are satisfactory.
3.) Discard the current initialization with an antenna dump (loss of satellites).
4.) Reoccupy the mark observed in Step 2, and reinitialize the survey using the Known Point method of initialization to confirm the previous initialization is correct.
5.) Begin collecting data using this initialization. If initialization is lost repeat steps 1 through 4 before continuing to collect additional data.
6.) Collect these points again for a second verification after enough time has passed to allow for a significant change in the satellite constellation. The preferred method is to move the base station to a second known location for this data set.

Table 6-1 GPS Control Survey Guidelines

Guideline	Static	Fast-static	RTK
General			
Minimum number of reference stations to control the project **(1) (2)**	3 HARN	3 HARN	N/A
Location of horizontal control stations (relative to center of project); minimum number of "quadrants", not less than	3	3	N/A
Minimum number of vertical control stations (benchmarks) for the project **(3)**	4	4	N/A
Location of vertical control stations (relative to center of project); minimum number of "quadrants", not less than	4	4	N/A
Maximum distance between project survey points	10 km	10 km	10 km
Maximum distance between the survey project boundary and network control stations	50 km	50 km	10 km
Minimum percentage of all baselines contained in a loop	100%	100%	100%
Direct connection between survey points which are less than 20 percent of the distance between those points traced along existing or new connections (adjacent station rule)	Yes	Yes	N/A
Minimum percentage of repeat independent baseline measurements	5%	5%	5%
Minimum number of independent occupations per station	100% (2 times) 10 % (3 or more times)	100% (2 times) 10 % (3 or more times)	100% (2 times) 10 % (3 or more times)
Direct connection between intervisible azimuth pairs	Yes	Yes	Yes
Field			
Dual Frequency Receivers	Yes	Yes	Yes
Maximum PDOP during station occupation	6 (75% of time)	6	6

Continued

Table 6-1, Continued

Guideline	Static	Fast-static	RTK
Minimum observation time on station 1-6 km	30 minutes	15 minutes	5 epochs
Minimum observation time on station 6-10 km	30 minutes	20 minutes	N/A
Minimum observation time on station 10-15 km	30 minutes	30 minutes	N/A
Minimum observation time on station > 15 km	1 hour	1 hour	N/A
Minimum number of satellites observed simultaneously at all stations	4 (75% of time)	5	5
Epoch interval for data sampling	15 seconds	5 seconds	1 second
Minimum time between repeat station observations	20 minutes	20 minutes	20 minutes
Fixed height antenna tripod required	Yes	Yes	Yes
Antenna height measurements in feet and meters at beginning and end of each session **(4)**	Yes	Yes	Yes
Minimum satellite mask angle above the horizon **(5)**	10 degrees	10 degrees	13 degrees
Office			
Fixed integer solution required for all baselines	Yes	Yes	Yes
Ephemeris **(6)**	Broadcast	Broadcast	Broadcast
Initial position: max. 3-d position error for the initial station in any baseline solution	10 m	10 m	10 m
Loop closure analyses, maximum number of baselines per loop	8	8	4
Maximum loop length	75 km	75 km	25 km
Maximum misclosure per loop, in terms of loop length **(7) (8)**	10 ppm	10 ppm	10 ppm
Maximum misclosure per loop in any one component (x, y, z) not to exceed **(8)**	5 cm	5 cm	5 cm
Repeat baseline length not to exceed	10 km	10 km	10 km
Repeat baseline difference in any one component (x, y, z) not to exceed	10 ppm	10 ppm	10 ppm

Continued

Table 6-1, Continued

Guideline	Static	Fast-static	RTK
Maximum length misclosure allowed for a baseline in a properly-weighted, least squares network adjustment	10 ppm	10 ppm	N/A
Maximum allowable residual in any one component (x, y, z) in a properly-weighted, least squares network adjustment	3 cm	3 cm	N/A
Apply high resolution Geoid model	Yes	Yes	Yes

Notes:

1. If HARN monuments are inaccessible or impractical to utilize, GPS stations set by North Carolina Geodetic Surveys can be used if they have been adjusted to the High Accuracy Reference Network. The Project Data Support Group will coordinate with NCGS to acquire this information when it is needed.

2. The Horizontal Datum for the HARN network is NAD 1983/95 and the Vertical Datum is NAVD88. Although these will be the preferred datums, it may be necessary to use existing monumentation with NAD83 and NGVD29 in order to keep consistency with previously controlled Projects or with Standalone Projects such as Bridge jobs.

3. The HARN monuments can be used to help satisfy this guideline. However if there is supplemental vertical control available near the Project site, it is recommended that it be utilized as well to guarantee to good vertical transfer.

4. Antenna height measurements are not required if fixed-height antenna tripods or poles are used.

5. During office processing, start with a 15-degree mask. If necessary, the angle may be lowered to 10 degrees. This note is not applicable to RTK.

6. Precise ephemeris may be used and should improve results. The precise ephemeris is available 2-6 days after observations and can be found on the Coast Guard Web page at: http://www.navcen.uscg.mil/gps/precise/default.htm.

7. If azimuth control pairs are being established then the maximum misclosure per loop should be 10 ppm. However, if only panel controls are being established 50 ppm is allowable though not ideal.

8. The maximum allowable misclosure in any loop will be the smaller value of either the ppm or 5-cm.

General-order (Horizontal and Vertical) GPS Survey Guidelines

6.5–1 Applications

General-order horizontal accuracy is acceptable for the following typical Location and Surveys survey operations:

Collection of topographic and planimetric data
Casdastral surveys
Supplemental design data surveys; e.g., borrow pits, utility, drainage, etc.
Environmental surveys
Geographic Information System (GIS) surveys.

6.5-2 Guidelines

Methods

- RTK

Guidelines for general-order RTK surveys are the same as for Primary GPS Control Surveys. For less critical data such as GIS surveys it may be possible to eliminate the additional occupations. The Location and Surveys Unit will decide this on a case by case basis.