FDM 9-30-1 Introduction

November 15, 2023

1.1 Overview

This section attempts to provide practical procedures and methods for using Real Time Kinematic (RTK) Global Navigation Satellite System (GNSS) to obtain consistent results for surveys performed by and for the Wisconsin Department of Transportation.

The terms 'GPS' (Global Positioning System) and 'GNSS' (Global Navigation Satellite System) are often used interchangeably, but each of these terms has its own unique meaning. GNSS is an all-inclusive term used to describe a satellite navigation system from any country or region, while GPS refers specifically to the NAVSTAR satellite navigation system of the United States run by the Department of Defense. The most common GNSS systems are GPS (United States), GLONASS (Russia), Galileo (European Union), BeiDou (China) and QZSS (Japan). In the past, 'GPS' was synonymous with any form of satellite-based positioning because, for a period of time, the United States GPS system was the only GNSS system available for civilian surveying applications. This section will use the term GNSS rather than GPS.

RTK GNSS is a very good general observation tool for determining survey coordinates (horizontal and vertical) of a point. Some types of applications, such as pavement matches and bridge decks, require a more specific tool (e.g. total station) that RTK GNSS procedures should not be used for.

Stated accuracies in this section are achievable by using proper survey techniques described in the following pages which are based on recommendations and information from the following publications: National Geodetic Survey (NGS) Manual "*User Guidelines for Single Base Real Time GNSS Positioning*" (W. E. Henning, April, 2014), '*Geodesy for the Layman*' (R. K. Burkard July, 1985); manuals from state agencies and workshops, webinars and seminars offered by NGS and other professional organizations. When establishing positional data on geodetic survey monuments, redundant observations taken over a period of time utilizing different satellite geometries are critical to the success for the survey to achieve its desired accuracy. Due to the variables involved with RTK GNSS satellite surveying, it is impossible to guarantee that every RTK observation will be within a given range of any previous observation.

The following guidelines are written to aid the user in obtaining the desired accuracy for their survey. No set of specifications can account for every scenario that a user may encounter at a job site. Satellite signal obstructions, GNSS satellite constellation and health, cellular reception, radio interference, equipment calibration and a myriad of other factors make every GNSS observation unique. These standards assume that the user has practical knowledge conducting RTK surveys and has a good attention to detail. A knowledgeable user will also have the ability to adapt these guidelines to local conditions, if required, to produce an accurate survey. Typical adaptions to these guidelines might involve extra observation times or sessions based on site conditions, observation statistics and/or satellite geometry. The user who understands the many variables involved in RTK GNSS observations will have better success in obtaining consistent results.

RTK GNSS surveying techniques yield a three-dimensional survey result made up of a horizontal and vertical component. The horizontal component is based on a mathematically derived ellipsoid that is designed and manipulated to represent the shape of an area of concentration. Briefly, RTK GNSS surveys collect latitude and longitude data based on an ellipsoid (currently GRS 80). These latitude and longitude values are converted to a two-dimensional coordinate system using the mathematically derived coordinate system parameters that are created when the coordinate system is developed.

The vertical component also uses the ellipsoid in determining an elevation. During GNSS observations, the GNSS receiver measures how high above the mathematical ellipsoid the survey monument is. Using a geoid model, an elevation is determined based on the amount of separation that has been determined at that exact spot between the ellipsoid and the earth's surface (geoid separation) at the survey location. The amount of geoid separation is not consistent across the state to provide accurate survey elevations. Therefore, geoid models are produced by the National Geodetic Survey to better define the amount of geoid separation across the country. Geoid models are created based on thousands of miles of leveling that has been performed to determine precise elevations for stations combined with GNSS observations of the same stations to determine the geoid separation at these stations. This data is then used to create models that allow users to predict elevations based on ellipsoidal heights at a particular location. Geoid models are constantly being refined based on additional leveling and GNSS observations that are being performed. Providing leveled elevations and GNSS observations for refinement of geoid models is one of the primary functions of the Wisconsin Height

Modernization Program. In areas of sparse leveling and GNSS observations, geoid models will not yield an elevation that is as accurate as areas where more activity has taken place.

Horizontal positions are determined using rigorous mathematical procedures and vertical values are determined by non-mathematical modeling techniques. Therefore, vertical values are more difficult to determine accurately than horizontal positions. Strategies to provide accurate vertical values in difficult areas include: site calibration techniques, additional observation sets, longer observation times, augment GNSS observation with leveling or total station trig leveling, or a combination of these methods.

Again, repeated/redundant observations are critically important when establishing positions using RTK GNSS techniques.

If the user feels that any additional procedures or specifications should be included or discussed, please send your suggestions to geodetic@dot.wi.gov, call 1-866-568-2852 or write;

WisDOT Office of Surveying & Mapping

3502 Kinsman Blvd

Madison, WI 53704-2549

These specifications will be reviewed on a periodic basis and updated to reflect subsequent improvements in technology.

FDM 9-30-5 RTK Application Categories and Their Uses — *November 15, 2023*

Primary control application refers to the establishment of supplemental control stations in the project area. This type of positioning is used in areas where spacing of control stations from the Wisconsin Height Modernization Project (HMP), a county User Densification Network (UDN) or other network of control stations cannot sustain RTK survey methods. Stations established using primary control standards typically are permanent or semi-permanent monuments that will be used as control for future work and maintain a stable position beyond the life of the project.

Secondary control application involves determining geodetic control positions for monuments that are generally a part of a transportation improvement project. Monuments set for a project are generally less stable than primary control applications and are expected to hold their positions only for the life of a project. Typically, these monuments are wooden stakes, PK nails, rebar with caps or chiseled shapes which are used as targets and or control for geospatial projects. Other secondary control applications would include positional determination of United State Public Land Corners, right-of-way monuments, any monument that depicts property interests (easement, property pin) or any other similar feature.

General (Topo) Position application is also commonly called a ‘topo shot’. They are a one-time observation of items or features to determine their location and or elevation or are a collection of observations used for topographic mapping purposes. Typically, features collected for this application do not lend themselves to repeat observations and likely will not have the accuracy that Primary and Secondary Control Applications will have due to the lack of repeated/redundant observations. Examples of items collected using the General (Topo) Position application include, but are not limited to feature location, collecting or augmenting existing surface data, and control checks. Observations using General (Topo) Positioning applications can be used to check existing control values, but should never be used to establish or update control station horizontal coordinates or elevations.

The General (Topo) Positioning application does not have the benefit of redundant observations nor an internal network adjustment to help assure an accurate position for every observation. The user should be aware that accuracy at any one observation may be relatively elusive when compared to the Primary and Secondary Control applications detailed in this section and other GNSS methods. These concepts are also further discussed in FDM 9-30-15 - Guideline 1.

Recovered benchmarks or monuments of older or unknown coordinates should be observed. If the user wishes to provide a position and elevation to place the monument in a GIS-type mapping application, the monument needs only to be observed to a General (Topo) Positioning specification. If the user wishes to update the horizontal coordinates or elevation values for future use, the monument should be observed to Primary Control specifications.

FDM 9-30-10 General Scheme of RTK Survey Data Collection — *November 15, 2023*

All application categories described in this section have requirements for individual observations based on the expected accuracy of the survey. The Primary Control and Secondary Control applications also require repeated sets (groups) of GNSS RTK observations. For repeated observations on the same monument, the user should rotate the rover pole 180 degrees between observations to reduce systematic errors with the rover pole.

Observations that are done to General (Topo) Positioning standards consist of a single observation which must meet observation standards specific to that application. General (Topo) Positioning application does not require repeated observations nor observation sets.

These specifications assume that the user is using dual frequency receivers. The use of GLONASS and/or other GNSS satellite systems is not required, but highly recommended.

FDM 9-30-15 RTK Surveying Guidelines November 15, 2023

15.1 Table of RTK Surveying Guidelines

The following is a table of RTK surveying guidelines.

Table 15.1 Table of RTK Surveying Guidelines

Guideline	Application		
	Primary Control	**Secondary Control**	**General (Topo) Positioning**
1. Desired Accuracy (95% Confidence Interval) A. Horizontal B. Vertical	+/- 0.05' (1.5 cm) +/- 0.066' (2.0 cm)	+/- 0.05' (1.5 cm) +/- 0.082' (2.5 cm)	+/- 0.066' (2.0 cm) +/- 0.18' (5.5 cm)
2. Initialize rover receiver in area where at least three quadrants have no obstructions 15 degrees above the horizon and maintain initialization until point is observed.	YES Do not initialize on a survey station	YES Do not initialize on a survey station	YES Do not initialize on a survey station
3. Initialization of Rover A. Monitor observation statistics (PDOP, RMS, etc.) to ensure good initialization. B. Maximum general RMS at initialization.	YES 0.07 feet	YES 0.07 feet	YES 0.12 feet
4. Maximum distance Between Base Station and Rover (Base/Rover Operation only)	5 miles	5 miles	5-1/2 miles
5. Obstructions Unless noted, Guideline 5 applies to both GNSS rover units and base station setups (if used). Significant obstructions will require longer observation times or additional observation set(s) to achieve desired application accuracy. Obstructions projecting below the elevation mask set for the base and/or rover (Guideline 13) can be ignored. New control points being established for Primary and Secondary Control applications should be located in a spot with as few obstructions as possible.	The Southern three quarters of the sky should be clear above 15 degrees. It is important that there are as few obstructions as practical, but obstructions up to 30 degrees may exist north of the station.	The Southern three quarters of the sky should be clear above 25 degrees. Obstructions up to 40 degrees may exist north of the station attempting to limit blockage to one portion of the sky.	Base stations. Obstructions for base stations for this application shall be the same as the Secondary Control application. Rover Units- See guideline 6 for discussion on rover operation in areas of poor GNSS signal reception.

6. Fixed or Float GNSS solution	Fixed	Fixed	Fixed
7. Check shots of known control stations. 7A. Minimum number of published/known control points used as checks prior to beginning of survey data collection. 7B. Check into known control survey stations before and after every survey session. 7C. Check into known control stations during survey session.	1 Horizontal 2 Vertical Required Recommended	1 Horizontal 1 Vertical Required Recommended	1 Horizontal 1 Vertical Required Recommended
8. Check shot- maximum difference from published/known control station value which should be achieved before survey begins.	+/- 0.08' horizontal. +/- 0.10' vertical	+/- 0.08' horizontal. +/- 0.12' vertical	+/- 0.10' horizontal. +/- 0.15' vertical
9. Minimum number of different control points used to set base station on when using base/rover system.	2 Horizontal 2 Vertical	2 Horizontal 2 Vertical.	Not Applicable
10. Maximum Positional Dilution of Precision (PDOP) at the rover and base station (if used)	4.5	5.0	6.0
11. Collection interval (sec)	1	1	1
12. Minimum number of satellites tracked simultaneously and continuously during entire observation	7	6	6
13. Minimum Satellite Elevation Mask (zero is horizon and 90 is vertical)	15 degrees	15 degrees	15 degrees
14. Minimum number of observation sets per station.	2	2	1
15. Minimum number of observations within each observation set, rotating the rover pole after each observation	1	1	1
16. Minimum cumulative epochs (time) of observations per observation set for each station.	300 Approximately 5 min. (e.g., 1 observation of 300 epochs, 4 observations of 75 epochs, or 6 of 50 epochs)	180 Approximately 3 min. (e.g., 1 observation of 180 epochs, 4 observations of 45 epochs, or 6 of 30 epochs)	5 Approximately 5 sec
17. Break initialization between observation sets?	Yes	Yes	Not Applicable
18. Ideal time interval between observation sets	4 Hours	4 Hours	Not Applicable
19. Absolute minimum time between observation sets of the same station. Note that repeat observations shall not be 11 to 13 or 23 to 25 hours after previous set.	2-1/2 Hours (150 Minutes)	2 Hours (120 Minutes)	Not Applicable
20. Site Calibrations			
20A. One Point Calibration			

A1. Minimum number of appropriate control stations to be used for GNSS site calibration. Note that a vertical calibration requires only vertical control stations, horizontal calibration requires only horizontal control stations and a total calibration requires appropriate number of horizontal and vertical control stations.	Two, one for calibration, and one for a check.	Two, one for calibration, and one for a check.	Two, one for calibration, and one for a check.
A2. Maximum distance of project observations from calibration control station.	2-1/2 mile radius	2-1/2 mile radius	3 mile radius
A3. Maximum residuals of a check point used to verify accuracy of GNSS site calibration solution	0.08' horizontal and vertical	0.10' horizontal and vertical	No Maximum The residual should be within a reasonable tolerance to assure there are no blunders.
20B. Four or more point calibration			
B1. Minimum number of control stations to be used in final calibration solution.	3 Horizontal 5 Vertical.	3 Horizontal 4 Vertical.	3 Horizontal 4 Vertical.
B2. Maximum distance between adjacent calibration control stations.	4-1/2 miles	4-1/2 miles	5 miles
B3. Maximum horizontal residual of calibration stations in GNSS site calibration solution.	0.05'	0.07'	0.10'
B4. Maximum vertical residual of calibration points used in GNSS site calibration solution. Note that if a control station used in a GNSS site calibration does not meet specifications', it should be withheld from the calibration. The minimum number of GNSS control calibration points with residuals at or below the maximum must be achieved.	0.07'	0.10'	0.15'
21. Maximum point tolerance residual for horizontal and vertical values between the final coordinate result and individual observations.	H 0.066 feet V 0.082 feet	H 0.082 feet V 0.10 feet	Not Applicable
22. Equipment Checks and Equipment Calibrations	Follow manufacturer's instructions. Inspect accessories after each use.	Follow manufacturer's instructions. Inspect accessories after each use.	Follow manufacturer's instructions. Inspect accessories after each use.
23. Survey Report required	YES	YES	YES

15.2 Discussion of Items in Table

Guideline 1- Desired Accuracy

This guideline discusses what positional accuracy (horizontal and vertical) that the user can expect following the procedures outlined for that application. Positional accuracy is determined as being relative to a known station. As stated in the introduction, multiple/redundant measurements are a key component to achieving the desired project accuracy. Better horizontal accuracy is generally easier to attain than vertical accuracy. This is because horizontal coordinates are based on a mathematically derived ellipsoid and a vertical coordinate is based on a geoid model, which is a modelling of the difference between the earth's surface and the ellipsoid at any location. In other words, latitude and longitude is mathematically based while elevations on the irregular earth's surface are not mathematical but can be very accurately estimated with the use of GNSS surveying.

The user should keep in mind that to achieve the greatest amount of accuracy and precision for RTK GNSS surveys, every application guideline goal should not only be met, but surpassed. This is not always possible nor practical. For example, the guideline for GNSS signal blockage for the Primary Control Application states that obstructions can exist above 30 degrees north of the station. A more accurate result may be achieved if there were no GNSS signal blockage at the station rather than some. Examples of how a user can improve accuracy include but are not limited to: using a bipod or tripod for stability of the rover pole, making sure that equipment is in proper adjustment, verifying that the rod tip and GNSS antenna are fastened securely, and that there is no multipath conditions at the site. An experienced user is aware of what conditions lead to better accuracy and can try to adjust the survey accordingly.

General (Topo) Positioning requires the user to be aware of environmental conditions that may adversely affect results and keep a vigilant watch on observation accuracy data being collected, such as RMS (Root Mean Square) or PDOP (Positional Dilution of Precision). For successful Primary and Secondary Control Application surveys, redundant measurements are critical in addition to monitoring environmental conditions and observation data during collection.

It is important to distinguish between precision and accuracy. Accuracy is defined as how close a measurement or series of measurements are to the true value of what is being measured. Precision is the amount of consistency/uniformity/repeatability that can be expected from a series of similar measurements. The smaller the amount of discrepancy among a group of measurements, the greater the precision.

Example, four people are assigned to measure the length of a parking lot that is exactly 100 feet long. The resulting measurements are listed below in Table 15.2.

***Table 15.2* Example of RTK Surveying Measurements**

Person	Measurements	Average	Range	Result
A	100.9’, 100.9’, 99.8’	100.5’	1.1’	Neither accurate nor precise
B	100.9’, 100.0’, 99.1’	100.0’	1.8’	Accurate, but not precise
C	100.5’, 100.4’, 100.6’	100.5’	0.2’	Precise, but not accurate
D	100.1’, 100.0’, 99.9’	100.0’	0.2’	Accurate and precise

The table shows how a series of measurements can be accurate, precise, both, or neither. Ideally, the user will always strive for measurements that are both accurate and precise.

The accuracy numbers listed in Guideline 1 are a 95% confidence interval (also known as 2 sigma) value that the user can expect.

The user should note that statistically, not every observation (about 5 of 100) will be within the confidence interval range. The use of redundant observations in Primary and Secondary Control Applications allow the user to remove observational outliers from the final solution.

RTK GNSS is a very good general observation tool for determining survey coordinates (horizontal and vertical) of a point. Some types of applications such as pavement matches and bridge decks require a different tool (e.g. total station) that RTK GNSS procedures should not be used for.

<u>Guideline 2- Obstructions during Initialization</u>

It is important that the initialization occur in an area that is as clear of obstructions as practical to allow initializations to as many satellites as possible. Try to maintain the initialization until the point is measured. Loss of initialization in an environment with many GNSS satellite obstructions may result in a poor re-initialization resulting in poor point quality.

Do not initialize on or very near (within 10 feet) a point that is going to be observed because movement from the point of initialization to the point being observed will help provide a check on the initial initialization.

<u>Guideline 3- Initialization Statistics</u>

A. Observation statistics should be monitored to assure the user that a good initialization is achieved. Root Mean Square (RMS) and Positional Dilution of Precision (PDOP) values are the more important observation statistical that the user should check, but other statistics should be noted to make sure that nothing is drastically out of line from normal.

B. The Root Mean Square is an indication of the quality of the GNSS observation. A high RMS is an indication that the GNSS rover is having problems determining a good point position solution. A high RMS may be a result of multipath, poor initialization or too much movement in the rover pole. If the issue persists at a given site, move to another site to see if the RMS falls into a normal range. If a high RMS persists at several sites, you should contact your equipment’s representative to resolve this issue.

The RMS is the accuracy of a point measurement to about 67% (one sigma) confidence interval. In other words, statistically, about 67% of observations will be equal to the true value +/- the RMS/2.

Guideline 4- Maximum Distance between Base and Rover

For a base/rover RTK survey, Guideline 4 specifies the maximum straight-line distance allowed between an RTK base station and rover receiver. Typical maximum radio range is generally 4 to 6 miles depending on the power of the radio and topography. A powerful radio repeater can extend the radio range beyond the recommended distances stated in guideline but extending the Base/Rover spacing beyond the recommended distance may increase errors due to ionosphere activity and other atmospheric affects that degrade a radio signal the further it gets from the source.

This guideline is not applicable for WisCORS use. When using WisCORS, a virtual base station is automatically created and located by the network software based on the rover's latitude and longitude, thus a rover unit using WisCORS is always within the tolerable range of a virtual base station.

When using the WisCORS network, the user shall use a Network Solution and not a Single Base Solution. Equipment manufacturers have a setting that allows the user to use a single base solution. A network solution is typically a better solution due to the increased amount of integrity checks as compared to a single base solution. The WisCORS network software is constantly monitoring the rover position in relation to the physical base stations to provide the most accurate corrections to the rover. If the rover is in the vicinity of a physical WisCORS station, the corrections coming from the network software will be weighted more heavily to the closer base station. When using a Single Base Solution, the software creates a virtual base station, but it may be tied to a physical base station that is or will become way out of range, creating more error due to the large distance between the rover and physical base. If the consultant has a specific need to utilize a Single Base WisCORS solution instead of a Network solution for a WisDOT project, contact the region survey coordinator prior to the beginning the survey.

Guideline 5- Obstructions

Accurate determination of positions and/or elevations depends on GNSS receivers being able to receive signals from as many GNSS satellites for as long as possible. The more precise that the user wants the final result to be, the more critical above information becomes. There are generally three types of GNSS obstructions: blockage, multipath, and interference. Each has a different effect upon GNSS observations and needs to be considered when choosing a location for a GNSS derived control point or observation.

Ideally, the GNSS receiver will have a 'clear' sky where there are no objects higher than the antenna that will block or interfere with the GNSS signal as it travels from the satellite to the receiver. GNSS signals travel in a straight line from the satellite to the receiver. Any hindrance or interference of these signals reaching the GNSS receiver will degrade the final accuracy of the observation or will require longer observation times to achieve the desired accuracy.

Reconnaissance for locations of potential long-term Primary Control and Secondary Control survey stations should take into account any potential future changes to the site in addition to evaluating the current site conditions. Changes that the user should be evaluating include: tree and vegetation growth, construction or expansion of nearby buildings and roads or any other items that could create GNSS signal interference.

Blockage of GNSS signals is caused by any solid object that will not allow a GNSS signal to reach the receiver (see Figure 15.1). The signal will be 'lost' as long as there is an object is between the satellite and receiver. Blockage results in less data (epochs) being received from an individual satellite and/or fewer satellites providing enough data to assist coordinate determination. The loss of too much data may result in a position calculation that will not meet desired project accuracy specifications. Guideline 16 of FDM 9-30-15 identifies the minimum amount of cumulative epochs required to meet the specifications for Primary Control and Secondary Control applications. Blockage of satellite signals to the receiver for the entire observation session, especially where large portions of the sky are blocked, will result in poorer satellite geometry, higher Positional Dilution of Precision (PDOP) and may yield a substandard positional calculation.

Multipath is an error that results when a GNSS signal from the satellite is reflected prior to reaching the antenna and is inherent to GNSS technology (see Figure 15.1). Any type of surface can reflect GNSS signals and lead to multipath. Highly reflective objects are most troublesome. Examples of highly reflective objects that the user should avoid are: buildings, solar panels, highway signs, snow, ice, chain link fences, radio towers, water towers, vehicles, etc. Multipath problems can be partially mitigated by antenna designs, filtering routines and project planning.

When a GNSS signal reaches the receiver by two or more different paths, the reflected paths are longer and cause incorrect distance calculations (also called ranges) from the satellites. Multipath errors can create positional error 'spikes' during GNSS observations. In some respects, receiving incorrect signal data is worse than having the signals blocked. This is why the user must choose a control station location that is as free of GNSS obstructions as practical and follow the recommended time interval between observation sets (Guideline 18) to allow for a different satellite geometry to help identify and mitigate multipath errors.

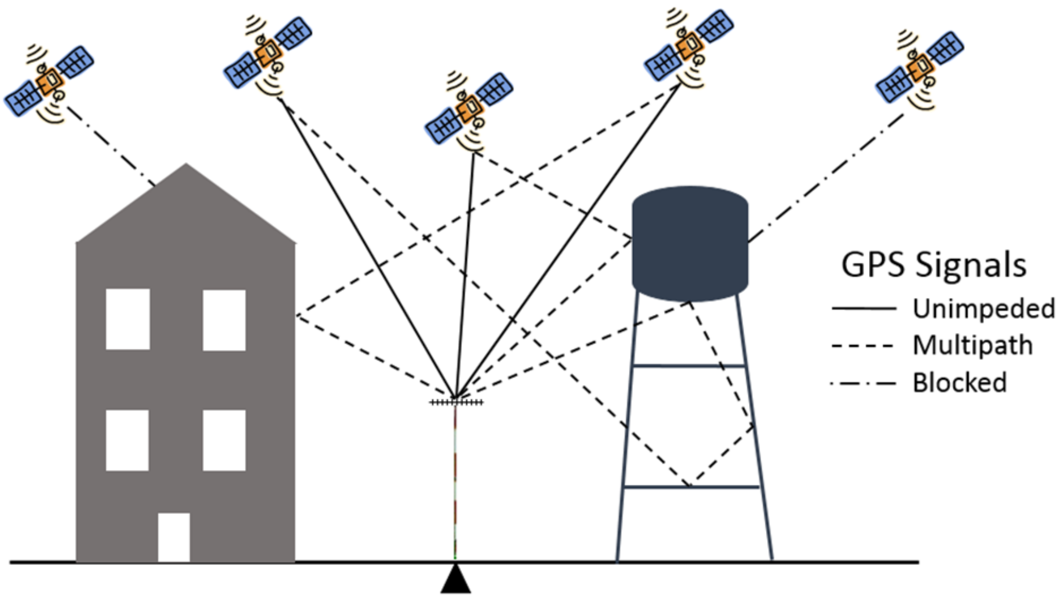

***Figure 15.1** GNSS Signal blockage and multipath*

GNSS interference - GNSS signals are relatively weak and reside in frequencies that are reserved for its use. Interference can come from a variety of sources, including radio emissions in nearby bands, intentional or unintentional jamming, and naturally occurring space weather. In the United States, it is illegal to intentionally jam or interfere with GNSS signals. The U.S. government works with law enforcement agencies to minimize intentional and unintentional man-made sources of GNSS interference. It is still good surveying practice not to locate GNSS control stations near or underneath powerlines, radio, or microwave towers.

Placement of Primary Control and Secondary Control station should be located in an area with as few GNSS obstructions as possible. If an open sky above 15 degrees (see Figure 15.2) is not possible, then it is better that the southern sky be open and blockage pushed north of the station. In Wisconsin, GNSS satellites are located in the southern sky a majority of the time. Often, when placing control station, a balance has to be struck between the design requirements of the point location and GNSS needs for an open sky. The user will have to rely on experience when setting GNSS control stations. Contact the region survey coordinator if there is any questions or concerns regarding station locations.

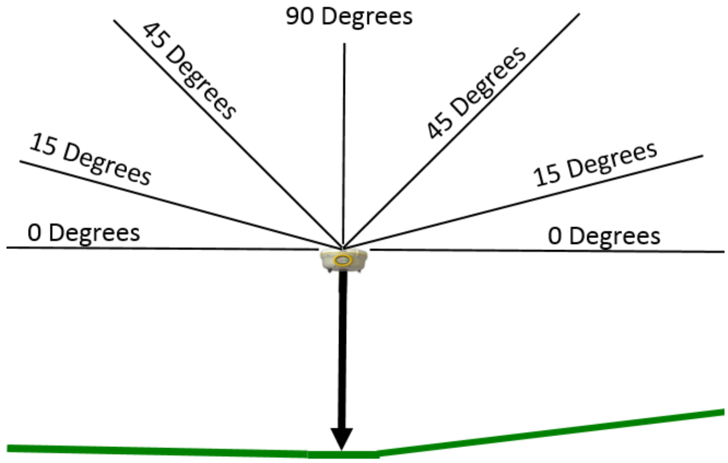

***Figure 15.2* GNSS Satellite Elevation Diagram**

For stations being established per primary control specifications, the southern sky should be clear above fifteen degrees and free from any potential multipath issues. Obstructions of up to thirty degrees may exist north of the station, preferably in only one portion of the sky. Primary control survey stations will also likely be used for total station control in addition to a GNSS base station, so the user should keep in mind the requirements for good total station control (e.g. safety, visibility to other stations etc.) when setting these stations.

Survey station being surveyed to Secondary Control survey specifications should have the southern sky clear above 25 degrees and be free of nearby multipath issues. Obstructions of up to 40 degrees may exist north of the station and should be limited on only one portion of the sky.

To observe features with the General (Topo) Positioning specification in areas of considerable GNSS blockage or multipath the user has to decide how much positional error can be accepted due to blockage and/or multipath issues versus the convenience of obtaining a position via GNSS techniques. The user will have to rely on his/her experience in working in these types of conditions in addition to considering the project accuracy requirements, number of satellites available at the site, PDOP, RMS, etc. In difficult GNSS environments, observation times should be extended beyond the minimum in order to obtain more data in hopes of achieving an acceptable solution. If the blockage is so extensive at a location that a GNSS derived position cannot be achieved, the user should consider establishing a pair of intervisible points in an open area and then measure the feature(s) with a total station.

For stations with a relatively large amount of GNSS signal blockage, a Visibility Diagram (WisDOT form DT2262 - Control Survey Station Record) should be completed and become a part of the survey report to alert future users of a station of potential GNSS signal issues. See Figure 15.3 for examples. If there is no blockage, it is recommended that the user indicate on the form that there is ‘No Blockage’ or there is “Clear Sky’ at that station to be certain that the diagram not omitted.

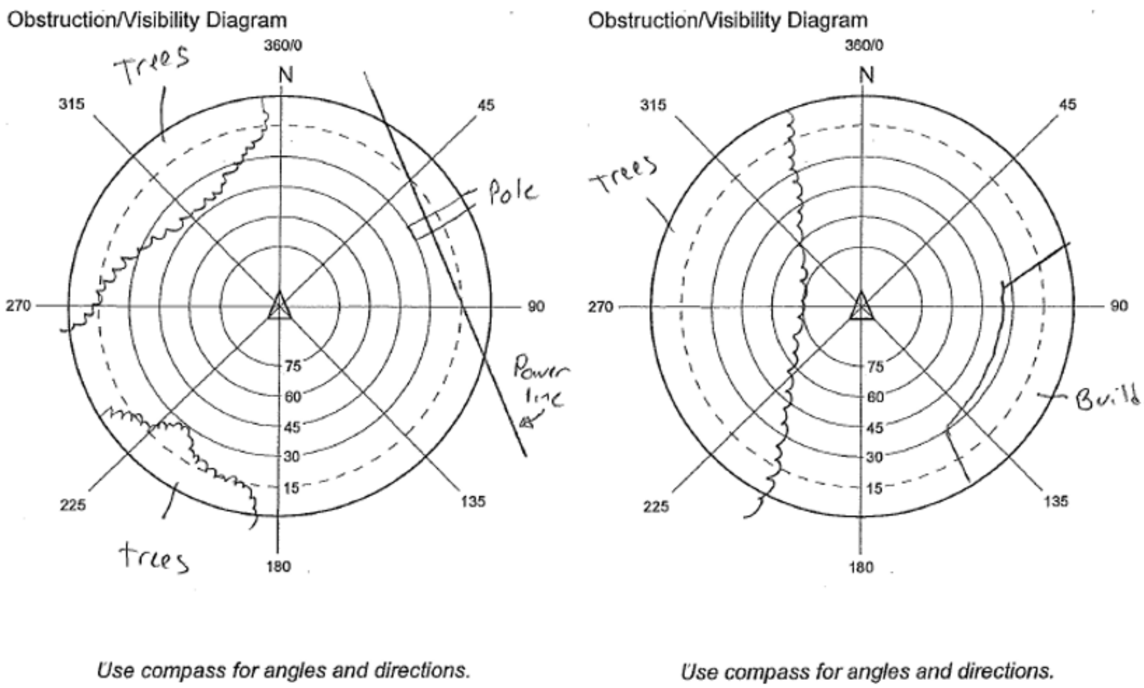

***Figure 15.3* Sample Visibility Diagrams of Obstructions**

In areas of especially troublesome blockage or multipath issues, like (e.g. section corners or urban canyons) it is highly recommended that the user uses a GNSS Planning tool that comes with most GNSS Processing software. GNSS planning tools are also available online.

GNSS Planning Tool - A GNSS planning tool is an effective way to determine the most favorable time periods for GNSS observations based on inputs from the user such as observation location, site obstructions and times of desired observations. The program then uses GNSS satellite ephemeris data to help the user determine observations times that will be useful in achieving the desired accuracy for a station. Figure 15.4 below shows Positional Dilution of Precision (PDOP) for a location without any GNSS signal blockage. Figure 15.5 is a PDOP graph for the same location except that there are significant GNSS signal obstructions. The user should look for periods of time where the PDOP will be below 5.0 (from Guideline 10) and avoid observations when the PDOP spikes above 5.0. Typically, a GNSS planning tool will offer a variety of data output (PDOP, HDOP, visible satellites, etc.) in many formats.

Manufacturers typically include some sort of mission planning tool with their software. There are also mission planning tools available online.

http://mapsupport.seilerinst.com/2012/04/02/trimble-gnss-planning-online-and-in-your-GNSS-software-under-plan/

http://www.trimble.com/GNSSPlanningOnline

http://fpisurvey.com/2014/05/28/gnssplanningonline/

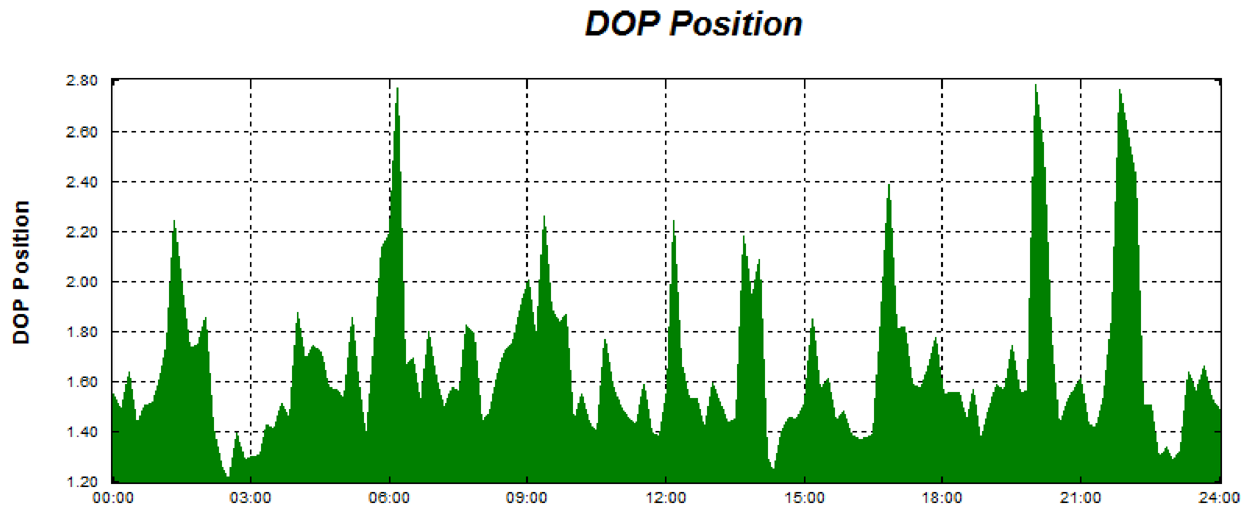

***Figure 15.4* PDOP plot from a GNSS Planning software (Note that for the entire day, the PDOP is well below 5.0)**

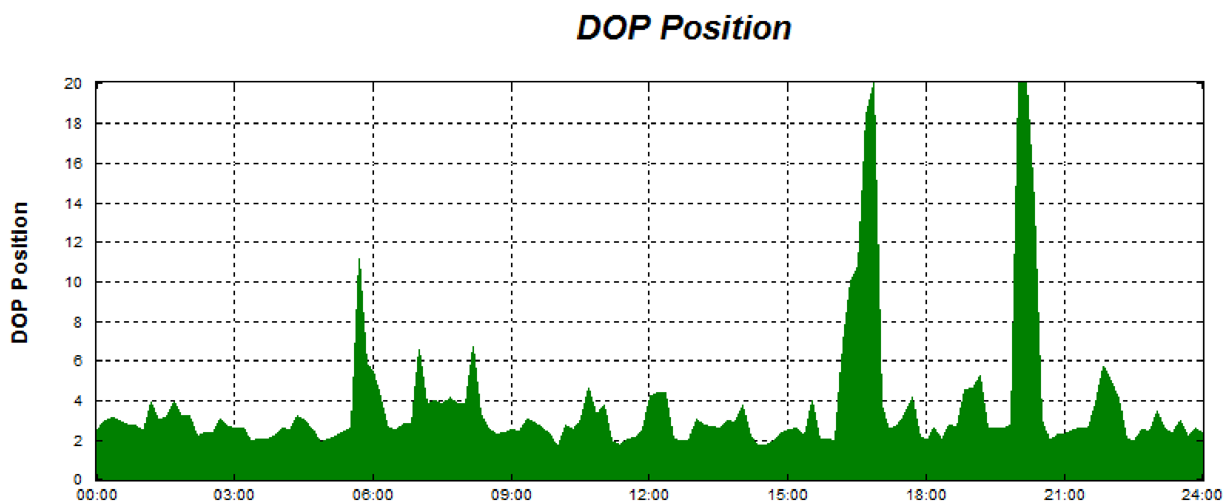

***Figure 15.5* The PDOP plot from the same location with extensive GNSS signal blockage (Note the different scales on the left side of the graph)**

The increased number of GNSS satellites available due to the use of GLONASS and other international GNSS systems has made the mission planning tool less critical. However, it is still an important tool that should be utilized for any GNSS observations with significant signal blockage.

Mission Planning should be utilized in situations where:

A. There is a large amount of satellite obstructions due to trees, buildings etc.

B. The equipment being used is able to utilize only the United States based GPS satellites, which limits the number of satellites available to the user.

Guideline 7 - Check Shots of Known Control Stations

Observation shots of geodetic survey control station(s) with published or validated horizontal and/or vertical coordinates shall be performed prior to, during, and at the end of every survey session. For this section, a survey session begins with the unit start up and ends when it is shut down. If the RTK unit is inactive, but still operating for at least 20 minutes, a check shot should be taken before resuming a survey.

Check shots should be at least a 5 epoch observation (General (Topo) Position Application). Multiple check shots are not required but may be needed if the first check shot does not meet specifications. During periods of elevated RMS or PDOP levels, longer observation times may be needed to assist the user meet the specification. Geodetic survey control stations used for the check can be published control (e.g. NGS) or control that has proven to work in the past, such as project control. The relative precision of the control station must be better than the desired precision of the survey.

Guideline 7A - Minimum number of Survey Control Stations with Known Control to use as Checks

The user needs to check into the minimum number of horizontal and vertical control points before and after every survey session. Ideally, there will be geodetic survey control stations with both horizontal and vertical published coordinates near the project. If there are no survey stations with known control near the project, the user can establish a survey station using the procedures for the Primary Control Application of this section in lieu of long drives to reach a suitable station. A single geodetic survey control station with published/proven horizontal and vertical control values may be used as both a horizontal and vertical check shot.

The purpose of the control station checks is to verify that the unit is working properly and the project settings are correct. If the checks at the beginning and end of a session meet specifications, then it is likely that the data in between the checks is good. This is why it is important that a session does not begin until the station check specification is met.

Guideline 7B - Check Shots on Survey Control Stations with Known Control before and After Survey Session

At the beginning and end of every survey session, it required that the user take check shots of known geodetic survey control stations in the vicinity of the project to verify that the unit is still functioning properly.

Check shots during and at the end of a survey session should exceed or be close to the stated guideline. If a large individual difference for a check shot is observed or a pattern of high residuals is noted, the user should attempt to determine the cause(s) of the problem(s) and also evaluate the quality of the observations taken since the last good control check shot.

Guideline 7C - Check Shots on Survey Control Stations with Known Control during a Survey Session

The stipulation that the user check into known control stations during a survey session is not required, but is highly recommended as a good surveying practice. There is no need to go off site during a survey session for a known control station unless the user has reason to believe that there are accuracy issues with the current survey session. Checking into known geodetic survey control stations during a session will help to identify which portions of data session are good in the event that the check at the end of a session does not meet specifications.

Benchmarks or monuments found along a project with older or unknown coordinates should be observed. A check shot will be sufficient if the user wishes to provide a position/elevation to place the monument in a GIS-type mapping application (a 5 epoch observation is also the requirement of a General (Topo) Observation). If the user wishes to update the horizontal coordinates or elevation values for future use, the monument should be observed to Primary Control Application specification.

Guideline 8 - Check Shot Residuals

It is required that a user measure a geodetic control station with known horizontal and/or vertical coordinates before and after every survey session. When measuring the geodetic survey control station as a check shot, the difference horizontal and vertical differences from the control values to the survey derived coordinates shall be less than the stated value. If there is a large difference between the known and surveyed values, the user should check the equipment and procedures for blunders. A common blunder is for the wrong antenna height to be entered into the project settings. If differences are minor, the user may be able to achieve the desired settings by re-observing the station, observing for a longer period of time, or choosing another station to use as a check.

As stated in other guidelines, it is not a requirement that the control station used as a check be a station with coordinates published by that National Geodetic Survey. Any stable benchmark with positional values (horizontal and vertical) equal to or better than the desired accuracy of the project may be used for a control check. This could include project coordinates from a previous project in the area, coordinates that are a result of local or regional survey networks. It is important to verify that the horizontal and or vertical control of the project and any monumented control used for check shots are on the same datum and adjustment. If there is not any geodetic survey station control for check shots in the project vicinity, control values for monuments to be used for check shots may be established using the Primary Control application guideline of this section. If using geodetic survey control station and coordinates that are neither Wisconsin Height Modernization Program (HMP) geodetic control stations nor provided by the WisDOT region survey section for use as project control, the contractor should verify that other stations and coordinates are acceptable for use for that WisDOT project by the appropriate WisDOT region survey section prior to their use.

Guideline 9 - Setting Base Station on Different Control Stations

For RTK surveys that utilize a Base and Rover RTK GNSS receivers to establish positions using either the

Primary Control or Secondary Control application shall set the RTK base station on at least two different horizontal and two different vertical geodetic survey control stations when observing a control survey station. This provides a check that the proper horizontal and vertical coordinates are being used as base station coordinates. Ideally, the user will want to use geodetic survey control stations with both horizontal and vertical positional values, however, this is not always possible.

All control stations used as base stations shall have published/proven horizontal and vertical coordinates of equal to or better accuracy than the desired accuracy of the project survey. The user should try to use Wisconsin Height Modernization Program (HMP) stations as a base station benchmark. Other survey network stations may be used for a base station provided the coordinate accuracy of the station(s) can be verified by the consultant and is approved for use by the appropriate WisDOT region survey office.

If a suitable second base station benchmark cannot be found within the range of the base/rover setup, the first station may be used again. If a single station is used, it is critical that the time difference between sets of observations (Guideline 18 and 19) be followed. In some circumstances, it may be useful to establish horizontal coordinates on a vertical Wisconsin Height Modernization Program (HMP) geodetic control station to provide a second station. The horizontal coordinates shall be established per the Primary Control application guidelines detailed in this chapter. This scenario will yield a control station with a horizontal accuracy of ‘Secondary’ and vertical accuracy of ‘Second Order Class 1’ assuming the vertical control station is a Wisconsin Height Modernization station.

As stated in Guideline 4, the user shall use a Network Solution and not a Single Base Solution when using the WisCORS Network for WisDOT projects. Connecting to two different WisCORS base stations using a Single Base WisCORS solution does not adequately satisfy the two different base stations required of the base and rover GNSS receivers. When using the WisCORS Network, these criteria are accomplished when the WisCORS network software creates two different virtual base stations as a result of either the user traveling out of the work area or restarts the rover after a complete shutdown, both cause the software to create a new base station. Simply breaking initialization on site without a complete shutdown or leaving the site does not satisfy these criteria.

Contact the region survey coordinator prior to beginning the survey if there is any doubt about the reliability or accuracy of a geodetic survey control station that is to be used as a base station or the consultant seeks permission to use a Single Base WisCORS solution for WisDOT projects.

<u>Guideline 10 - Maximum PDOP - Positional Dilution of Precision</u>

PDOP (Position Dilution of Precision) is a relative indication of the strength of the three-dimensional position that can be expected for a GNSS receiver based on the number and geometry of the GNSS satellites available for a location at a particular moment in time. The lower the PDOP value, the better the resulting data should be. For most equipment, the RTK unit will not record collected observation data if the PDOP exceeds the value that is input into the project settings. Mission Planning tool (See Guideline 5) can predict the PDOP for given locations during the expected survey timeframe. Other factors, such as obstructions and multipath will cause the PDOP to increase. Maximum PDOP settings should be the same value at both the rover and the base station.

<u>Guideline 11- Collection Interval</u>

Collection interval is the time interval between the recordings of GNSS observation data by the RTK equipment. For WisDOT RTK survey projects, the RTK rover and base (if used) should both be set to collect data at a one second intervals.

For GNSS surveys, the term, epoch is defined as a specific interval or time period over which a GNSS observation is conducted or a successful data measurement at the specified collection interval. So at a one second collection interval, a user may collect 118 successful measurements (epochs) of data over a two minute time span. Other types of GNSS surveys utilize different epochs (or collection intervals). RINEX data from the WISCORS Reference Data Shop can be downloaded in epochs that vary from one to sixty seconds. A larger epoch value allows the user to collect data over a wide time frame without creating extremely large file sizes.

<u>Guideline 12 - Minimum Number of Satellites</u>

Guideline 12 states the minimum number of GNSS satellites to be tracked by the RTK rover unit and base station (if used) during all project observations. The greater the number of satellites that the user can use, the larger amount of data that be collected which will yield better results. An increased number of GNSS satellites available due to the use of GLONASS and other international space-based navigation systems has made the minimum number of satellites much easier to obtain now than in the past. The use of the absolute minimum number of satellites for a survey should be reserved for very limited situations.

Older GNSS receivers that are unable to receive multiple GNSS systems and/or observations of stations that have a large amount of signal obstructions should make sure that the minimum satellite guideline is being met. A Mission Planning tool (see Guideline 5) should be used if any of the above conditions exist to ensure proper accuracies are being achieved.

Guideline 13 - Elevation Mask

Minimum elevation mask sets the elevation in degrees at which no GNSS signals will be utilized by the GNSS receiver. GNSS elevations range from zero degrees at the horizon in all directions to 90 degrees straight up vertically from the receiver (See Figure 15.6).

An elevation mask is used to remove GNSS signals that must travel thorough more of the Earth's atmosphere and encounter more distortions. Signals that travel through more atmosphere are undesirable because they are subject to additional errors due to:

- Increased time it takes signal to travel from the satellite to the receiver compared to signals above the elevation mask (latency). GNSS processing assumes that all signals reach the receiver at the speed of light. The additional time latency cannot be accounted for and leads to positional errors.
- GNSS signals approaching the receiver from a very shallow angle are subject to more blockage and more reflections causing signal multipath errors.
- Additional multipath issues that are more likely to arise.

The specified elevation mask is 15 degrees but may be raised to reduce multipath problems in hostile GNSS environments like urban canyons.

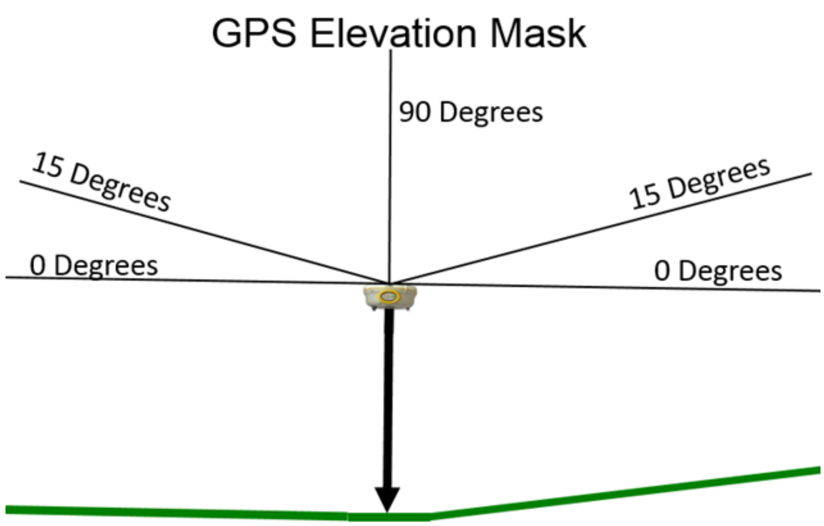

***Figure 15.6* GNSS Elevation Mask Values**

Guideline 14 - Observation Sets

To establish control on a benchmark to meet Primary Control or Secondary Control application requires a minimum number of sets of GNSS observations. Every observation set has a required number of observations (Guideline 15) and a minimum number of observation epochs (time) (Guideline 16) based on the application that the user is following. An observation set is considered complete when the minimum number of observations and epochs have been obtained.

If a full observation set cannot be completed, observations required to finish a set may take place at any time. After the observation set is completed, the next set shall not begin until Minimum Time Between Observation Sets (Guideline 19) requirement has passed.

Observations that are done for General (Topo) Positioning applications do not require observation sets because these types of observations are not typically repeated.

Additional observation sets and observations are recommended on survey stations to ensure adequate data redundancy and better results. This is especially true for stations in difficult GNSS environments (i.e. heavy blockage).

Guideline 15 - Observations within an Observation Set

Rotation of the rover pole between observations is recommended to help reduce systematic errors associated with the rod (level bubble, tip etc.). The rover pole can be rotated 360 degrees throughout all of the observations to reduce the effects level-bubble error. For example, three observations with a rotation of 120 degrees after each observation or 4 at 90 degrees are minimum requirements. Six observations, rotating 90 degrees each observation is also acceptable. When only one observation is used for an observation set, rotate rover pole 180 degrees between observations.

Additional observations within an observation set are a good survey practice to ensure additional data redundancy. This is especially for survey stations in difficult GNSS environments. Additional observations are also recommended for stations that require a long walk-in. This will help the user achieve the minimum number of acceptable observations required for that application and not have to revisit the station.

Observations for General Positioning category are in almost all cases are a single observation and do not require that the pole be rotated.

Guideline 16 - Minimum Amount of Data Collected per Observation Set

Every observation set shall meet or exceed the minimum required number of epochs per observation set. From Guideline 11, an epoch is defined as ‘a successful measurement at the specified collection interval’. It is desirable that every individual observation be roughly the same number of epochs, but not required. Longer observation times in excess of the minimum are always advisable especially if conditions warrant. Such conditions may include but are not limited to: large amount of GNSS signal blockage, increased signal multipath conditions (near glass or metal buildings), higher than normal PDOP or RMS values.

Guideline 17 - Break Initialization between Observation Sets

Initialization of the RTK rover must be broken at some point between observation sets for every station. This is accomplished by shutting the receiver down or when using WisCORS, traveling outside of the immediate area and back again so that a new virtual base station is created by the WisCORS system. Breaking initialization can be accomplished without leaving the site by shutting the rover down completely and then restarting, simply turning the rover receiver upside down to lose initialization is not acceptable to satisfy this requirement.

Guideline 18- Ideal Time Interval between Observation Sets

This guideline specifies the ideal minimum time separation between observation sets of the same survey station. This time interval assures that the observation sets will have different satellite constellations and geometry. It is a sign of good survey data if the same calculated survey position comes from different satellite constellations.

Satellite constellations repeat every 11 hours and 56 minutes; therefore, subsequent observation sets should not be performed between 11 to 13 hours or 23 to 25 hours after the previous set.

Guideline 19- Absolute Minimum Time between Observation Sets

For certain observation sets (e.g. stations that require long hikes or large amounts of signal blockage), it is not always practical or possible to wait the ideal amount between observations sets. This guideline specifies the minimum amount of time separation permitted between observation sets of a survey station to allow the satellite constellation to change enough to provide some redundancy. As stated in Guideline 18, it is an indication of good survey data if the same calculated survey position for a survey station can be achieved using different satellite constellations. The ideal time separation stated in guideline 18 should be used for almost all instances, and absolute minimum time interval should be used only as an absolute necessity

Guideline 20- Site Calibrations

A GNSS site calibration is a process where surveying software attempts to best-fit a flat plane to match the curved surface of the earth in the survey project area with minimal distortions or errors. The goal is to match the coordinates determined via a GNSS survey for a survey station with the known coordinates of that survey station. The remainder of the survey data collected for that project is performed on this adjusted plane. The initial plane prior to adjustment is generally a defined Cartesian coordinate system (e.g. County Coordinate System Zone) but may be an assumed coordinate system. For more information on Cartesian coordinate systems used for WisDOT projects, see FDM 9-20-25.

Calibrations can be vertical only, horizontal only or both, and will require the appropriate number of horizontal and or vertical geodetic survey control stations with known or proven positions. All control stations used in a GNSS site calibration must have the identical datum, adjustment, coordinate system (horizontal only) as the project. The user shall use a geoid model for site calibrations and note the correct name of the geoid model used. Use of different geoid models in site calibrations will lead to inconsistent and erroneous results. The region survey coordinator should provide direction to consultant survey firms regarding the use of geoid models.

The user should take care when observing site calibration control stations because small amounts of error in the survey will be covered up in the site calibration results. Large blunders by the user should be detected by the calibration if proper procedures are followed.

For horizontal site calibrations, the flat survey plane is scaled and rotated to best-fit the known coordinates. For vertical site calibrations, the plane is raised or lowered and/or ‘tipped and tilted’ to make the GNSS derived elevation (ellipsoidal height combined with the geoid model) fit the known elevations of the observed GNSS survey control stations. It is advised that if the user needs to perform more than one survey calibration for a given project, the appropriate region survey coordinator should be contacted for directions on using multiple site calibrations for a project.

The horizontal and vertical coordinates of the ’known’ survey stations must be of an equal or higher accuracy than the desired accuracy of the survey project. For example, a user should not use the coordinates for a General (Topo) survey point as control for a GNSS site calibration if the desired accuracy of the survey project is Secondary Control Coordinates because the accuracy of a General (Topo) point is less than a Secondary Control point. Only a one-point calibration (20A) or four or more point calibration (20B) method is permitted to be used for WisDOT survey projects. The use of a two or three-point calibration is not allowed for WisDOT work because using two or three control points will hide errors/blunders rather than expose them. This causes very poor survey results despite the calibration residuals being within tolerances.

It is important to note that the use of the same geodetic survey control stations for a project site calibration in all phases of the project will lead to more consistent results. In theory, any geodetic control stations that are on the same horizontal and vertical datum and adjustment can be used to produce consistent calibration results. However, to assure the most consistent results, it is highly recommended that users use the same geodetic control stations for a project when performing a site calibration. The region survey coordinator should provide direction regarding geodetic control stations to be used for a site calibration.

Guideline 20A - One Point Calibration

A one-point calibration is best used for projects that are smaller in size with a limited amount of known geodetic survey control. If the project extends more than the maximum listed distance from the location of the single control station used as control for a GNSS site calibration, a ‘4 or more’ point calibration should be considered (see Guideline 20B).

The user occupies a single geodetic survey control station with known horizontal and/or vertical coordinates, then the survey software ties the survey to the chosen coordinate system projection through this one point by adjusting the GNSS derived observed coordinates from the rover horizontally and/or vertically to match the known coordinate(s) of the station. For horizontal calibrations, the plane that the survey is on is shifted in the northing and easting direction(s) to match the known coordinates of the calibration control station. For a vertical calibration, the survey plane is raised or lowered to match the known elevation.

For a one-point horizontal calibration, the parameters of the horizontal coordinate system chosen by the user (e.g. WISCRS- Adams Zone) will not be altered (the parameters are slightly altered in a 4 or more point calibration). If performing a one-point vertical site calibration the vertical datum remains unaltered. In both cases, the coordinate values of the calibration survey are adjusted to fit the published coordinates. All survey positions obtained during the project after the calibration will be adjusted by similar amount as the calibration result. All observations of site calibration control points should be performed using the Primary Control or Secondary Control application guidelines published in this section.

The control station used for a one-point calibration should be located somewhat near the center of the project. GNSS observations should not be taken beyond the stated maximum distance from the survey station used for a one-point GNSS site calibration (see Guideline 20.A.2). The user should be cautious when using a one-point calibration because any blunders and errors that occur when observing the survey control station will be covered up and will cause subsequent horizontal and vertical values to be in error. Mistakes and blunders can be discovered prior to survey by meeting the requirement to check into another survey station with known control points on the project (see Guideline 20.A.1).

Guideline 20A.1 - Minimum Number of Survey Control Stations with Known Control Values to be used

Two control stations are needed for a GNSS site calibration, one to use for the calibration and one for a check. The stations must be on the same horizontal and or vertical datums. Never do a one-point GNSS site calibration without checking into at least one other control point. It is good survey procedure to check into any known survey control stations if they are encountered during the survey as a check. Ideally, the survey control station used for the site calibration will be somewhat near the center of the project and a survey check station will be located near the edge of the project limits.

Guideline 20A.2 - Maximum Distance of Observations from Calibration Control Station

The maximum distance from a GNSS Site calibration control station that any survey observations can be taken is listed. If the user needs to have multiple one-point GNSS site calibrations for a single project, the user should use a ‘4 or more’ point calibration method (see Guideline 20.B). In very rare instances, multiple ONE POINT calibrations may be the better method of surveying a project. However, the use of multiple ONE POINT calibrations for a single project must be approved in advance by the WisDOT region survey coordinator in charge of the project.

Guideline 20.A.3 - Maximum Residual of Observations of Check Stations

Maximum residuals of a check point are defined for each type of survey listed in this section. If the user does not achieve the desired residual when checking a second control station, the user can reshoot the second station or observe a different control station. There many reasons why residuals will not meet the standards, so the user will have to rely on training and experience in determining if there are issues with the site calibration. The residuals of all checks to other control station(s) should be part of the survey report turned in with the project data.

There are no maximum check point residuals for General (Topo) Positioning applications. The residuals for this application should be within a reasonable tolerance determined by the user that will allow the desired expected accuracy of the survey to be achieved.

Guideline 20B - Four or More Point Calibration

A Four or More Point Calibration is the preferred site calibration method for most WisDOT projects. This method is best suited for long linear projects that are larger in size. Observing four or more GNSS calibration control points for adds redundancy on the control stations used for a GNSS site calibration.

If a calibration is done for a project, the minimum number horizontal and vertical control points listed in Guideline 20B.1 must be used to adequately scale and level the calibration plane. A new horizontal Cartesian coordinate system will be created as a result of the site calibration survey. Different equipment manufactures provide different mechanisms for saving, sharing and editing site calibration results, so the instructions provided by the manufacturer should also be followed. Assuming that there are no blunders during the site calibration survey, the new site calibration coordinate system should be very similar, but not exactly the same as the coordinate system of the area that you are working in (e.g. WISCRS- Adams Zone).

Any Control Stations used for Site Calibration must be a higher quality (more accurate) than the desired project accuracy. The control stations should surround (box in) the project area and be as evenly distributed as practical to provide a better network geometry (see Figure 15.7 and Figure 15.8). It is recommended that stations used in a GNSS site calibration be observed to SECONDARY CONTROL standards and the ‘final’ computed position of the surveyed points are used in the calibration.

Surveying these control stations as part of a GNSS site calibration will create a local Cartesian coordinate system and adjusted elevation plane based on the results of the site calibration surveys. A one-point calibration should be considered if the project is small and a good box around the project area is not practical. The user is encouraged to use more than the minimum number of GNSS calibration control points to provide more redundancy for the final solution.

Moving outside the box of control for the area calibrated will require a new calibration survey for that area.

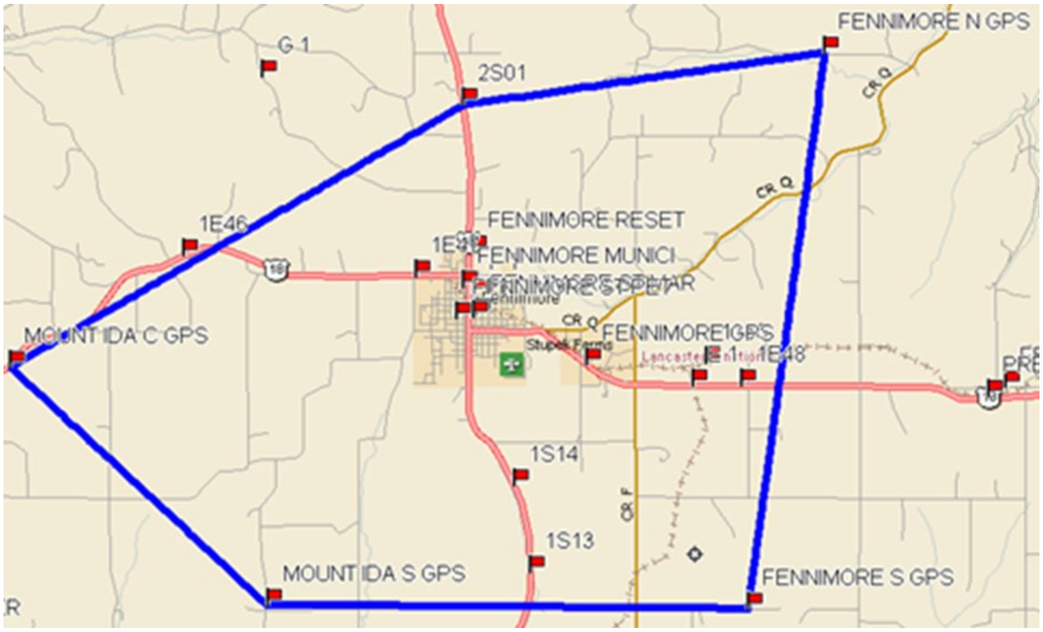

Figure 15.7 **_Boxing in the project area with Control_**

<u>Guideline 20B.1 - Minimum Number of Horizontal and Vertical Survey Control Stations with Known Control Values to be used</u>

This guideline specifies the minimum amount of horizontal and vertical control stations that must remain in a final horizontal and or vertical calibration solution. If more stations are available, the user is encouraged to use more stations than the minimum to provide more redundancy and be able to discard any survey control stations without having to perform additional field work. It is advised to have other survey stations in the project area that are not part of the calibration solution to be used as checks.

<u>Guideline 20B.2 - Maximum Distance between Adjacent Calibration Control Stations</u>

This is the maximum distance between calibration control stations represented by the letter ‘a’ in Figure 15.8. Calibration control stations shall be outside the project area and encircle/‘box in’ the project (Figure 15.7 and Figure 15.8). As Figure 15.8 illustrates, the general perpendicular distance across the project shall also be less than the distance stated in Guideline 20.B.2.

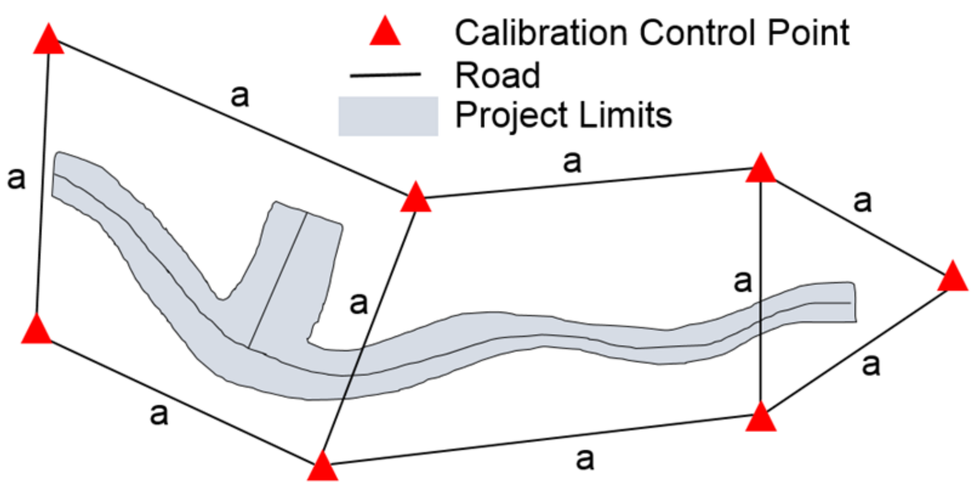

Figure 15.8 **_Distance between control stations_**

<u>Guideline 20B.3 - Maximum Horizontal Residual of Calibration Control Stations in a Site Calibration Solution</u>

Specifies the maximum horizontal residual for any calibration control station that is included in a final horizontal site calibration solution. If more stations than the minimum are observed, they may be dropped out of the solution as long as the minimum number of control stations meet or exceed the stated tolerance.

Guideline 20B.4 - Maximum Vertical Residual of Calibration Control Stations in a Site Calibration Solution

Specifies the maximum vertical residual for any calibration control station that is included in a final vertical site calibration solution. If additional vertical stations are observed for the calibration, they may be dropped out of the solution as long as the minimum number of control stations are at or below the stated tolerance.

Four or more Point Calibration Review

- A calibration is best-fitting a plane to match the curved surface of the earth with minimal distortions or errors.
- The plane is adjusted horizontally and/or vertically to fit the results of a calibration survey, and the remainder of the survey data collection is then based on this adjusted plane.
- For ease of calculations all surveys are performed on some type of horizontal and/or vertical plane based on projection parameters.
- Calibrations can be:
  - Horizontal only
  - Vertical only
  - Both horizontal and vertical
- Calibrations work the same with any method of survey, RTK, WisCORS and/or conventional.
- A ‘box’ created by the observed control points surrounding the area of interest.
  - A large calibration area becomes too large to be adequately depicted using relatively simple calibration equations.
  - Large areas are better suited to full-scale projection parameters and not site calibrations.
- Surveying outside the area calibrated ‘box’ will require a new calibration survey.
- All of the survey control stations used as a calibration point are on the same horizontal and vertical datum as the project.
- All survey control stations of a calibration survey must be of a higher order (better quality) than the resulting survey.
- It is recommended that you observe the calibration control station multiple times and average the results before applying the GNSS derived point to the calibration. This results in a better quality GNSS station being used for calibration.

Guideline 21 - Maximum Point Tolerance Residual

Guideline 21 is commonly called a ‘point tolerance setting’ and there is a maximum tolerance value for both horizontal and vertical coordinates. When comparing individual observation values with the final computed coordinate value for a survey station, any individual observation that has a horizontal and/or vertical coordinate value larger than the point tolerance value specified in Guideline 21 should not be included the final point coordinate result. For any given observation, it is permissible to include only the horizontal coordinates, vertical coordinate, both or neither.

Example: A person is asked to measure the length of a parking lot that is exactly 100 feet long. The measurements in numerical order are: 99.6’, 99.8’, 99.9’, 100.0’, 100.1’, 100.3’, 100.5’, and 100.6’. The average of all the measurements is 100.1. If the point tolerance for this exercise is set at 0.35’, only the following measurements will be included in the final average: 99.8’, 99.9, 100.0’, 100.1’ and 100.3’, yielding a new average of 100.0’. The point tolerance setting is designed to reduce the number of data outliers from a final result.

This guideline is not applicable to General (Topo) Positioning applications as repeated observations for this application are not required.

Guideline 22 - Minimum Number of Horizontal and Vertical Observations used in Final Point Determination Solution

This guideline specifies the minimum number of individual observations and the minimum number of observation sets that must contain at least one valid observation used for the determination of the final coordinate value. For any given observation, it is permissible to include only the horizontal coordinates, vertical coordinate, both or neither. No final position should be accepted from the point determination software unless the minimum number of observations are within the tolerances specified in Guideline 21 are achieved. It is not a requirement that every observation or that a certain percentage of observations or a percentage of observation sets be included in the final point coordinate determination. There is no requirement that there must be an equal number of horizontal and vertical observations in the final result, only that the minimum number of observations and observation sets are achieved.

In areas with more difficult GNSS signal environments (e.g. blockage) more observations and sets should be taken to assure the user that at minimum number of observations and sets is met. This guideline only specifies how many observations and sets of data must be used; it DOES NOT mandate that a percentage of all observations be used. Nine of twelve good observations satisfy the requirement of Guideline 22 just as much as 9 of 25 good observations.

Example 1 - Three sets of four observations are taken to determine a station coordinate for a Primary Control application with the following results:

Observation set 1 - 4 horizontal and vertical observations meet specifications.

Observation set 2 - 2 horizontal and 1 vertical observation meets specifications.

Observation set 3 - 4 horizontal and vertical observations meet specifications.

The results for this station meets the criteria for Primary Control application as there are 10 successful horizontal observations and 9 successful vertical observations both from three different observation sets.

Example 2 - For a section corner with relatively large amount of GNSS signal blockage the user decides to perform four sets of four GNSS observations to determine Secondary Control application coordinates with the following results:

Observation set 1 - 0 observations that meet specifications.

Observation set 2 - 4 observations that meet specifications.

Observation set 3 - 3 observations that meet specifications.

Observation set 4 - 0 observations that meet specifications.

The results for this station do not meet the criteria for Secondary Control application as there are only 7 successful observations from two observation sets.

Example 3 - For a section corner with relatively large amount of GNSS signal blockage the user decides to perform four sets of four GNSS observations to determine Secondary Control application coordinates with the following results:

Observation set 1 - 1 horizontal and vertical observation that meets specifications.

Observation set 2 - 4 horizontal and vertical observations that meet specifications.

Observation set 3 - 3 horizontal and vertical observations that meet specifications.

Observation set 4 - 1 horizontal and vertical observation that meets specifications.

The results for this station meets the criteria for Primary Control application as there are 9 successful horizontal and vertical observations from four different observation sets.

Guideline 23 - Equipment Checks and Calibration

Guideline 23 states that the user shall follow the manufacturer's recommendations for maintenance and repair of survey related equipment (antennas, receivers, and collectors) and accessories. Accessories used in conjunction RTK GNSS surveys should be inspected after every use for wear or damage. Examples of accessory equipment include, but are not limited to: tripods, bipods, rods/poles (for straightness), level bubbles, cables, pole tips (dull or bent), etc. The user should also be certain that rod tips and antennas and screwed on securely and rechecked often during the course of a survey.

If check shots to multiple known survey control stations are consistently yielding incorrect values and the RTK accessories seem to be in good condition, then the equipment manufacture should be contacted to determine if your equipment is in need of repair.

Guideline 24 - Survey Report

A survey report shall include all relevant information and supporting files for the survey project. That this report is about a project survey and is to be provided in addition to any contracted items. It is preferred that the survey report be in an electronic format and utilize subfolders that contain data in an orderly manner agreeable to the region survey coordinator or another person in responsible charge of the project for which the survey is being done.

Any text files contained in the report should be in a standard format (preferably PDF) that can be read or viewed on most computers.

The project folder should contain, but is not limited to the following:

- All raw data collector files and office surveying software files normally created and used during the project, this includes the survey project processing project file(s) (e.g. Leica dbx file, or Trimble vce file). Any raw data collector files shall be in their native format as used onboard the data collector and contain raw GNSS vectors and terrestrial surveying observation data. This may require copying the raw file off the data collector. Any files exported from the data collector to the office software shall be included.
- A LandXML file that can be imported into AutoCad for review.
- All reports generated for the project shall be submitted. Examples of these types of reports are: survey report, point coordinate file(s) (.wsi, .csv, txt) with project metadata, WisDOT forms completed for the project, stakeout reports, resection reports, benchmark check residuals, horizontal and vertical benchmark information (coordinates and description), loop closure reports, horizontal and vertical calibration reports, network adjustment reports, least squares adjustment reports, leveling reports etc.
- Copies of any project files imported into the survey project or received by the user. Examples of these files may include aerial target document, horizontal and vertical benchmark information, other surveys relevant to the current survey, etc.
- Any sketches created and/or images taken related to the survey project.
- Any project correspondence related to the survey project.
- Any other materials relevant to the survey project or requested by WisDOT region survey unit or other interested parties.

FDM 9-30-25 Definitions

November 15, 2023

Accuracy - The absolute nearness of observed quantities to their known or 'true' value.

Blockage (of GNSS Signals) - GNSS signals are prevented from reaching a GPS receiver because a solid object (building, trees, etc.) in the direct line from the satellite to the receiver.

Check shot - An observation to determine how close positions determined via a GNSS observation is to a published or previously determined horizontal position and or vertical elevation. Check shots validate that the equipment is properly calibrated and or the proper survey project settings are being used. Typically, check shots are six epoch observations, but longer observations may be required in difficult GNSS locations with blockage or multipath.

Confidence Interval - A numerical interval used to express the degree of uncertainty associated with a data sample. A confidence interval is typically an interval estimate combined with a probability statement (e.g. 95% confidence interval of 0.6').

Confidence Interval - One Sigma - (See Root Mean Square)

Confidence Interval - Two Sigma (95%) - Statistically, a user can expect that 95% of observations will be within the stated confidence interval range centered on the actual or 'true' value. Another way to think of this is that 95% of the observations will be in a range of the true value +/- one half the confidence interval value. The stated 95% vertical confidence interval for General (Topo) Positioning Application is 0.18 feet. Statistically, 95% of these shots should be within +/-0.09' of the true value.

Primary Control Application - refers to the establishment of supplemental control stations in the project area. This type of positioning is used in areas where spacing of control stations from the Wisconsin Height Modernization Project (HMP), a county User Densification Network (UDN) or other network of control stations cannot sustain RTK survey methods. Stations established using Primary Control standards typically are permanent or semi-permanent monuments that will be used as control for future work and maintain a stable position beyond the life of the project.

Epoch - defined as a specific interval or time period over which a GNSS observation is conducted or a successful data measurement at the specified collection interval.

General (Topo) Positioning Application - They are a one-time observation of items or features to determine their location and or elevation or are a collection of observations used for topographic mapping purposes or surface creation. Examples of items collected using the General (Topo) Position application include, but are not limited to feature location, utilities, centerlines, collecting or augmenting existing surface data, and control checks.

GNSS (Global Navigation Satellite System) - A term used to describe a satellite navigation system from any country or region. The most common GNSS systems are GPS (United States), GLONASS (Russia), Galileo (European Union), BeiDou (China) and QZSS (Japan). In the past, 'GPS' described any form of satellite-based positioning because, for a period of time, the United States GPS system was the only GNSS system available for civilian surveying applications.

GNSS Site Calibration - A GNSS site calibration establishes a relationship between GNSS derived WGS84 obtained in the field and the corresponding Cartesian plane coordinate and or elevation of a site calibration survey station. Surveying software attempts to best-fit a flat plane to match the curved surface of the earth in the survey project area with minimal distortions or errors.

GPS - See GNSS

Monument - A physical object that indicates the location of a corner or a point determined by survey. Monuments may include (but are not limited to) a brass disk in concrete, iron rods or pipes with or without plastic caps, chiseled X's, PK nails etc. More than one monument may define a location. The terms Monument, Mark, Landmark, Corner, Point and Station are not synonymous, but are often used interchangeably.

Multipath (or GNSS multipath errors) - Errors that occur because the GNSS signal from a satellite does not take a direct path to the GNSS unit antenna because the signal bounces off of an object or objects prior to reaching the antenna. The additional distance that the reflected signal travels causes incorrect distance measurements from the GNSS satellite to the GNSS unit leading to positional errors.

Open Sky - A location where there are no GNSS obstructions in any direction greater than 15 degrees above the horizon.

PDOP (Position Dilution of Precision) - A relative indication of the strength of the three-dimensional position that can be expected for a GNSS receiver based on the number and geometry of the GNSS satellites available for a location at a particular moment in time. The lower the PDOP value, the better the resulting data should be. Ideally, using Mission Planning tool (see Guideline 5), a user will be able to schedule GNSS observations during periods of low PDOP values forecast for the observation location.

Precision - The degree of consistency of a group of observations/measurements. Precision is a measure of the variance on repeated measurements of the same object. The lower the variance among observations, the better the precision.

Secondary Control Application - involves determining geodetic control positions for monuments that are generally a part of a transportation improvement project or are not going to be used as a control station for other applications. Monuments set for a project are expected to remain stable only for the life of a project. Secondary control applications would include positional determination of United State Public Land Corners, aerial photogrammetry targets, lidar targets, right-of-way monuments, any monument that depicts property interests (easement, property pin) or any other similar feature.

Root Means Square (RMS) - The statistical estimation of the accuracy of point measurement when compared to the 'true' result to about 67% (one sigma) confidence interval. Statistically, about 67% of observations will be equal to the true value +/- the RMS/2.

Site Calibration - See GNSS Site Calibration

Survey Session - a survey session is a period of time where the RTK rover is continuously operating. If the unit is shut down to go to another site or lunch, a new session will begin when the unit is turned on again.

'True' Value of a Measurement The 'true' value of a measurement is the value that would be obtained by a perfect measurement without error. In surveying, the true value (horizontal coordinate and/or elevation of a monument) is never known and is constantly subject to adjustments, mostly due to additional measurements and better techniques. Many measurements have a range of values rather than one 'true' value.

Wisconsin Continuously Operating Reference Stations (WISCORS) - A Statewide Global Navigation Satellite System (GNSS) reference station network developed by the Wisconsin Department of Transportation This network consists of over 80 permanent GNSS reference stations that can provide GNSS corrections to mobile users in real-time. Mobile users properly equipped to take advantage of these GNSS corrections can position in the field to the 2-centimeter accuracy level in real-time.

Wisconsin Height Modernization Program (HMP) - The Wisconsin Department of Transportation's Division of Transportation Systems Development, Bureau of Technical Services, Geodetic Surveys Unit (GSU) is responsible for the development and maintenance of the statewide vertical, horizontal, and gravitational geodetic control network in support of the Wisconsin Spatial Reference System (WSRS).

In 1998, the WisDOT's Geodetic Surveys Unit, in conjunction with the National Geodetic Survey (NGS), began work on a Height Modernization Program in Wisconsin. The goal was to construct a dense statewide network of permanent Geodetic Survey Control stations with highly accurate, reliable heights using global positioning satellite technology with traditional leveling, gravity, and modern remote sensing methods.

Upon completion of initial Height Modernization Program efforts, the Geodetic Surveys Unit serves as chief custodian of the statewide Geodetic Survey Control Network, which includes the core functions of replacement and reestablishment of Geodetic Survey Control Stations that are disturbed and/or destroyed.