Guidelines for the Use of Global Navigation Satellite Systems (GNSS) In Cadastral Surveys

v.1

June 18, 2019

Prepared by

Mike Londe, PhD, Geodesist

WY 957

Guidelines for the Use of Global Navigation Satellite Systems (GNSS) in Cadastral Surveys

Introduction

The Bureau of Land Management (BLM), in coordination with the United States Department of Agriculture (USDA) – Forest Service (FS), jointly issued the "Standards and Guidelines for Cadastral Surveys Using Global Positioning Methods" to guide the use of satellite positioning technology in conducting Cadastral Surveys almost twenty years ago. The BLM issued the Standards as Instruction Memorandum (IM) 2001-186, and the USDA-FS issued the Standards in accordance with its directives system. The agencies issued updated accuracy standards in 2010, under their respective directives system; the BLM released IM 2010-094: "Standards for the Positional Accuracy of Cadastral Surveys using Global Navigation Satellite Systems (GNSS)," and the USDA-FS released the document separately under their official memorandum system. However, even though they updated the standards in 2010, the agencies did not update the procedural guidelines. Both BLM IMs have now officially expired; however, the cadastral survey program continues to refer to them as the standards and guidelines when using satellite positioning based measurement technologies to perform cadastral surveys.

In the 18 years since the agencies first released the standards and guidelines, technology and procedures have evolved. The original procedures, while still fundamentally sound, focused on the practice of using large control networks and static Global Positioning System (GPS)-only observation protocols. Today, surveyors use Precise Point Positioning Tools (PPP) like the National Geodetic Survey (NGS) On-line Positioning User System (OPUS) as the basis of control and use Real Time Kinematic (RTK) tools for corner observations. In addition, satellite receivers are no longer limited to the United States GPS satellite network, as they can now connect to multiple satellite constellations such as GNSS (U.S) and GLONASS (Russia) or GALILEO (European Union) for positioning. In 1997, when the original work for these documents began, PPP type tools did not exist and RTK surveys were in its infancy. These Guidelines update procedural methods to reflect changes in how we conduct surveys and support appropriate use of new advances in technology. Surveyors should refer to these Guidelines in conjunction with the "Standards for the Positional Accuracy For Cadastral Surveys Conducted Using Global Navigation Satellite Systems (GNSS)" and any updates to either.

These procedures are for guidance only. These procedures do not preclude the appropriate use of one or more of the many good observational methodologies available to ensure that Cadastral Surveys meet accuracy standards. Rather, this Guidance provides a basic set of procedures to which surveyors can refer, and upon which they can develop appropriate methodologies. The Standards for the Positional Accuracy for Cadastral Surveys Conducted Using Global Navigation Satellite Systems have not changed since the BLM issued IM 2010-049; however, the BLM is reissuing the Standards alongside this Guidance for the convenience of practitioners.

The Guidelines outlined in this document address field data acquisition methods, field survey operations and procedures, data processing and analysis methodologies, and documentation. The use of these Guidelines and the manufacturers' specifications provide a means for the surveyor to evaluate the survey and to verify the specified accuracy standard has been achieved.

These Guidelines are designed to ensure a cadastral survey performed with GNSS technology is repeatable, legally defensible and referenced to the National Spatial Reference System (NSRS) (see Appendix A) by providing for the following:

- Elimination or reduction of known and potential systematic error sources.
- Occupational (station) and observational (baseline) redundancy to demonstrate the stated accuracy.
- Documentation of baseline processing, data adjustment, and data analysis that demonstrates compliance with the recommended procedures and required accuracy.
- Compliance with the *BLM Manual of Instructions for the Survey of the Public Lands of the United States (2009)* and applicable state laws.
- Following these Guidelines will produce data that meet the accuracy standards and reduce the amount of data analysis required of the surveyor.

GNSS survey guidelines continually evolve with advances in equipment and techniques. The BLM and the USDA-FS expect these Guidelines to change as these advances occur. The size, scope and site conditions of a project may also require variations from these guidelines.

Surveyors should design any variation from these Guidelines to meet the above criteria and to achieve the accuracy standard of the survey as required by this document, and must document all variations, including the rationale for such variation, in the project report.

Section One

Field Data Acquisition Methods

While there are a number of GNSS field data acquisition methods, there are two predominant methods used for ***Cadastral Measurements*** (see Appendix A) and ***Cadastral Project Control*** (see Appendix A).

Real-time Kinematic (RTK) Positioning:

Real-time kinematic positioning is similar to a total station radial survey. RTK does not require post processing of the data to obtain a position solution. In this method of data collection, point observation times can be as low as several seconds. This allows for real-time surveying in the field. This method allows the surveyor to make corner moves (stake out) similar to total station/data collector methods. While surveyors could use RTK positioning to collect baselines for use in a project control network, practitioners typically use RTK positioning for the Cadastral Measurement portion of a Cadastral Survey.

The most basic RTK setup consists of a base receiver set up on a control point, a data link such as a radio connected to the base receiver that broadcasts the real time corrections, and a roving receiver that moves between points. This system works by having the base receiver tracking the visible GNSS satellites and computing instantaneous correctors. The base receiver then broadcasts these correctors via the datalink to the roving receiver. The roving receiver then utilizes the correctors to calculate a baseline connecting the base and rover receivers on a second by second basis. Observing a point for a longer time span can increase the accuracy of the baseline and the resultant positions.

The nature of the datalink and other factors can limit the length of the baseline measured with RTK. Research shows that practitioners can measure fixed RTK baselines of 10 to 20 mile. By comparison, practitioners can use a broadcast radio link to measure fixed baselines 10 to 15 miles long. However, the baseline length for a radio broadcast can be reduced to 3 to 5 miles due to various radio datalink issues such as radio broadcast power, topography, battery strength, or the broadcast antenna height. Use of a radio repeater can extend the length of a baseline to compensate for these effects. Datalinks that utilize the internet can cover 20 miles but depend on having cellular coverage, which can vary.

Caution: Use of RTK is most successful in open sky conditions. Use of RTK or static methods under a forest canopy are not recommended. However, these methods are acceptable if they result in a solution that meets the survey standards. The surveyor must make an informed decision when choosing the appropriate methodology to use in a particular project area. Conventional optical measurement methods should be considered for survey projects in a forest canopy environment with marginal sky visibility in lieu of using RTK or static based positioning methods.

Static / Fast-Static Positioning:

Static and Fast-Static positioning are the same measurement technique. The difference lies in length of the baseline measured and the purpose for which the baseline is measured. This method requires a receiver to occupy a location for a fixed length of time. The exact amount of time will depend on the proposed use for the data collected and the length of the baseline measured. Surveyors using either method can use multiple receivers and measure multiple baselines.

Static positioning is used for the measurement of long baselines or when long observation times are needed in order to achieve higher positional accuracies. This method is typically used in setting up a project control network or using a multiple baseline approach for positioning. It may consist of multiple receivers, multiple baselines, multiple observational redundancies and multiple sessions. Surveyors should use a least squares adjustment of the observations to adjust the baselines and determine the final coordinates and positional accuracy. This method provides the highest accuracy achievable and requires the longest observation times. Observation times can range from 30 minutes to several hours depending on the baseline length. Static positioning is primarily used for ties to the National Spatial Reference System (NSRS) when observing Cadastral Project Control. Surveyors may also use this method for the Cadastral Measurement portion of a cadastral survey.

Fast-Static Positioning requires shorter occupation times (i.e., 5 to 20+ minutes) than static positioning and is typically used to measure baselines less than 10 to 15 miles in length. As with static positioning, multiple receivers can be used to simultaneously measure multiple baselines during a fast static survey. Practitioners can use least squares adjustment or use of processing software capable of producing a weighted mean average of the observations. Surveyors may use Fast-static positioning for observing both the Cadastral Project Control and the Cadastral Measurements of a cadastral survey.

Section Two

Field Survey Operations and Procedures

The procedures discussed in the following sections address the basic two-receiver GNSS survey system used by most cadastral surveyors. While the procedures reference data processing tools like least squares adjustments and results like network and local accuracies, the agencies developed the procedures outlined below to ensure that compliance with them would meet the required positional accuracies. This is so that the surveyor can focus on their primary job and not spend inordinate time on data analysis.

Practitioners should perform field survey operations using the BLM specifications outlined below or the manufacturer's recommended receiver settings and observation times unless otherwise noted below or modified on an individual basis (document rationale). Operations under adverse conditions, such as under a forest canopy, may require longer observation times than specified by the manufacturer.

Surveyors should use fixed height or adjustable height antenna tripods/bipods for rover GNSS observations. Surveyors should check the elevation of an adjustable height antenna tripod/bipod on a regular basis to make sure they have not slipped.

Surveyors should check all plumbing/centering equipment periodically for proper adjustment.

We recommend that surveyors make all observation utilizing all of the available GNSS constellations supported by their equipment.

Cadastral Project Control

Cadastral Project Control is a network or a set of GNSS based control points, tied to the NSRS, established to control all subsequent GNSS Cadastral Measurements.

Cadastral Project Control can be established by using an accepted Precise Point Positioning (PPP) tool like the NGS OPUS (Online Positioning User Service) or one of its variants to locate a series of control points, surveying a classical network of control stations, or utilizing a Real Time Network broadcasting correctors over the internet or other transmission.

The number of control points needed on a project will depend on a number of factors like the size of the project, access, topography, measurement procedures, or other logistical concerns. The surveyor should establish at least two control points for projects more than 6 sections in size. On small projects of 6 sections or less it is acceptable to use a single control point.

Cadastral Project Control is designed to meet the following purposes:

- Provides a framework to reference the survey to a datum, a mapping projection, and the NSRS.
- Supports registration of the Cadastral Measurements into the Geographic Coordinate Data Base (GCDB).
- Serves as the basis for all subsequent GNSS Cadastral Measurements. These stations are the "glue" that holds the survey together.
- Allows for reporting of the Network Accuracy for the Cadastral Measurements per FGDC Geospatial Positioning Accuracy Standards.

Using the NGS OPUS or OPUS – Rapid Static Online Positioning Tools to establish Cadastral Project Control Points

The NGS OPUS suite of online processing tools has become a main method for establishing Cadastral Project Control. These tools allow the surveyor to establish control points where and when needed on a project. OPUS-derived project control coordinates, if properly observed, can be equivalent to the values of a properly observed, processed, and adjusted control network. OPUS use eliminates the need to survey and process control networks at the start of a project. However, establishing control only as needed can increase the possibility of introducing errors into the survey if data is not handled properly. A discussion of the pros and cons of this method is included below.

OPUS and OPUS – Rapid Static are online tools created and maintained by the National Geodetic Survey (NGS) that allow users to submit dual frequency GNSS data collected on a point to a NGS website that then processes and returns the computed point position coordinates and associated quality control values to the user. The processing software packages used in the OPUS tools are the same ones that the NGS uses when it processes its own surveys. Use of this tool saves the surveyor from having to do their own baseline processing and adjustment of data and simplifies the workflow.

Use of the OPUS tools allows the surveyor to establish control when and where needed during a project. This can eliminate or reduce the time to scout a project, monument control points, plan, observe, and process a control network prior to starting the survey. It can also simplify the logistics of the survey by reducing the need for extra GNSS receivers and personnel to observe the network.

A drawback to the use of OPUS is that the resulting control coordinate is a point position. There are no multiple observations, redundant occupation of the point and adjacent points, or other checks built into a network. Since the OPUS suite processes the data against the CORS network, the surveyor is also reliant on data being available from these stations. In addition, other errors can be introduced through the incorrect transformation of the collected data to the RINEX format, observation times that are too short, incorrect antenna identification, and other sources that might be identified in the survey of a network.

When establishing control, the OPUS user must also keep track of the correct computed control coordinates and not mix control coordinates determined from autonomous keyed-in coordinates or use coordinates in the wrong datum or epoch. The surveyor needs to have good work-flow and procedures to eliminate this problem.

Best practices for using OPUS

For control purposes the surveyor should use a minimum 3-hour observation for files to be submitted to OPUS and a minimum 30-minute observation for OPUS – Rapid Static observations. These longer observation periods, which differ from the NGS recommendations, ensure achievement of the best possible accuracy for the control points.

The surveyor should collect and submit a second file to OPUS to check that control point coordinate is not in error.

As control points are established, it is a good practice to do RTK or rapid static observations between the new control point and existing control points to check for errors.

If possible, the surveyor should establish all control points before making cadastral corner measurements.

Establishing a Cadastral Project Control Network.

A well-designed Cadastral Project Control network offers the surveyor more flexibility for using fast static or RTK survey methods for the Cadastral Measurement portion of a survey. It provides an adequate amount of reference (base) station locations, ties the Cadastral Measurement points together, allows for expanding area of the survey and provides accurate checks throughout survey project.

Cadastral Project Control networks should be referenced (tied) to at least two Continuous Operating Reference Station (CORS). It would also be acceptable to use High Accuracy Reference Network (HARN) stations/High Precision Geodetic Network (HPGN) of the NSRS if they already have established coordinates in the most current realization of NAD 83. Surveyors should not use NSRS points that do not have coordinates in the current NSRS realization as the basis of control as they could introduce large distortions and errors into the network. It is a good practice to update the coordinates of points like this by including them in the project control network or using a tool like OPUS-Share.

The current national reference datum is the North American Datum of 1983 (NAD 83) (2011) (epoch 2010). Surveyors should reference all control and project information to this datum or its successors. If the surveyor needs to report elevations for the work, the correct reference is to the North American Vertical Datum of 1983 (NAVD 83).

All Cadastral Project Control networks should conform to the following:

- Be referenced to two or more NSRS or other published horizontal control stations, located in two or more quadrants, relative to the cadastral project area.
- Points are established by at least two independent baselines (see Appendix A).
- Contain loops of a minimum of three baselines.
- Baselines should be processed using an IGS or NGS derived Ultra-rapid, Rapid, or Precise ephemeris instead of the broadcast ephemeris downloaded from the receiver.
- Baselines have a fixed integer double difference solution or adhere to the manufacturer's specifications for baseline lengths exceeding the fixed solution criteria.
- All stations in the cadastral project control network should have at least two independent occupations (see Appendix A).
- The Cadastral Project Control network must be a geometrically closed figure. Single radial (spur) lines or side shots to a point are not acceptable.

Real Time Networks

Government-run or commercial Real Time Networks are becoming a more readily available option in some states and areas. These networks are built around CORS or CORS equivalent GNSS stations that use the internet to distribute the correctors. These networks expand the effective broadcast and increase the range to a 20 to 30-mile area as compared to the 3 to 10 mile range of a RTK UHF radio based system. The surveyor can use these networks instead of establishing their own control, improving efficiency.

However, there are several limits to using these systems that the surveyor must take into account when deciding whether to use the networks. First, the surveyor must ensure the correct reference datum for the stations and correctors. For instance, is the station set up relative to NAD 83 and if so, what realization is being used? The surveyor might need to have an independent NSRS point or an OPUS-based or other control point to check against to be certain. Second, successful use of a real time network requires adequate network coverage in the project area. Third, successful use of these network systems via the internet requires reliable cellular coverage in the area, as well as appropriate smart phone technology. Finally, subscriptions to a network can cost several hundred to several thousand dollars per year per receiver.

A variation on the real time network is a satellite based corrector network of the type operated by companies like Trimble, John Deere, or Fugro to name a few examples. These networks broadcast the correctors via a satellite frequency like the L1 GNSS frequency that require a receiver to have the appropriate firmware and a subscription. These networks eliminate the need for a cellular connection. The accuracy of these systems can be on the same order as RTK systems. Drawbacks are that annual subscriptions can be several thousand dollars per receiver and initializations can take 15 to 30 minutes, and must be regained if the satellite signal is lost. This can cause problems in areas of rugged topography, other obstructions, or canopy.

Cadastral Measurements

Cadastral Measurements are the measurements used to define the location of PLSS corners and boundaries. Cadastral Measurements are referenced to the Cadastral Project Control coordinates or by direct ties to the NSRS.

All Cadastral Measurement observations should conform to the following:

- Each shot should have a minimum of two observations made to it. These observations could be from the same control point or different control points
- If static or rapid static observations are used then baselines have a fixed integer double difference solution.
- While there is not a redundant observation requirement from a different control point or the same control point but separated in time by several hours, it is a good practice to re-observe a point at a different time or from a different control station if possible as a check.
- Single radial (spur) lines or side shots to a point are not acceptable.

Real-Time Kinematic (RTK) Survey Methods

When using RTK survey methods as the sole measurement method for Cadastral Measurement the Cadastral Project Control and the Cadastral Measurements are separate.

RTK uses a radial style survey scheme with one or more reference (base) receivers and one or more rover receivers for Cadastral Measurements.

The radial nature of RTK requires the surveyor to make additional redundant measurements as part of the field survey operations and procedures as discussed in these Guidelines.

There are three parts of an RTK survey, including:

- System check
- Corner measurements
- Corner moves (stake-out)

<u>RTK System Check</u>

The surveyor should conduct a RTK system check at the start of each day's observations and should repeat these checks throughout the day, as appropriate. This check is a measurement from the RTK base setup to another Cadastral Project Control station or a previously observed Cadastral Measurement point.

When observing these measurements, the rover will be set to the manufacturer's specifications for duplicate point tolerance (see Appendix A) or less for the measurement of a known point and existing point name. The surveyor then compares the resulting observed position by inverse to the previously observed position for the known point. The inverse should be within the manufacturer's recommended values for duplicate point tolerance measurements.

This RTK system check is designed to check the following:

- The correct reference base station is occupied and being used at the rover.
- The GNSS antenna height is correctly measured and entered at the base and rover.
- The receiver antennas are plumb over station at base and rover.
- The base coordinates are in the correct datum and plane projections are correct.
- The reference base stations or the remote stations have not been disturbed.
- The radio-communication link is working.
- The RTK system is initialized correctly.
- RMS values are within manufacturer's limits.

The checks on the RMS and initializations are valid only at the time of observation. The most important check is at the start of the day in order to verify the base receiver information and check that the data broadcast link is operational.

<u>RTK Corner Measurements</u>

The surveyor will usually make corner measurements with RTK using one or more base and one or more rover receiver configurations.

The surveyor must make any RTK corner measurements only after completing the system setup check.

The surveyor should follow the manufacturers' recommendations for specified observation times for the highest level of accuracy using RTK for corner measurements. For example, 180 seconds of time or when the horizontal (0.025m) and vertical (0.050m) precision has been reached.

Under optimal conditions (clear sky, low RMS), the corner observation should be at least 30 seconds of time and 25 epochs of measurement data for a basic topo point. If the surveyor is making a corner as a control point then the surveyor should use at least a 180-second observation. These are minimum periods; observations can be longer. The surveyor should set observation times to account for field conditions, measurement methods and the type of measurement checks being performed.

Methods for RTK corner measurement:

The basic procedure is to collect a minimum of two baseline measurements at a found corner location or temporary point (unknown position). The two baselines measurements (M1 and M2) are stored to the data collector using a different point identifier for each measurement. (An example would be for M1 use 10077M1 and for M2 use 100700M2. The surveyor should invert the antenna to force a loss of satellite lock, if possible, between the measurements and force the system to reinitialize.

The surveyor may conduct a field check of the level of accuracy between the measurements by an inverse between M1 and M2. The resulting horizontal inverse distance should be less than 2.5 cm (0.083 sft). Staying below this limit should ensure that the surveyor could meet the accuracy standards.

The timing of a check shot can be variable. The surveyor may immediately invert the antenna, lose lock, then reinitialize and collect a new observation. In the alternative, the surveyor may wait from several minutes to several hours before taking the check observation. Experience and testing shows that either approach can achieve the same results. The surveyor may increase observation time if they collect a separate fast static data file and post-process the field data as a check.

Another method is to observe the unknown point two or more times with the same point name (e.g., 100700) and use a duplicate point tolerance measurement criteria of 2.5 cm. When observing these measurements, the surveyor must invert the antenna and allow the receiver to reinitialize between observations. The surveyor can then process this observation scheme using Least Squares Adjustment software to determine the point accuracies.

The above discussion assumes that the M1 and M2 measurements are relative to the same control point. If the surveyor conducts the check shots from different control points, then they might need to use the ***Cadastral Measurement Tolerance*** of 8.6 cm (0.28 sft) to determine whether the shots check.

Note: The ***Cadastral Measurement Tolerance*** of 8.6 cm (0.28 sft) is the maximum acceptable distance for M1 – M2 inverse when the surveyor makes measurements from different control points. The surveyor should only accept this tolerance when the control coordinates have large errors dependent on the Cadastral accuracy specifications, or under extremely poor GNSS conditions due to tree cover, multi-path, etc. The surveyor would only encounter this worst-case condition in the most marginal field conditions for RTK surveys. The Cadastral Measurement Tolerance value of 8.6 cm is derived from standard error propagation relationships that account for the errors in control point locations and measurements.

The following are examples of other observation schemes and checks:

- Using RTK, make a new measurement (M3) to the unknown point (e.g., 100700) from the same base receiver setup separated in time by a minimum of 15 minutes.
- Perform a check measurement (M3) from another Cadastral Control Project Station taken simultaneously with the M1 and M2 measurements or at least 15 minutes after the M1/M2 measurements.
- Using RTK, Fast Static, or static, make a new measurement (M3) to the unknown point (e.g., 100700) with the base receiver setup on another Cadastral Project Control station operating simultaneously.
- Position the leveling bubble for the M2 shot 180^{o} from the M1 shot to cancel the leveling error

- Change the antenna height for the M2 observation relative to the M1 observation to create a different set of observation conditions.

Static / Fast Static Survey Methods

Surveyors typically use static or fast static observations for corner measurements in the event that the RTK broadcast link is unavailable for some reason, and should follow the same basic procedure of doing a shot and a check shot. Manufacturer-suggested guidelines for observation periods can be used to determine the length of time a point should be occupied. The surveyor then downloads the data to the office software, and computes and adjusts the baselines as necessary. In open conditions, the surveyor should use a 10 to 20-minute observation.

The surveyor can also use these methods when working in forested conditions, with the at least a one-hour observation. However, even longer observations might be needed to get enough usable data to process a baseline.

RTK Corner Moves (stakeout)

RTK technology allows the surveyor to make a corner move or stakeout from a known position to an unknown (calculated) position relative to the controlling corners for a PLSS survey or resurvey.

Prior to making a corner move, the surveyor may conduct a system check at any time during the survey to detect for blunders and the initialization quality of the survey prior to making any RTK observation for Cadastral Measurements.

Note: The survey should exercise caution when using grid coordinates for stakeout. It is important that the surveyor account for the appropriate corrections for convergence, elevation and distance relative to the rules of the PLSS.

The surveyor should use the following procedures to make a corner move using RTK:

1) Take a measurement (e.g., 140700M1), inverse between M1 and compare to the calculated position (e.g., 140700CP), and move the remaining distance and direction to the true (calculated) location as necessary. Repeat as required until satisfied you are at the position then store M1 and overwrite previously stored point.
2) Force loss of satellite lock and initialization by inverting the rover antenna. Reinitialize and take another measurement (e.g., 140700M2) and store.
3) Inverse between the measured one (140700M1) and the measured (140700M2). If the measured positions (M1 and M2) are within the duplicate point tolerance of the calculated position, the initializations and measurements are correct. Note, these M1 and M2 measurements are of a shorter duration (30 seconds).
4) Set the monument at the true corner location. You should take a final measurement at this time. You will use this measurement for a number of checks. Taking this measurement will also ensure that the corner position will move if control coordinates are reseeded.
5) As a check, inverse from the stored position (e.g., 140700) to the calculated corner position to determine the set true corner location, next inverse to the controlling corners and check the bearing and distance to ensure you have followed the correct procedures. The

established corner location should be within the defined local spatial accuracy standards required of the survey.

Section Three

Data Processing and Data Analysis

All data processing (baseline solutions) and data analysis (least squares or weighted mean average) shall follow the manufacturer's recommended procedures.

A double difference fixed integer solution is required for all cadastral measurements regardless of the positioning technique used.

If a Project Control network is observed it shall be processed to derive the baseline solutions and be adjusted by least squares independently of the observed Cadastral Measurements.

When integrating GNSS observations with conventional terrestrial survey procedures, the surveyor must verify the following:

- The State Plane or local plane horizontal scale factors, angular rotation factors, zone and units of measure are applied correctly.
- The combined scale factors for elevation, to determine ground distance at project elevation or an average project elevation are applied correctly.
- The appropriate datum has been used.
- A check to insure no hidden transformation or double transformations of the data has occurred.
- If using GNSS with terrestrial data, then a check (e.g., measure the distance between two known points with an EDM) should be done to ensure the computation of the combined scale factors are correct and, therefore, that the ***ground distance*** (see Appendix A) is appropriate.
- A check to ensure the computation and reporting of basis of bearing are appropriate.

Section Four

Project Documentation

All GNSS measurement projects which establish geodetic Project Cadastral Control or Cadastral Measurements for survey and resurvey of Public Lands must be conducted under responsible charge of a federally authorized Surveyor or a Professional Land Surveyor licensed to practice Land Surveying in the applicable state.

Typically, the surveyor responsible for the project prepares the surveyor's narrative report and submits it to the Group (Project) File as documentation of the successful completion of the land survey or cadastral survey project.

The surveyor's project report should include the following:

- Make and Model of the GNSS receiver, Antenna, and related equipment.
- A processing generated report regarding the baseline processing results and the software and version number used, if completed.
- If appropriate, network adjustment results including a summary of covariances, standard deviation or RMS values and the software and version number used. The NGS OPUS reports should be included if it was used in place of a network.
- A diagram showing the location of control points within the project.
- A list of final coordinates for control points or observed corner locations including project metadata such as datum, geoid model, epoch, and measurement units used. These coordinates should all be referenced to the most current realization of the NSRS.
- Document any variations from these guidelines.

Reporting bearings and Distances:

The surveyor shall express a Basis of Bearing for a Government Cadastral Survey, when using GNSS technology as "Geodetic Bearing or Azimuth." This bearing or azimuth shall be determined at the midpoint of the observed line as the "mean" between the Normal Section Forward Azimuth (NSFA) and the Normal Section Back Azimuth (NSBA) between points.

All ground distances shall be determined at ground elevation, except where the requirements are for sea level, using the appropriate geoid model to determine the geoid separation. For a cadastral survey, the height above the geoid and the orthometric height shall be considered the same.

Appendix A

DEFINITIONS

Cadastral Project Control is the network of the GNSS baselines tied to the NSRS, which is surveyed to control all subsequent GNSS Cadastral Measurements. The Project Control is adjusted independently of other cadastral measurements.

Cadastral Measurement Tolerance is the maximum acceptable distance for inverse between two measurements to the same point. This value is 8.6 cm. When measurements are made within this tolerance in an RTK survey the two observations may be recorded as the same point number. These redundant measurements can then be included in a least squares or multi-baseline analysis. The surveyor should only encounter this worst-case condition in the most marginal field conditions for RTK surveys. The surveyor's narrative report should note these points.

The Cadastral Measurement Tolerance value of 8.6 cm is derived from standard error propagation relationships that account for the errors in control point locations and measurements.

Cadastral Measurements are the measurements used to define the location of *Public Land Survey System (PLSS)* corners and boundaries. Cadastral Measurements are based on the Cadastral Project Control coordinates or direct ties to the NSRS.

Duplicate Point Tolerance is the maximum distance in an RTK system setup check by which two observations of the same point can differ. It also the maximum distance in an RTK survey by which two observations of the same point can differ and still be recorded as the same point for least squares or multi-baseline analysis. The duplicate point tolerance for these guidelines is 2.5 cm.

The **Geographic Coordinate Data Base (GCDB)** is a database containing geographic coordinates, and their associated attributes, for all corners of the Public Land Survey System.

Ground distance is the horizontal distance measured at the mean elevation between two points.

Independent Baselines (Non-Trivial): For each observing session there are n-1 independent baselines where n is the number of receivers collecting data simultaneously during a session.

Independent Occupations: Two or more independent occupations for the stations of a network are specified to help detect instrument and operator errors. Operator errors include those caused by antenna centering and height offset blunders. When a station is occupied during two or more sessions, back-to-back, the antenna pole or tripod will be reset and plumbed between sessions to meet the criteria for an independent occupation.

Local Accuracy, as defined in Part 2, Standards for Geodetic Networks, FGDC Geospatial Positioning Accuracy Standards, is an average measure (e.g. mean, median, etc.) of the relative accuracies of the coordinates for a point with respect to other adjacent points at the 95% confidence level. For horizontal coordinate accuracy, the local accuracy is computed using an average of the radii of the 95% relative confidence circles between the point in question and other adjacent points. This indicates how accurately a point is positioned with respect to other adjacent points in the local network. Based upon computed relative accuracies, local accuracy provides practical information for users conducting local surveys between control monuments of known position. Local accuracy is dependent upon the positioning method used to establish a point. If very precise instruments and techniques are used, the relative and local accuracies related to the point will be very good.

The reported Local Accuracy for cadastral survey purposes will be computed from the error ellipses generated by a least squares or other multiple baseline statistical analysis, which is fully constrained to the Cadastral Project Control.

National Spatial Reference System (NSRS) is defined and managed by the National Geodetic Survey (NGS). It is a consistent national coordinate system that specifies latitude, longitude, height, scale, gravity, and orientation throughout the Nation, as well as how these values change with time. NSRS consists of the following components:

- The National CORS, a set of Global Positioning System Continuously Operating Reference Stations meeting NOAA geodetic standards for installation, operation, and data distribution.
- A network of permanently marked points including the Federal Base Network (FBN), the Cooperative Base Network (CBN), and the User Densification Network (UDN).
- A set of accurate models describing dynamic geophysical processes affecting spatial measurements.
- High Accuracy Reference Network or High Precision Geodetic Network stations established by GNSS observations.
- Vertical control marks, which define elevation and are referenced to NGVD 29 or NAVD 88.
- All other horizontal and vertical marks established to define the NSRS.

NSRS provides a highly accurate, precise, and consistent geographic reference framework throughout the United States. Stations or marks established by GNSS or High order levels should be used with GNSS survey projects.

Network Accuracy is the absolute accuracy of the coordinates for a point at the 95% confidence level, with respect to the defined reference system. A surveyor can compute network accuracy for any positioning project that is connected to the National Spatial Reference System (NSRS).

The network accuracy of a control point is a number, expressed in centimeters, that represents the uncertainty in the coordinates, at the 95% confidence level, of this control point with respects to the geodetic datum. For NSRS network accuracy classification, the datum is expressed by the geodetic Values at the Continuously Operated Reference Site (CORS) supported by National Geodetic Survey (NGS). By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero.

References

"Analysis of Real-Time Kinematic and Fast Static/Kinematic Least Squares Derived Coordinates Using a Wisconsin County UDN"; Paul Hartzheim and Darin Henkel, Wisconsin Department of Transportation, Trimble User Conference Proceedings, 1998.

"Accuracy Standards for Positioning", Version 1.0 (DRAFT) July 1996, Natural Resources Canada-Geodetic Survey Division.

"Standards and Guidelines for Cadastral Surveys Using Global Positioning Methods", BLM I.M 2001-186, 2001

"Geometric Geodetic Accuracy Standards and Specifications for Using GNSS Positioning Techniques", Version 5.0, May 11, 1988, reprinted with minor corrections August 1, 1989, Federal Geodetic Control Committee.

"Geospatial Positioning Accuracy Standards", FGDC-STD-007-1998, Federal Geographic Data Committee.

"Standards for the Positional Accuracy of cadastral Surveys When Using Global Navigation Satellite Systems (GNSS)", BLM I.M. 2010-094, 2010

"Utilizing Real-Time Kinematic GNSS for Control Surveys", Ronald Berg, Ministry of Transportation, Ontario, Trimble User Conference Proceedings, 1998.