Geographic Information Coordinating Council
Statewide Mapping Advisory Committee

Statewide
Global Navigation Satellite System (GNSS)
Data Collection and Documentation Standards

Version 4
March 2014

[*]Formerly known as the "Statewide Global Positioning System (GPS) Data Collection and Documentation Standards"

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1. Executive summary

Due to the increasing use of [1]Global Navigation Satellite System (GNSS) receivers (which are now available in a multitude of models having varying levels of accuracy, error correcting ability, and data quality documenting potential) by North Carolina state government agencies to produce maps or Geographic Information System (GIS) data sets, the Geographic Information Coordinating Council (GICC) Statewide Mapping Advisory Committee (SMAC) has updated the *"Statewide Global Positioning System (GPS) Data Collection and Documentation Standards"* document to the more inclusive, more technically up to date *"Global Navigation Satellite System Data Collection and Documentation Standards"* document.

GNSS is a generic name for satellite navigation systems that provide autonomous positioning worldwide. GNSS includes:

- **Global systems**

System	Country	URL
Navigation Signal Timing and Ranging Global Positioning System (NAVSTAR GPS)	U.S.A.	http://www.gps.gov/systems/gps/
GLObal NAvigation Satellite System (GLONASS)	Russia	http://www.glonass-center.ru/en/GPS/
Galileo	European Union	http://www.esa.int/Our_Activities/ Navigation/The_future_-_Galileo/What_is_Galileo
Bediou or Compass	China	http://en.beidou.gov.cn/

- **Regional systems**

System	Country	URL
Indian Regional Navigation Satellite System (IRNSS)	India	http://www.isro.org/satellites/irnss.aspx
Quasi-Zenith Satellite System(QZSS) or Michibiki	Japan	http://www.qzs.jp/en/

At the present time (March 2014), GPS and GLONASS are the only satellite-based positioning and navigation systems that are fully operational.

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[1] A GNSS receiver is a receiver that has been manufactured to receive signals from at least GPS and GLONASS satellites and may or may not have been manufactured to receive signals from WAAS, Galileo, Bediou or Compass, IRNSS, and/or QZSS satellites. Thus, these standards will refer to satellite-based positioning, navigation, and timing receivers as GNSS receivers.

Each state agency that collects locational data must understand that there may be other users of the data (in the present and/or in the future) with even more stringent accuracy requirements than their requirements. Therefore, each state government agency that collects locational data shall:

- Ensure that their locational data collecting personnel have a strong foundation in GNSS theory and have been trained in the proper use of GNSS equipment.

- Use either mapping-grade or survey-grade receivers in GNSS data collection efforts where horizontal accuracy ranging from five (5) meters to sub-centimeter is required or the data are being collected for authoritative purposes.

- For inventory (non-authoritative) type applications, a procedure described in Section 6 can be used to collect non-authoritative information with a non-professional grade receiver in lieu of using a mapping or survey-grade receiver. Such receivers can only be used when the procedure in Section 6 is strictly followed to ensure that the state standard for horizontal accuracy has been met. Non-professional grade receivers are <u>not</u> adequate for <u>any</u> state locational data collection for authoritative purposes. A non-professional grade receiver should not be used to collect vertical information that is used for any state authoritative application.

- Test their GNSS receivers for accuracy daily if geodetic horizontal control monuments are located at the place of work or near the project site. Testing should occur at a minimum immediately prior to and immediately following the conclusion of a project, and at a minimum monthly.

- Differentially correct GNSS data (Figure 1) using post-processing software or via a real time correction service.

- Archive the digital products representing all stages of the GNSS data collection and processing chain (e.g., uncorrected field files, base station files used for differential corrections, electronic data entry forms, corrected GNSS files, and final GIS datasets).

- Document all GNSS-derived GIS data products with appropriate forms of metadata.

These minimum GNSS data collection and data documentation standards will have five (5) important effects:

- Agencies that collect GNSS data will know exactly what is required
- Each agency's GNSS data will contain metadata
- Agencies that use state GNSS data will have confidence in the data's quality
- The state will save money by eliminating the need to re-collect locational data
- The use of GNSS will become more prevalent in state government

When you collect and process GNSS data according to these standards (i.e. collect with a mapping-grade or survey-grade GNSS receiver and differentially correct your GNSS data), it allows your spatial data to be used by others with confidence, which saves time and money, and contributes to the common good.

X_{23} Y_{23} Z_{23}

X_{19} Y_{19} Z_{19}

X_{14} Y_{14} Z_{14}

X_{21} Y_{21} Z_{21}

d_{23} d_{19} d_{14} d_{21}

Rover unit at an unknown location

The rover unit's true position is unknown, because the positional error is unknown.

Base station at a known location (True: X Y Z)

The positional error (Correction: X Y Z) can be determined at a base station, because it has a surveyed reference position (True: X Y Z).

$$\frac{\text{True}_{Base}: X\ Y\ Z}{-\text{Measured}_{Base}: X\ Y\ Z}$$
$$\text{Correction}_{Base}: X\ Y\ Z$$

Measured$_{Rover}$**: X Y Z**

Original application

Other application

Other application

Your differentially corrected GNSS data

Other application

Other application

Differential correction in real-time or post-processing uses the base station's corrections to remove the positional error, which increases the accuracy and precision of the GNSS data.

$$\frac{\text{Measured}_{Rover}: X\ Y\ Z}{-\text{Correction}_{Base}: X\ Y\ Z}$$
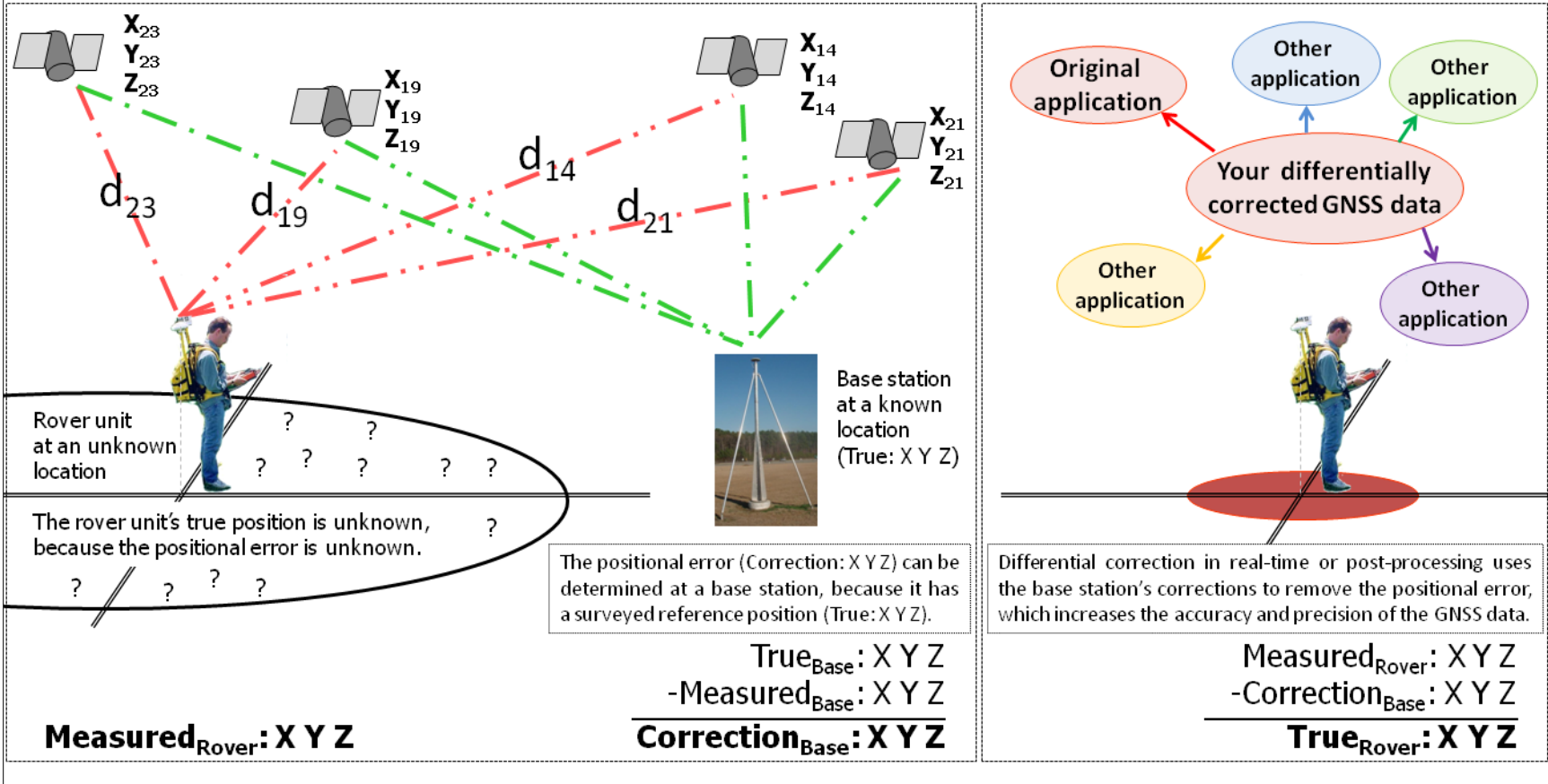$$\text{True}_{Rover}: X\ Y\ Z$$

Figure 1. A graphical explanation of the importance of collecting and processing GNSS data according to these data collection and documentation standards.

2. Position statement

This document is an update to the minimum standards that were adopted in 1994, and revised in 1999 and 2006, to be used by all state agencies and their contractors using GNSS technology to generate locational data. The demand for more accurate and precise locational data within North Carolina state government will only increase with the continued automation of locational data sets. GNSS will be the principal tool for collecting locational data used in systems, such as a computer models or a GIS, for which horizontal geographic accuracy is critical. GNSS is an important and cost-effective method for locating features too numerous or too dynamic to be mapped by traditional methods. Therefore, GNSS mapping is being recommended by many state and federal agencies as the locational data collection method of choice.

There are three segments to GNSS:
- **Space segment:**   The constellation of navigation satellites
- **Control segment:**   The worldwide network of satellite tracking stations
- **User segment:**   The people who use a GNSS receiver to collect locational data, navigate, and/or collect time information (note: satellite navigation systems are based on very accurate atomic clocks).

GNSS receivers or units fall into two categories: Non-professional and Professional. For the purpose of these standards, the professional receivers discussed are used to produce mapping and survey products. This document does not address standards for survey-grade, but is focused on the use of professional mapping-grade receivers and non-professional grade receivers for non-authoritative applications. The choice of a GNSS receiver depends upon the intended use and the accuracy requirement of the GNSS locational data.
- Non-professional (previously referred to as "recreational-grade") GNSS receivers are sold primarily for outdoor sports or recreational activities and have horizontal accuracy requirements that do not meet the state standard for GIS data. Non-professional receivers operate in autonomous point positioning mode without the GNSS-derived positions being differentially corrected in either real-time or post-processing. These GNSS receivers are the least accurate of all the grades.
- "Enhanced" recreational-grade GNSS receivers that have been equipped to operate in a differential GNSS (DGPS) mode could meet state standards if their output files documented which points were differentially corrected and the age of the real-time data on each differentially corrected point.
- Mapping-grade GNSS receivers have the capacity for higher accuracy (sub–foot to five-meter horizontal accuracy) and are designed to facilitate data collection for a GIS program. Mapping-grade GNSS units use differential correction for high accuracy.
- Survey-grade GNSS receivers also use differential correction for the highest accuracy and are used for surveying tasks that require very high accuracy (within 1 cm).

This document does not address standards for survey-grade GNSS activities. Agencies involved in locational data collection must decide whether or not their projects require survey-grade accuracy (**+/-** 1-2 cm). Surveying activities are governed by strict standards beyond the scope of this document. This document defines standards for on-ground field collection using GNSS. It does <u>not</u> address aerial GNSS data collection or control. These standards apply to current GNSS technology. Thus, these standards will require periodic review and possible revision as GNSS technologies evolve.

There are five (5) main uses for GNSS today:
- **Navigation**: Getting from one location to another
- **Position**: Determining a basic position using precise locational data
- **Tracking**: Monitoring the movement of people and things
- **Mapping**: Attaching coordinates to features, attributes, and metadata
- **Timing**: Providing precise timing

GNSS techniques are one of the primary tools for locating features on or above the earth's surface. In North Carolina, government agencies, academic institutions, and private companies are using GNSS to determine the location of a multitude of features, including:
- **Points:** Features such as pollutant discharges and water supply wells
- **Lines:** Features such as roads and streams
- **Areas:** Features such as waste lagoons

Before GNSS, such features had to be located with surveying equipment, aerial photographs, or satellite imagery. Now with GNSS, these features can be located by a single operator using hand-held equipment. However, the accuracy of data collected using GNSS technology is highly variable depending on field methods, type of equipment, and post-processing of the data.

When collecting location information for producing maps or GIS data sets, all state government agencies must:

- **Use professional-grade GNSS receivers**
- **Differentially correct the GNSS derived locational data**
- **Use the procedure outlined in Section 6 if a non-professional grade GNSS unit is used for data collection**

Professional and non-professional GNSS units are designed and built for different purposes. Professional units have been engineered and built to provide accurate location coordinates and efficient collection of attribute information and metadata.

GIS users typically require horizontal accuracies within 5 meters or better for mapping features so that data layers can be overlaid and spatial relationships determined. It is imperative that all state agencies collect locational data with the knowledge that there may be other users of the data in the future. Potential users, unknown to the original data collectors, may have accuracy requirements exceeding those of the collecting agency.

Typically, GNSS does not capture vertical positions as accurately as horizontal positions. The vertical accuracy from a GNSS observation is 2-3 times worse than the horizontal accuracy. Mapping units should not be used to obtain elevation values for applications that require accurate elevations of less than three (3) meters.

These minimum GNSS data collection and data documentation standards will have four important effects:

1. Agencies collecting GNSS data will know exactly what is expected from their time and effort spent to collect and document the data with Federal Geographic Data Committee (FGDC) compliant metadata.
2. Local, state, and federal agencies using state-collected GNSS data can do so with confidence in its quality, because the data will be collected, corrected, and documented according to standardized procedures.
3. The state will save money by maximizing original locational data collection accuracy and documentation, which will eliminate the need for additional trips to previously located sites.
4. The use of GNSS for collecting locational data will become more prevalent in state government because GNSS technology, training, and data documentation will be more consistent and more readily accessible.

The GICC supports the development and adoption of standards for the successful collection, exchange, and use of locational data. GNSS data collection standards are necessary so that state agencies and their contractors have minimum specifications for collecting GNSS data. Contractors should be in compliance with North Carolina General Statute Chapter 89C (Engineering and Land Surveying) (http://www.ncleg.net/EnactedLegislation/Statutes/HTML/ByChapter/Chapter_89C.html), when applicable, with respect to the collection of GNSS data.

GNSS data documentation in the form of metadata is required in order to provide spatial data users with specific information about the lineage of a spatial data set (e.g. source, quality, and content). Adequate metadata is required for the appropriate, responsible, and defensible use of any spatial data set. Consequently, the GICC has adopted the FGDC *"Content Standards for Digital Geospatial Metadata"* (CSDGM) (http://www.fgdc.gov/metadata/csdgm).

3. Global Navigation Satellite System

Global Navigation Satellite System (GNSS) is a generic name for satellite navigation systems that provide autonomous positioning worldwide. GNSS includes:

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Galileo	European Union	http://www.esa.int/Our_Activities/ Navigation/The_future_- _Galileo/What_is_Galileo
Bediou or Compass	China	http://en.beidou.gov.cn/

- **Regional systems**

System	Country	URL
Indian Regional Navigation Satellite System (IRNSS)	India	http://www.isro.org/satellites/irnss.aspx
Quasi-Zenith Satellite System(QZSS) or Michibiki	Japan	http://www.qzs.jp/en/

At the present time (March 2014), GPS and GLONASS are the only satellite-based positioning and navigation systems that are fully operational.

Background on GPS

GPS, which is a satellite-based positioning, navigation, and timing system, is a $12 billion project that was initiated by the U.S. Department of Defense (DoD) in the 1970s for military purposes. Although DoD still manages the system, the use of GPS has spread to a wide range of civilian and commercial applications. For more information, please peruse the following resources on the Internet:

- GPS information resources: www.gps.gov
- GPS Information: http://www.gps.gov/systems/gps/
- How GPS Works: http://www.gps.gov/multimedia/poster/
- GPS Accuracy: http://www.gps.gov/systems/gps/performance/accuracy/

The GPS system consists of the following three segments:

- **Space:** The constellation of 32 (as of December 19, 2013) NAVSTAR satellites that orbit the earth twice a day at an altitude of approximately 20,200 km (12,500 miles).

    Note: Although the original design had 24 satellites, there may be more than 24 satellites in orbit at a given time due to the longer than expected lifespan of some of the earlier satellites. At the time of this writing, 32 satellites were in orbit.

- **Control:** The DoD operated ground stations, data links, and command and control facilities.

- **Users:** GNSS users throughout the world on land, sea, and in the air.

The GPS satellites broadcast high-frequency radio signals, which contain satellite position and precise time data, twenty-four hours a day to enable anyone with a GNSS receiver to determine his/her 3-D position, velocity, and time. Each GPS satellite broadcasts two signals:

- L1 signal (1575.42 MHz) for Standard Positioning Service (SPS) users (i.e. civilians)
- L2 signal (1227.60 MHz) for Precise Positioning Service (PPS) users (i.e. the military)

The DoD has continually modernized the system with more advanced satellites as older satellites become non-functional. Newer generation satellites are providing a third frequency (L5), a civilian code on L2 (L2C), and a military code on all signals. Additional information on GPS modernization can be found at the following URL:

    http://www.gps.gov/systems/gps/modernization/

The basis of GPS technology is precise information about time and position. To determine a horizontal or vertical location on earth, signals from at least four (4) satellites are required. Accurate and precise time is obtained through the use of atomic clocks, which are accurate to within one (1) second every 70,000 years. GNSS receivers calculate the distance to each satellite by measuring the time interval between the transmission and the reception of a satellite signal. Once the distance measurements of at least four (4) satellites are known, the GNSS receiver uses the process of trilateration to determine its position.

GPS can be used worldwide, 24 hours a day, and in all types of weather. While positional accuracy is very high, it does vary depending on the receiver, field techniques used, post-processing of data, and the following inherent errors:

| Error	Description
Atmospheric	Interference with the GPS radio signals as they pass through the charged particles in the ionosphere and the water vapor in the troposphere.
Ephemeris or satellite position	Inconsistencies or uncertainties about a satellite's exact position in orbit.
Timing	Minute discrepancies in a satellite's atomic clock that translate into travel time measurement errors.
Multipath	The GPS signal's non-straight line path as it reflects off objects in the local environment (e.g., trees, fences, and/or buildings) before it reaches a GNSS receiver, which results in derived distant errors.
Positional Dilution of Precision (PDOP) value	The satellite position geometry index for precision (Figure 2): • Low PDOP (favorable configuration) where the GPS satellites are spread out across the sky (left image) • High PDOP (less favorable configuration) where the GPS satellites are bunched together in the sky (right image)
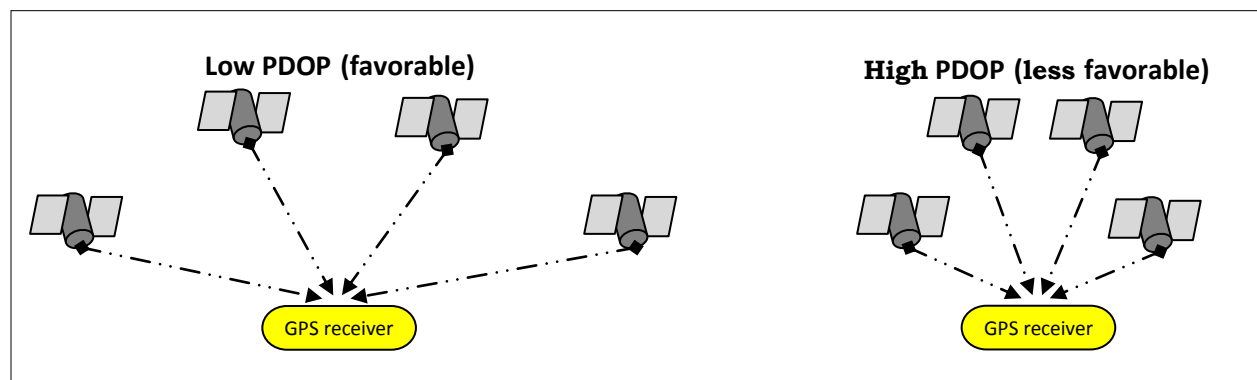
Figure 2. A diagram showing the satellite position geometry index for precision, Positional Dilution of Precision (PDOP):

- Low PDOP (favorable configuration) where the GPS satellites are spread out across the sky (left image)

- High PDOP (less favorable configuration) where the GPS satellites are bunched together in the sky (right image)

Note: Previously, a PDOP value greater than or equal to 6 was considered as a "bad" or "poor" configuration. In the past few years, technological and software improvements have made it possible for certain GNSS receivers to extract useful positional information from a set of GPS satellites with a considerably higher PDOP value, which may or may not involve an extended observation period and/or using carrier signals. Nevertheless, a GNSS user must not exceed the recommended settings for his/her receiver and software.

Each of the preceding inherent errors, except for multipath and high PDOP, can be eliminated or significantly reduced through the use of Differential GPS (DGPS) techniques (Figure 1). DGPS involves the use of a stationary receiver, referred to as a base station or a Continuously Operating Reference Station (CORS) that continuously records satellite measurements at a fixed and known location. Since the base station's position is known, the errors in the signal to each satellite can be determined by measuring the ranges to each satellite and comparing the measured ranges to the calculated ranges from the known position of the base station. The difference between the measured range and the calculated range is the differential correction for each satellite that is in view from the base station's GNSS antenna. This error correction factor information can be either:

- Broadcasted by a radio transmitter or transmitted via the internet for real-time differential correcting by GNSS receivers equipped with a radio link or cell phone data link, respectively.

- Stored on an Internet server for post-processing (i.e. a GNSS user downloads the corresponding base station data after completing the GNSS data collection and does the differential correcting procedure on a computer)

In contrast, the roving receiver collects measurements (ranges) in the field at unknown locations:

- Real-time differential correcting: The roving GNSS receiver applies the broadcast or transmitted differential corrections to its GNSS range observations as they are collected in order to remove errors in the ranges and improve the accuracy.

- Post-processing differential correcting: The GNSS user transfers the stored GNSS range observations from the GNSS receiver to a computer, downloads the corresponding base station data via the Internet, and uses post-processing software to remove errors in the ranges and improve the accuracy

Note: In order for differential correction to work, whether in real-time or post-processing, the roving receiver needs to record its measured positions and the exact time that each measurement was made. This timing information is then used in the differential correction procedure to remove the positional error at each instant.

The North Carolina Geodetic Survey (NCGS) maintains the NC GNSS CORS Network. Due to the fact that NCGS is continually adding new CORS, users are advised to view the current status map on the "CORS and GNSS" web page at the following URL:

    http://geodeticsurvey.nc.gov/Pages/CORS-and-GNSS.aspx

The quality of the GNSS receiver also has a significant impact on positional accuracy. Survey-grade receivers are the most expensive and produce data of the highest precision and accuracy. Mapping-grade receivers are mid-range in price and provide sufficient accuracy for most locational and GIS applications.

Data obtained using non-professional-grade receivers, the least expensive type of receiver, is the least accurate. Some non-professional-grade receivers have add-on modules that can be used for real-time differential correction. Companion data-logging and post-processing software are now available for a very limited number of the most high-end non-professional-grade GNSS receivers. The horizontal accuracy of such "enhanced" non-professional-grade GNSS receivers can in most instances meet the "within 5 meters 95% of the time" state standard.

Note: **The specific type of enhanced non-professional unit shall have been tested and approved by NCGS before it can be used for state GIS data collection.** The cost of the extra data-logging hardware and post-processing software required to bring the accuracy of data collected with a non-professional-grade GNSS unit up to mapping-grade standards begins to approach that of lower-end mapping-grade GNSS units. It is questionable whether this approach to acquiring GNSS equipment is a sound investment.

Without differential correction, the accuracy of any GNSS receiver, regardless of grade, will not meet the accuracy requirements to support the development of locational information for geographic information systems in North Carolina.

Using DGPS can result in much greater accuracy, as shown in Table 1. Vertical error is typically two to three times higher than horizontal error.

Table 1: GNSS receiver types and horizontal accuracies with differential GPS

Type of receiver	Differential GPS capabilities	Real-time differential GPS	Differential GPS with post-processing
Survey	Yes	$\pm$ 1 cm	$\pm$ 1 cm
Mapping	Yes	$\pm$ 1-5 m	$\pm$ 1-5 m
Enhanced non-professional	Note[1]	Note[2]	Some open source options.

Note[1]: Requires external hardware device or built in data collection capacity.

Note[2]: Requires external radio beacon or built-in capability to receive range corrections.

4. Mapping-grade receiver levels

Mapping-grade receiver levels:

- Sub-foot mapping-grade
- Sub-meter (1-3 feet) mapping-grade
- Sub-5 meter (3-15 feet) mapping-grade

Note: Regardless of the mapping-grade receiver's stated level of accuracy, the locational data must be differentially corrected either in real time [e.g. NC Real-Time Network (RTN), Nationwide DGPS (NDGPS), or another real time correction service] or after the data is collected by post-processing.

5. Best practices for GNSS use

The best practices for using GNSS technology include:

- Coordination of purchases with NCGS
- Using the most appropriate grade receiver
- Data collection
- Data processing
- Training
- Operator certification

5.1. Purchasing

State government agencies are encouraged to coordinate their purchases of GNSS technology with NCGS. The NCGS staff are aware of the latest developments in the technology and the relative specifications between product offerings of the various GNSS vendors.
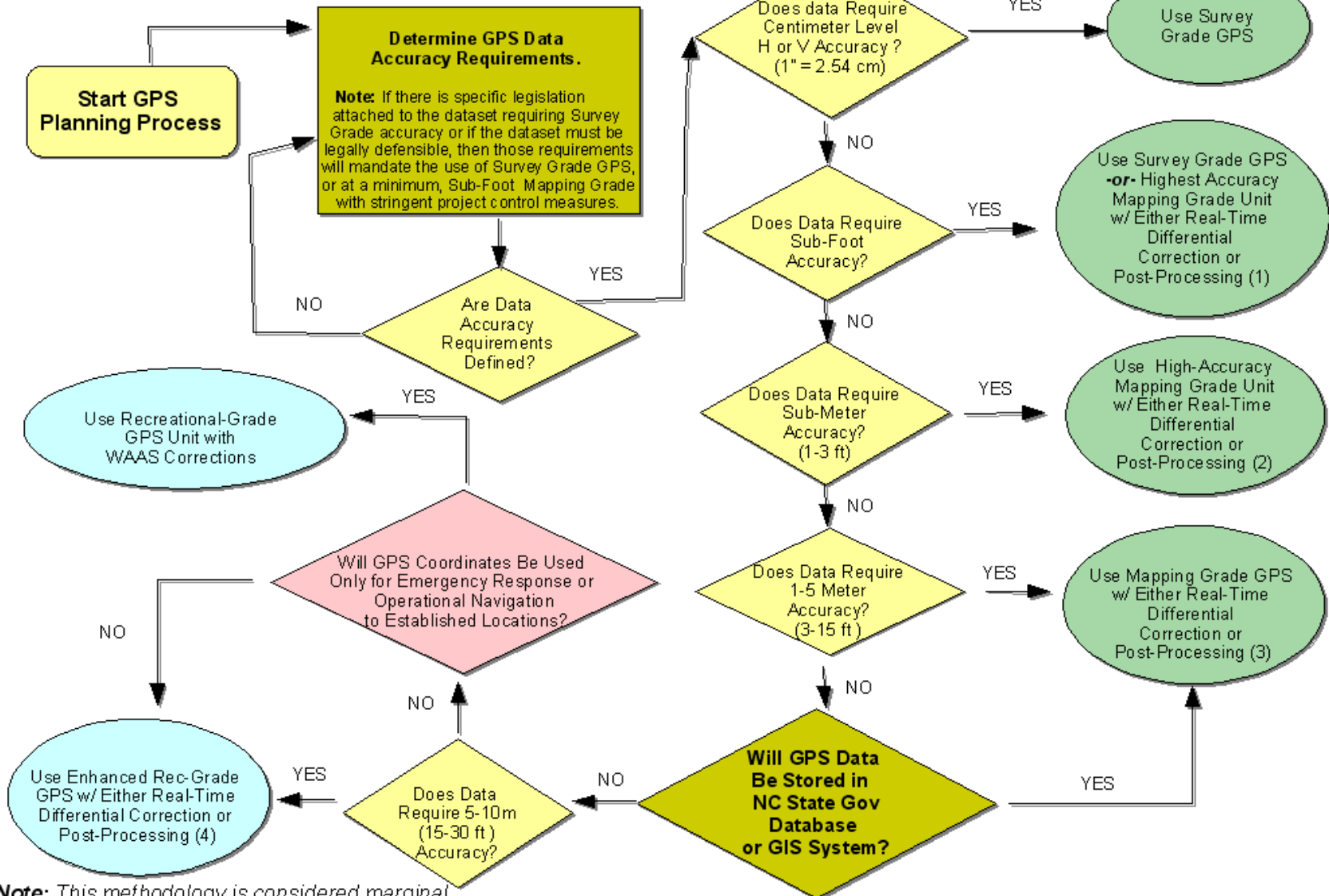
5.2. Using the most appropriate grade of receiver

To select the most appropriate GNSS receiver grade, answer the questions in the GNSS receiver selection decision tree (Figure 3).

Note: For those applications that require 5-10 m (15-30 ft) accuracy, an agency could use an enhanced recreational-grade receiver with either real-time differential correction or post processing. However, the positional data derived from such a GNSS receiver would not be suitable for any NC State government database or GIS.

State of North Carolina GPS Data Collection Standards
GPS Receiver Selection Decision Tree Diagram

Start GPS Planning Process

Determine GPS Data Accuracy Requirements.

Note: If there is specific legislation attached to the dataset requiring Survey Grade accuracy or if the dataset must be legally defensible, then those requirements will mandate the use of Survey Grade GPS, or at a minimum, Sub-Foot Mapping Grade with stringent project control measures.

Are Data Accuracy Requirements Defined?

Does data Require Centimeter Level H or V Accuracy? (1" = 2.54 cm)
— YES → Use Survey Grade GPS

Does Data Require Sub-Foot Accuracy?
— YES → Use Survey Grade GPS -or- Highest Accuracy Mapping Grade Unit w/ Either Real-Time Differential Correction or Post-Processing (1)

Does Data Require Sub-Meter Accuracy? (1-3 ft)
— YES → Use High-Accuracy Mapping Grade Unit w/ Either Real-Time Differential Correction or Post-Processing (2)

Does Data Require 1-5 Meter Accuracy? (3-15 ft)
— YES → Use Mapping Grade GPS w/ Either Real-Time Differential Correction or Post-Processing (3)

Will GPS Coordinates Be Used Only for Emergency Response or Operational Navigation to Established Locations?
— YES → Use Recreational-Grade GPS Unit with WAAS Corrections

Will GPS Data Be Stored in NC State Gov Database or GIS System?

Does Data Require 5-10m (15-30 ft) Accuracy?
— YES → Use Enhanced Rec-Grade GPS w/ Either Real-Time Differential Correction or Post-Processing (4)

Note: This methodology is considered marginal and is **not** suitable for GPS data stored in NC State Gov. Databases or GIS Systems.

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Figure 3.   A decision tree diagram on how to select the most appropriate GPS receiver grade for conducting a particular locational project/task.

5.3. Capturing data

5.3.1. Static mode

Receiver procedures vary between models. Thus, a GNSS user should follow the manufacturer's guidelines. In general, a guideline to follow for static point positioning is to collect data at one (1) second intervals. The amount of data to be collected will vary with the type of receiver from a minimum number of ten (10) readings to a maximum of about one hundred and eighty (180) readings for very old GNSS units (e.g. GeoExplorer II series). These readings need to be automatically stored in the receiver for later downloading onto a computer for post-processing or the readings need to be differentially corrected in real time and then downloaded onto a computer.

5.3.2. Kinematic mode

The recommended measurement interval for collecting data in a kinematic mode (i.e. while moving) is dependent on the operator's velocity, shape of the feature, and the receiver model. Therefore, the user should follow the manufacturer's guidelines. If data is being collected from a fast moving platform such as an automobile, airplane, or train, the measurement interval shall not exceed one (1) second. In contrast, if the user is collecting data while walking, the measurement interval will vary depending on shape of the feature, the receiver model, and any blockages. These readings need to be automatically stored in the receiver for later downloading onto a computer for post-processing or the readings need to be differentially corrected in real time and then downloaded onto a computer.

5.3.3. Elevation mask

Greater than fifteen (15) degrees (recommended for older units). Note: An elevation mask is the setting to exclude signals from satellites below a certain angle from the horizon. Please refer to your GNSS receiver's manual for the mapping-grade or higher setting, because modern receivers and processing software are designed to utilize satellite signals from satellites below fifteen (15) degrees by filtering out poor signals.

5.3.4. Datum

NAD 83, the state legislated datum

5.3.5. Ellipsoid

Geodetic Reference System 1980 (GRS 80) ellipsoid

5.3.6. Satellites

Minimum of four (4) satellites

5.3.7. Signal to Noise Ratio (SNR)

39 dBHz (recommended).

Please refer to your GNSS receiver's manual for the mapping-grade or higher setting.

5.3.8. Positional Dilution of Precision (PDOP)

Less than six (6) (recommended for older units)

Please refer to your GNSS receiver's manual for the mapping-grade or higher setting, because modern receivers and their software are designed to utilize less favorable PDOP conditions.

The Positional Dilution of Precision (PDOP) is the satellite position geometry index for precision referring to how close or far apart the satellites are from each other in the sky (Figure 2).

5.4. Mission planning

GNSS mission planning is an effective method for GNSS users to determine the optimal time to perform field data collection. Two of the most important factors in obtaining the highest accuracy in your GNSS data are having at least four (4) satellites in view at a sufficiently high elevation above the horizon and having the lowest possible PDOP values. A low PDOP value indicates an evenly spaced arrangement of satellites in the constellation above the survey site at the time the data is to be collected. There are certain periods of the day in which the satellite constellation is in a poor configuration for collecting data (i.e. high PDOP) and should be avoided. Therefore, it is important to assess satellite availability before heading into the field to collect GNSS data. Furthermore, these high PDOP conditions are exacerbated in mountainous terrain, heavy forest cover, or urban canyon situations, because satellite signals would be blocked. Therefore, a user planning to collect data under such conditions should conduct the mission planning with a higher elevation mask (i.e. 20 or 25 degrees instead of the standard 15 degrees).

Trimble offers mission planning as a free online service with its Trimble GNSS Planning Online (http://www.trimble.com/GNSSPlanningOnline/#/Settings). The company used to include mission planning in its processing software, GPS Pathfinder Office (http://www.trimble.com/mappingGIS/PathfinderOffice.aspx), as the QuickPlan module, but has since removed that module. Although the company still provides a free stand-alone mission planning program, Trimble Planning Software v2.9 (http://ww2.trimble.com/planningsoftware_ts.asp), the program is no longer listed on their GPS Data Resources webpage (http://www.trimble.com/Support/GPD_Data_Resources.aspx) and the company has not updated the program since August 2010.

Whether a user utilizes a stand-alone program, an integrated module, or an online service, the mission planning software requires current (less than 2 weeks old) satellite orbit information, which is broadcasted from each GPS satellite in a file called an almanac. The advantage of using an online service is that the provider is responsible for using the most up-to-date almanac available. Unfortunately, the Trimble GNSS Planning Online service does not post the date and time of its current almanac file. However, this information can be obtained by visiting their GPS Data Resources webpage (http://www.trimble.com/Support/GPD_Data_Resources.aspx) and examining the file's information on their ftp site:

> **Latest Almanac Data**
>
> Latest Almanac files for use with Trimble planning utilities
>
> GPS/GLONASS almanac in Trimble Planning file format
>
> (ftp://ftp.trimble.com/pub/eph/almanac.alm)

The disadvantage of using a stand-alone program or an integrated module is that the user is responsible for obtaining and using the most up-to-date almanac available. Fortunately, a current almanac file can be easily obtained from the following resources:

- The U.S. Coast Guard Navigation Center (NAVCEN) GPS NANUS, ALMANACS, & OPS ADVISORIES webpage (http://www.navcen.uscg.gov/?pageName=gpsAlmanacs) offers almanacs in the following formats:
  - YUMA Almanac - .alm, .txt
  - SEM Almanac - .al3, .txt

  Note: Certain GNSS mission planning software may require almanac information in a specific format. Check your GNSS equipment manufacturer's documentation for specific details.

- A mapping-grade or survey-grade GNSS receiver

  Note: A GNSS user should have his/her GNSS receiver track GPS satellites until the receiver has reported that an almanac file has been downloaded, which may take 15+ minutes, before transferring the receiver's downloaded almanac file to a computer. In addition, the user should also verify the almanac file's date in order to ensure that the file is current.

- A GNSS manufacturer's GNSS data resources webpage, such as Trimble's GPS Data Resources webpage (http://www.trimble.com/Support/GPD_Data_Resources.aspx)

The advantage of using the stand-alone program or the module was that the PDOP values throughout a user's data collection period could be exported in either a graph or a table format. A graph was useful for quickly determining what parts of the day would have PDOP peaks. Whereas, a table was useful for knowing exactly when these PDOP peaks would occur. In contrast, the online version exports data only as graphs.

In contrast, the advantages of using the online version are as follows:
- It is convenient in not having to download and load an almanac.
- The site location can be determined by entering a street address into an Internet-based mapping service as well as the coordinates from a geodetic monument's datasheet.
- It provides time-lapse maps (global maps down to the user's site) of ionospheric total electron content (TEC) and scintillation (disruption).

5.5. Processing data

5.5.1. Processing data settings

5.5.1.1.   Units

Meters. North Carolina § 102-1.1.
(http://www.ncleg.net/EnactedLegislation/Statutes/PDF/ByChapter/Chapter_102.pdf) stipulates,
"*All coordinates of the system are expressed in metres.*" and then stipulates that, "*The U.S.
Survey Foot, 1 meter = 39.37 inches or 3.2808333333 feet, shall be used as a conversion
factor.*" for converting between feet and meters.

5.5.1.2.   Coordinate system

North Carolina State Plane, the state legislated coordinate system
(http://www.ncleg.net/EnactedLegislation/Statutes/PDF/ByChapter/Chapter_102.pdf).

5.5.1.3.   Vertical datum

North American Vertical Datum of 1988

5.5.2. Timely post-processing of GNSS data

GNSS data may be corrected by two methods:

- Real time corrections from either:
  - NC GNSS Real Time Network (RTN) (http://rtnweb.nc.gov/)
  - A satellite correction service provider, such as Omnistar (http://www.omnistar.com/) or StarFire (http://www.navcomtech.com/wps/dcom/navcom_en_US/technology/augmentation/starfire/starfire.page?).
  - Nationwide Differential GPS (NDGPS) (http://www.navcen.uscg.gov/?pageName=ndgpsMain)
- Post-processing by downloading the GNSS field file(s) from your GNSS receiver to a computer, downloading GNSS base station files, and then using desktop software to perform the differential correction.

In order to post-process a GNSS field file, the processing software needs base station correction files, which can be downloaded from the NC GNSS RTN Reference Data Shop using the following directions (http://geodeticsurvey.nc.gov/Documents/How_to_download_GNSS_base_station_data_from_the_NCRTN.pdf).

Note: The NC GNSS RTN Reference Data Shop posts GNSS (GPS + GLONASS) base station files for only the previous three (3) months in order to conserve space on the server. Therefore, a spatial data user should post-process his/her field files on a daily or weekly basis.

Base station files can also be obtained from the National Geodetic Survey (NGS) User Friendly CORS site (UFCORS) (http://www.ngs.noaa.gov/UFCORS/) as a "GPS only" file (i.e., no GLONASS data) or as a GNSS file. A spatial data user may access UFCORS directly (http://www.ngs.noaa.gov/UFCORS/) or from within a frame of a desired CORS webpage [e.g. ASHEBORO 2 (NCZO) (http://www.ngs.noaa.gov/cgi-cors/corsage.prl?site=NCZO]. Although the UFCORS interface is identical whether it is accessed directly or within a frame of a CORS webpage, this document will cover how to access it from within a frame of a desired CORS webpage to emphasize the fact that UFCORS does not automatically select a spatial data user's desired station even if the user accessed UFCORS as a frame from within his/her desired station's CORS webpage.

Note: The UFCORS webpage posted the following dated notices:

- **Updated: 2014-APR-08, Tuesday, 1414hEDT**
  Augmented GPS (L2C and L5) and GLONASS is now available **from 2007:208 [2007 JUL 29] -present. No earlier data is available**.

The UFCORS download webpage (http://www.ngs.noaa.gov/UFCORS/) can be accessed as frame within a desired station's CORS webpage by the following steps:

1. Visit the NCGS "CORS and GNSS" webpage (http://geodeticsurvey.nc.gov/Pages/CORS-and-GNSS.aspx):

    a. Observer that the network (Figure 4) has achieved not only statewide coverage at a dense 30-60 km spacing arrangement, but provides seamless coverage along the Tennessee and South Carolina borders due to a data sharing agreement with those two neighboring states.

    b. Click on the closest base station to your collection site [e.g. ASHEBORO 2 (NCZO)], which will direct you to the NGS CORS webpage for that station (e.g. http://www.ngs.noaa.gov/cgi-cors/corsage.prl?site=NCZO).
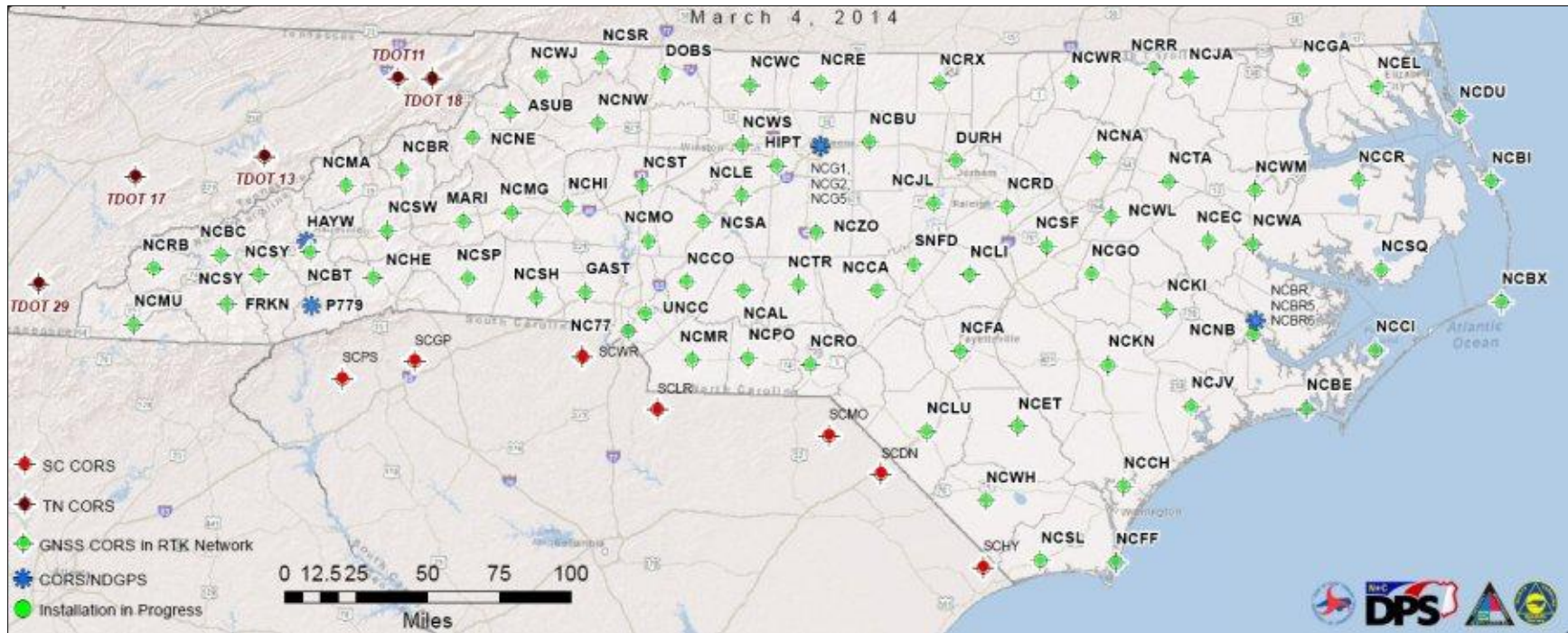

Figure 4.   The status map of the NC Continuously Operating Reference Station (CORS) Network and the NC Real-Time Network (RTN), which is also known as the Real-Time Kinematic (RTK) Network, showing the location and capability of each CORS:

   NC GNSS CORS site (i.e. can receive signals from both the U.S. and the Russian navigation satellites) in the RTN (i.e. can be accessed in real-time via a data cell phone and accessed for post-processing via the Internet)

   NC CORS site (i.e. can receive signals from only the U.S. navigation satellites) in the RTN

   NC CORS site not in the RTN (i.e. cannot be accessed in real-time, but can be accessed for post-processing via the Internet)

   NC GNSS CORS site that is being installed and will be incorporated into the RTN

   South Carolina GNSS CORS site that is accessible via the NC RTN

   Tennessee GNSS CORS site that is accessible via the NC RTN

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2. From the NGS CORS webpage for your selected station [e.g. ASHEBORO 2 (NCZO) (http://www.ngs.noaa.gov/cgi-cors/corsage.prl?site=NCZO] (Figure 5), which shows vicinity photographs of that station in a frame of that station's webpage,

Figure 5. The NGS CORS webpage for ASHEBORO 2 (NCZO).

   a. Click on the "Custom Files (UFCORS)" link on the left side of the page, which will replace the photographs in the frame (identified with the orange dashed line rectangle) with the UFCORS webpage.
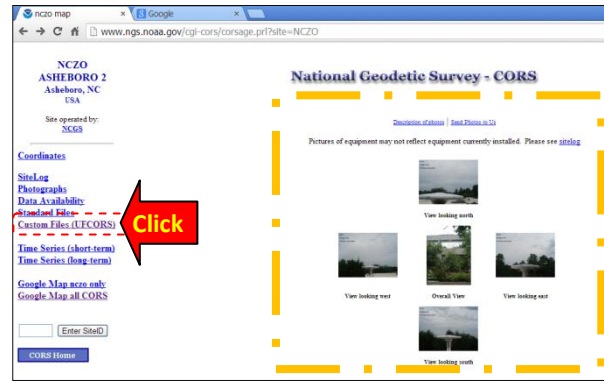
b. Please observe that UFCORS opens with no station selected (Figure 6). In addition, the UFCORS download site is a context sensitive form in that it will only offer the option of downloading GNSS data if you select a station that has a GNSS receiver. Every CORS in the NCGS CORS Network utilizes a GNSS receiver. However, the following CORS in North Carolina utilize a "GPS only" receiver:

   - PARI_OBS_NC-2008 (P779), which is operated by UNAVCO (http://www.unavco.org/aboutus/aboutus.html)

   - GREENSBORO 5 (NCG5) and NEW BERN 6 (NBR6), which are operated by the U.S. Coast Guard (http://www.navcen.uscg.gov/)

Figure 6. The opening UFCORS dialog box as a frame within the NGS CORS webpage for ASHEBORO 2 (NCZO).

c. Decide on which time zone you will utilize for referencing your data collection time period as either **Coordinated Universal Time (UTC)**, which is basically **Greenwich Mean Time (GMT)**, or the local time zone:

- **Eastern Standard Time (EST)**, which is **UTC - 5** or **GMT – 5**

    ~or~

- **Eastern Daylight Time (EDT)**, which is **UTC – 4** or **GMT - 4**

Hint: The sooner that you can think in UTC in the 24-hour format, the better.

d. Answer the following questions about your GNSS data collection period (Figure 7) and then press the **[Get CORS data file]** button:

- **Start Date**:

    1). Place the cursor in the "**Start Date**" field to activate the pop-up calendar.

    2). Select your starting date and then press the [**Done**] button, which will fill-in the following fields: "**Year**" and "**Day of Year**" (i.e. Julian Day).

- **Start Time**:

    1). Place your cursor in the "**Start Time**" field to activate the pop-up menu, which offers the starting time hour in the 24-hour format from 0:00 hrs to 23:00 hrs.

    2). Select the start time hour in the same time zone as what you will select for the "**Time Zone"** option.

Figure 7. The UFCORS dialog box completed to download base station files from ASHEBORO 2 (NCZO).

d. Answer the following questions about your GNSS data collection period and then press the **[Get CORS data file]** button (continued from the previous page):

- **Time Zone**:

  1). Place your cursor in the "**Time Zone**" field to activate the pop-up menu, which offers time zones listed as UTC (GMT), GMT-1…GMT-12, GMT + 1…GMT + 14.

  2). Select the time zone that you utilized for referencing your data collection time period.

- **Duration in Hours**:

  1). Place your cursor in the "**Duration in Hours**" field to activate the pop-up menu, which offers 1 to 24-hour long files in whole hour increments.

  2). Select the minimum number of hours to cover your time collection period.

- **Site ID**:

  If you do not remember the CORS ID of your selected station, press the "**CORS Map**" link and then zoom down to your collection area to find the closest CORS.

  1). Place your cursor in the "**Site ID**" field to activate the pop-up menu.

  2). Scroll down to your closest station and then select it, which will invoke the "**Available Satellite Systems**" option to list the satellite systems available for that particular station.

- **Sampling Rate**:

  1). Place your cursor in the "**Sampling Rate**" field to activate the pop-up menu, which offers the following options: "As is", 1 second, 5 seconds, 15 seconds, and 30 seconds.

  2). Select the "As is" option.

     Note: All the stations in the NCGS CORS Network record GNSS data at the 1-sec rate, which means that the "As is" is equivalent to the "1-sec rate" option. However, the three North Carolina CORS stations that are not in the NCGS network record at the following rates: NBR6 at 5 seconds, NCG5 at 5 seconds, and P779 at 15 seconds

     Note: Please remember that NGS decimates data files older than 30 days from the sampling rate that it was recorded at (e.g. 1-sec intervals) to a 30-sec sampling rate in order to save space on their server. Therefore, process your GNSS field data in a timely manner.

d. Answer the following questions about your GNSS data collection period and then press the **[Get CORS data file]** button (continued from the previous page):

- **Available Satellite Systems:**
    1). If you collected the data with an old (legacy) "GPS only" receiver and your processing software cannot handle GLONASS data or the new GPS signals, then select only the "**GPS (L1+L2 only)**" option.
    2). If you collected the data with a relatively new "GPS only" receiver and your processing software can handle the new GPS signals, but not GLONASS signals, then select only the "**GPS (L1+L2+L2C+L5)**" option.
        Note: If your processing software can handle the new GPS signals, it will very likely be able to handle GLONASS signals.
    3). Conversely, if you collected the data with a GNSS receiver or collected it with a "GPS only" receiver and use a processing program that can handle GLONASS data, then select the "**GLONASS**" option in addition to either the "**GPS (L1+L2+L2C+L5)**" or "**GPS (L1+L2 only)**" GPS options.

- **Optional files?**
    o **Coordinate File:** Yes or No (not needed for mapping-grade, but encourage the user to download for verification)
    o **NGS data sheet:** Yes or No (not needed for mapping-grade, but encourage the user to download for verification)
    o **IGS Orbits in SP3 format:** Yes or No (not needed for mapping-grade)

3). Download the requested zip file, which will be named CORS ID Julian day.zip (e.g. nczo061.zip).

Base station files can also be downloaded automatically from UFCORS by using download scripts with a GNSS processing software program, such as Trimble's GPS Pathfinder Office (http://www.trimble.com/mappingGIS/PathfinderOffice.aspx) or Leica's Leica Zeno Office (http://www.leica-geosystems.us/en/Leica-Zeno-Field-Office_79643.htm).

Whether a GNSS user downloads base station files from UFCORS automatically with a download script or by visiting the UFCORS, this section is titled "**Timely post-processing of GNSS data**" for a reason. It is important for each GNSS user to not delay differentially correcting his/her uncorrected field files (i.e. stockpiling them for en masse processing), but rather to download the necessary base station files and perform the differential correction process on a daily or a weekly basis, because NGS decimates the sampling rate of each base station GPS/GNSS file that is over 30-days-old from its original sampling rate (i.e. 1-sec for NCGS stations) to a 30-sec rate in order to conserve space on their server.

5.5.3. Processing of GNSS data in real time
5.5.3.1.   North Carolina GNSS Real Time Network (RTN)

The NC GNSS RTN is a recommended source of real-time GNSS differential corrections for GIS mapping by state agencies. In fact, the system is designed to support centimeter (cm) level survey applications. Thus, it is more than robust enough for GIS mapping applications.

A user with a GNSS receiver can connect to the RTN using a wireless Internet connection [i.e. a data enabled cell phone or a MiFi (i.e. a wireless router that can act as a mobile Wi-Fi hotspot)]. Once the RTN has determined that the user's GNSS receiver is operating within the network's coverage area (Figure 4), it will then send GNSS correctors back to the user's GNSS receiver for real-time differential correction.

NCGS developed the RTN with software that can stream real-time correction signals to individual users from a location-specific set of the six (6) closest stations within the statewide NC CORS Network while simultaneously doing the same operation for other users. However, instead of providing these correction signals as a set of correction signals from these closest stations, the RTN assembles a "virtual" amalgamated station with the correction signals from the closer base stations weighted more than those from the more distant stations.

5.5.3.2. Nationwide Differential Global Positioning System (NDGPS)

The Nationwide Differential Global Positioning System (NDGPS) began as a United States Coast Guard (USCG) maritime navigation system that has since expanded inland and become the world's largest ground-based GPS augmentation service covering the continental US, Alaska (southern coast), Hawaii, and Puerto Rico (Figure 8).
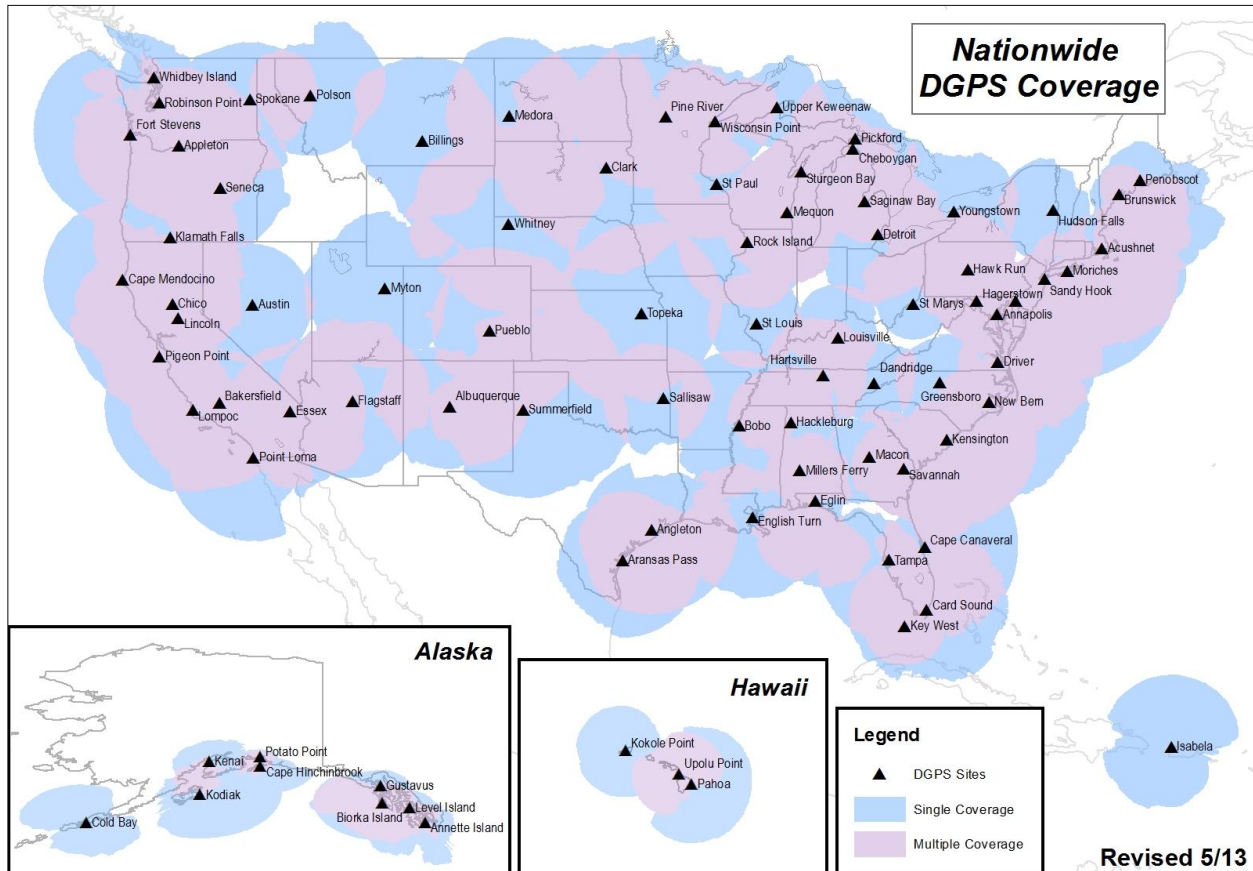

Figure 8.   The coverage area map of the Nationwide Differential GPS (NDGPS) network showing the location of DGPS sites in the network and the coverage areas with coverage from:
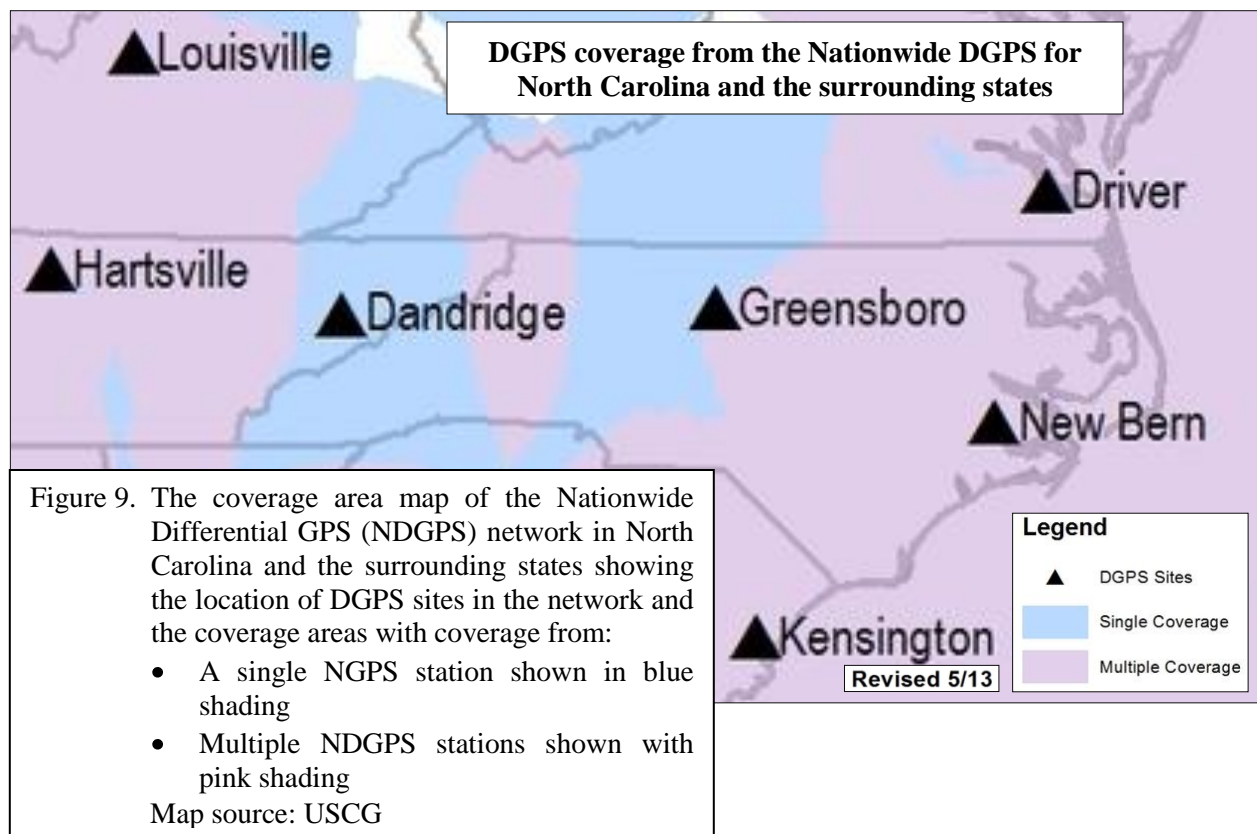
- A single NGPS station shown in blue shading
- Multiple NDGPS stations shown with pink shading

Map source: USCG

Currently, the tower sites are positioned at a density of at least single coverage (i.e. being able to receive signals from at least one tower) throughout nearly the entire coverage area of the system. However, the USCG is working to increase that density to double coverage (i.e. being able to receive signals from at least two towers) throughout the entire coverage area.

The purpose of the NDGPS is to provide accurate positioning and location information in real-time to meet surface transportation navigation needs (e.g. harbor navigation, emergency response units, positive train control, etc.). Since the major uses of the system are for critical navigation needs, each NDGPS site monitors the integrity of the GPS signal and will broadcast a warning if an anomaly is detected. In addition to using the system for navigation, the correction signals can also be used for a multitude of positioning needs, such as precision farming, land surveying, mapping, and scientific applications.

In North Carolina (Figure 9), NDGPS provides statewide coverage from a station in Greensboro and New Bern as well as from a station in Dandridge, Tennessee; Driver, Virginia; and Kensington, South Carolina. In fact, most of the state has double coverage.

Figure 9. The coverage area map of the Nationwide Differential GPS (NDGPS) network in North Carolina and the surrounding states showing the location of DGPS sites in the network and the coverage areas with coverage from:
- A single NGPS station shown in blue shading
- Multiple NDGPS stations shown with pink shading

Map source: USCG

These differential correction signals can be obtained in real-time from an NDGPS broadcast tower site by tuning a navigation radio beacon, which can be purchased from most GNSS vendors, to either the site's transmitting frequency or its ID (http://www.navcen.uscg.gov/?pageName=dgpsSiteInfo&All):

- New Bern, NC (294 kHz / ID 771)
- Greensboro, NC (303 kHz / ID 824)
- Dandridge, TN (305 kHz / ID 782)
- Driver, VA (289 kHz / ID 806)
- Kensington, SC (292 kHz / ID 778)

The Nationwide Differential Global Positioning System (NDGPS) provides GPS differential corrections that can yield a horizontal accuracy of 1-3 meters at the 95% confidence level. Thus, it is an acceptable source of differential corrections for GIS mapping by state agencies. However, since this differential correction procedure is dependent on receiving a radio signal corresponding to each collected GPS position, the user must set the GNSS receiver's real-time settings with the following cascading search protocol:

1. Search for an NDGPS signal

2. If an NDGPS signal is not received, then use uncorrected GPS.

Since it is impractical to check to see if each collected GNSS position was differentially corrected in real-time via an NDGPS signal, the user will still need to post-process the collected GNSS field data to ensure that each collected GNSS position has been differentially corrected. Basically, when NDGPS is used for:

- Mapping, the real-time corrections can create a good map of the mapped positions for the user to view <u>while</u> collecting data, but this map may contain uncorrected positions. Hence the need to post-process afterwards.

- Navigation, the real-time correction signals can be used to guide the user to the target site. If the receiver loses the signal during the navigation process, then the receiver should report a message like "Old navigation."

Although the system is led by the USCG, it is an interagency collaborative with the following partners (http://www.navcen.uscg.gov/?pageName=dgpsMain):

- US Department of Transportation (DOT): http://www.navcen.uscg.gov/?pageName=ndgpsMain

- US Army Corps of Engineers (USACE):
  http://www.navcen.uscg.gov/?pageName=ArmyCorpsEngineers

5.5.3.3. Wide Area Augmentation System (WAAS)

The Wide Area Augmentation System (WAAS) is not an acceptable sole source of differential corrections for GIS mapping by state agencies due to:

- Signal interruption problems from trees, buildings, and mountains
- Lower quality mapping accuracy (7 m)

When using WAAS as a source of differential corrections in the field, the data must still be post-processed to verifty that all data has been corrected [please the procedure outlined in section **5.5.2. Timely post-processing of GNSS data**].

Yet, the two high quality WAAS-based mapping receivers that are on the market now [SX Blue (http://sxbluegps.com/) by GENEQ inc. and ikeGPS (http://www.ikegps.com/)] and their accompanying software packages [PC-Mapper (http://sxbluegps.com/product/pc-mapper/) and ikeDesktop 2.0 (http://www.ikegps.com/ikegps/ikedesktop/)] are designed for users to not post-process. However, GENEQ inc. stated on its "Technology" webpage (http://sxbluegps.com/technology/) that they will provide High Accuracy Solutions (http://www.sxbluegps.com/survey-accessories-pp.html) for those who need information on how to collect data that can be post-processed and information about *"...specific L1 carrier phase software for the post-processing,"* but the link was diverted to their "Product Quote" request for information form webpage (http://sxbluegps.com/product-quote/). [Please see the note in the middle of p. 15 discussing the added costs of working with enhanced non-professional grade receivers.]

If a WAAS-based receiver and its accompanying software package exist that can be post-processed, the user would need to set the GNSS receiver's real-time settings with the following cascading search protocol:

1. Search for a WAAS signal
2. If a WAAS signal is not received, then use uncorrected GPS.

Basically, when WAAS is used for:

- Mapping, the real-time corrections can create a good map of the mapped positions for the user to view while collecting data, but this map may be contain uncorrected positions. Hence the need to post-process afterwards.

- Navigation, the real-time correction signals can be used to guide the user to the target site. If the receiver loses the signal during the navigation process, then the receiver should report a message like "Old navigation."

WAAS was developed by the Federal Aviation Administration (FAA) and the Department of Transportation (DOT) for en route and precision approach aircraft navigation, because unaugmented GPS alone cannot provide the positional accuracy to meet FAA's navigation requirements for accuracy, availability, and integrity. WAAS tackles each of these requirements accordingly:

- Positional accuaracy is achieved by providing differential correction to remove GPS signal errors caused by ionospheric disturbances, timing, and satellite orbit errors.
- Availability is achieved by broadcasting the differential correction signals from two (2) geostationary satellites positioned over the U.S.
- Integrity is achieved by monitoring the GPS signals to ensure that the corrections being transmitted are correct.

On 10 July 2003, FAA declared WAAS operational for aviation safety-of-life use in the U.S. National Airspace System (NAS) by providing

- En route navigation across the entire NAS
- Vertical guidance performance [localizer performance with vertical guidance (LPV)] to most of the continental U.S.

The system (Figure 10) utilizes a network of precisely-located ground Wide-area Reference Stations (WRS) positioned across the continental U.S., Alaska, Hawaii, Puerto Rico as well as additonal stations in Canada and Mexico. These stations collect and process GPS satellite data and send this data to either of the three Wide-area Master Station (WMS), which calculates GPS correction messages and then sends these messages to the Ground Uplink Stations, which in turn transmit these correction signals to the three WAAS satellites, which in turn broadcast these correction signals using the same frequency as the GPS satellites back to the earth for en route and precision approach aircraft navigation.
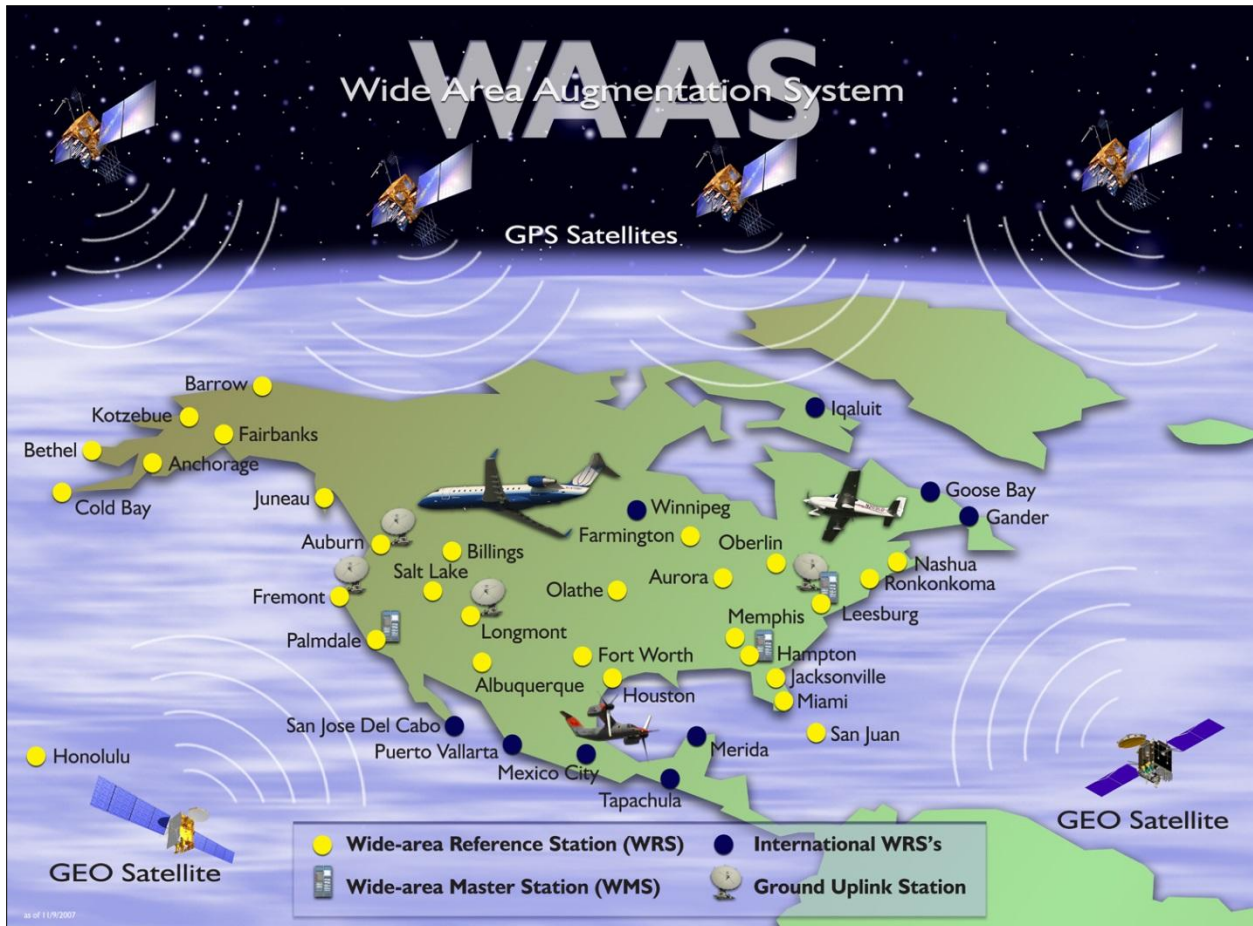

Figure 10. The basic design of the Wide Area Augmentation System (WAAS) (http://www.nstb.tc.faa.gov/):
- GPS satellites (shown at the top of the image) broadcasting GPS signals towards the earth.
- Wide-area Reference Stations (WRS) (shown as yellow circles in the U.S. and dark blue circles in Canada and Mexico) receiving GPS signals, which are then sent to the closest Wide-area Master Station (WMS) (shown as a rectangular server icon)
- WMS calculates correction signals and transmits them to the Ground Uplink Stations (shown as a parabolic antenna icon)
- The Ground Uplink Stations transmits the signals to the three WAAS satellites (shown at the bottom of the image as the two GEO Satellites)
- The WAAS satellites transmits the correction signals for en route and precision approach aircraft navigation

As for mapping and navigating on the ground, the GNSS receiver must have a clean line-of-sight to one of the geostationary WAAS satellites to receive the signals and be a WAAS enabled GNSS receiver to utilize the signals for differential correcting. Unfortunately, the necessity of obtaining a line-of-sight with one the WAAS satellites to receive the signals renders this differential correction source as too unreliable for some mapping projects. Although North Carolina is one of the states located closest to the WAAS satellite for the eastern U.S., (PRN 138, which is labeled as ANIK in Figure 11), the satellite always resides relatively low in the southwestern sky at ~40° elevation due to being positioned in a geostationary orbit at the equator at 107.3° W.
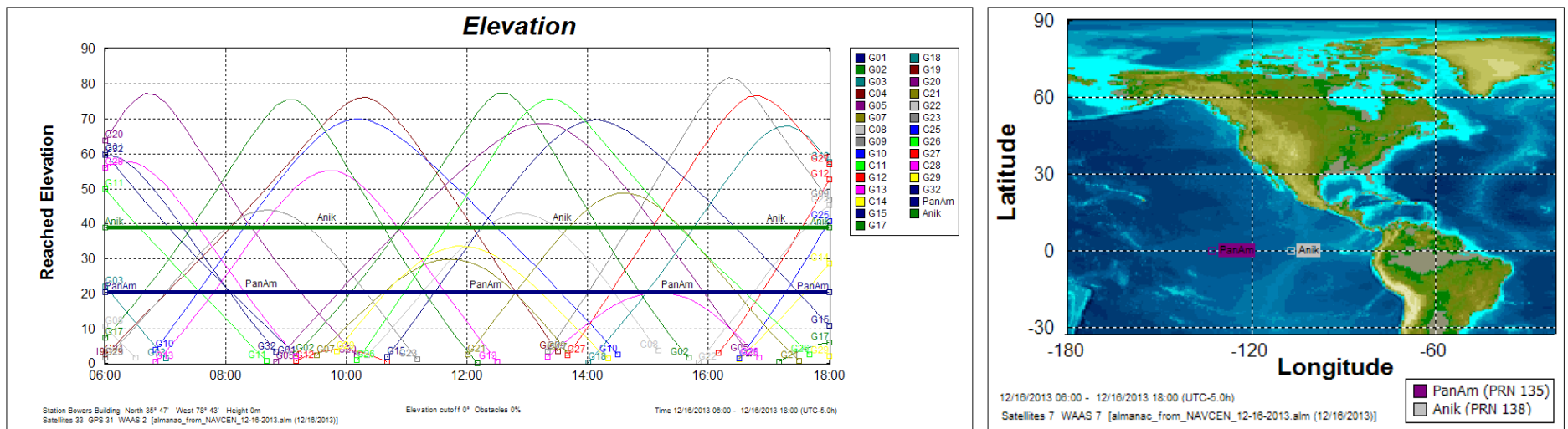

Figure 11. Left image: An angle of elevation chart showing the elevation angle that would be observed in Raleigh, NC for the two geostationary WAAS satellites (PRN 138, which is labeled as ANIK, and PRN 135, which is labeled as PanAM) as well as for the constellation of GPS satellites (G01-G32).
Right image: The location of the two geostationary WAAS satellites (PRN 138, which is labeled as ANIK, at 107.3° W and PRN 135, which is labeled as PanAM, at 133° W).

Therefore, any trees, mountains, and/or buildings on the horizon could easily obstruct the WAAS signal. Conversely, WAAS signal reception is ideal for recreational GNSS uses in either open land or marine locations.

5.6. GNSS records retention and accessibility

It is strongly recommended that GNSS data collectors archive (i.e., safely backed up on a server, CD, or DVD in an organized manner) all phases of the data used to create either a GIS data layer or GNSS coordinates stored in a relational database. The GNSS data files should be easily retrievable if questions about the processing methodology ever arise. Retaining the raw GNSS data and correction files allows for re-processing if errors in the original process are discovered later. More specifically, the data that should be archived in an easily recoverable and organized manner include the following file types:

- Uncorrected (raw) GNSS filed data files
- GNSS base station correction files that were used to perform the original differential corrections
- Electronic data entry form (e.g. data dictionary) used to collect each mapped feature's attributes
- Final differentially corrected GNSS datasets

5.7. Equipment and procedure testing

In order to ensure that faulty GNSS receivers can be identified for repair or disposal, all GNSS receivers used in state work (including new equipment, old equipment, and equipment owned by contractors) should be tested for accuracy every six (6) months by the following procedure:

1. Collect five (5) readings of ten (10) epics (1 or 5 second intervals) of any geodetic survey monument.
2. Perform the necessary differential correction.
3. Compare the differentially corrected state plane results (i.e. the northing and easting values) to the station's published horizontal position.
4. Retest each GNSS receiver that yielded accuracy results greater than the manufacturer's specified accuracy level.
5. Repair or dispose each receiver that failed the accuracy test twice.

The location and published horizontal position of geodetic survey monuments throughout the state can be found on the NCGS website at the following URLs:

> http://geodeticsurvey.nc.gov   Click on the [Geodetic Control] button at the top of the page.
> http://ncgs.nc.gov/geodeticmonuments/

Each agency that uses GNSS receivers should keep these biannual accuracy results of each receiver (identified by model number and serial number) in their archives.

5.8. Training and certification

An "Introduction to GNSS" course is available from NCGS for the benefit of the GNSS user. This course covers the basics of GNSS theory, field receiver operation, differential correction, and data documentation. It is recommended as a first step in the training process for new users of GNSS technology.

GNSS operator certification is one result of the training course described above. Certification is issued to the operator through NCGS. Continued certification requires completion of a refresher training course on an annual basis.

5.9. GNSS data documentation (metadata)

Data collected using GNSS equipment should contain data documentation or metadata that describe various aspects of the data set collected. Some of the pertinent information include:

- Model and accuracy of GNSS receiver
- Base station(s) used for differential corrections
- Software used for performing differential corrections
- Estimated horizontal and vertical accuracy of the data collected
- Datum
- Collection units (feet or meters)
- Coordinate system

All of these elements of the data set should be recorded in the data set's accompanying metadata file, which should be prepared in accordance with the FGDC *"Content Standards for Digital Geospatial Metadata"* (CSDGM) as adopted by the GICC. The pertinent information listed above is covered under the CSDGM's Section 2 (Data Quality Information):

http://www.fgdc.gov/metadata/csdgm/02.html

It is important that GNSS-collected GIS datasets contain two distinct forms of GNSS metadata information:

- Documentation in the FGDC metadata of metadata specific to the GNSS receiver, differential correction process, and export settings used to create the final GIS layer (Note: Please read the **5.9.1. Metadata: Receiver** section for a detailed explanation).
- Documentation in each feature's attributes of a GIS layer of the quality of GNSS positional information used to create that feature (Note: Please read the **5.9.2. Metadata: Feature** section for a detailed explanation).

5.9.1. Metadata: Receiver

Documentation in the FGDC metadata of metadata specific to the GPS receiver, differential correction process, and export settings used to create the final GIS layer.

The first type of documentation should reside in the FGDC metadata record for the final GIS dataset. This documentation should include the following information:

- The type of receiver(s) used to collect the GNSS data
- Number of receiver channels
- The manufacturer's published horizontal and vertical accuracy of receiver(s)
- The minimum number of satellites allowed during data collection
- The minimum elevation mask setting during data collection
- The maximum PDOP allowed during data collection
- The maximum SNR allowed during data collection
- The minimum number of positions collected for each feature, if applicable
- The dates of GNSS data collection
- The differential correction methods applied to the raw data, including type of correction, software name, and version used
- The GNSS base station(s) used for differential correction of GNSS data
- The approximate distance of the base station from the target GNSS data
- The projection or coordinate system used
- The datum used
- The units of measure used
- The altitude reference system [e.g. Height Above Ellipsoid (HAE) or Mean Sea Level (MSL)]. If MSL was used, then indicate which geoid model was used.
- The estimated percentage of vegetative cover (i.e., canopy) over feature locations
- The part of the feature where coordinates were recorded (e.g. general perimeter, center line, center point, shoulder of road/river, centroid of parcel, driveway entrance, or front door, etc.), if applicable
- The offsets used (if applicable)
- Collection speed [(i.e., stationary or moving) and mode of transportation (i.e., walking, bicycling, or driving in a motorized vehicle]. Note: This standard does not cover aerial GNSS data collection.

Occasionally, project restrictions or unavoidable circumstances may necessitate GNSS receiver settings or collection methods outside of those recommended by the State of North Carolina's GNSS standard. When this occurs, the actual GNSS collection conditions should be precisely documented in the metadata so that secondary users of the dataset will be able to determine if the data adequately supports their intended use. When GIS datasets covering the entire state or regional areas have employed more than one GNSS methodology for data collection in identifiable sub-areas, such as individual counties, each method should be separately documented in the FGDC metadata. Using a standard checklist (Table 2) to document this information for each data collection session is an efficient method of ensuring that this information is captured.

Table 2: A standard metadata checklist.

Requirement	Example

Receiver type (s) used	Manufacturer & model:
	    Leica Zeno 10 or 15
	    Trimble Geo7 series
	    Trimble GeoExplorer 5 series

Number of receiver channels	12
Horizontal accuracy of receiver (manufacturer's specifications for predicted error, including reporting statistic)	1-5 meters+ 2ppm (root mean square)
Vertical accuracy as stated by manufacturer	3-5 meters+ 2ppm (root mean square)
Minimum number of satellites required	4
Minimum elevation mask setting	15
Maximum PDOP allowed	6
Minimum SNR ratio allowed	4
Minimum positions collected for each point feature	10 - 180 depending on the manufacturer's guidelines
Dates of GNSS Collection	Between 1/15/2005 and 3/15/2005
GNSS correction methodology utilized	Code Phase Post-Processed Differential using Trimble's Pathfinder Office 5.6 software, including appropriate levels of detail in the metadata process steps. Other options might include: • Code Phase Real Time Differential (list correction source, e.g. NDGPS beacon, OmniStar, WAAS) • Carrier Phase / Real Time Kinematic • Carrier Phase / Static • Carrier Phase / Fast Static

Table 2: A standard metadata checklist. Table continued from the previous page.

Requirement	Example
Base station used for differential correction. If it is a statewide dataset and multiple base stations are used, specify the base station used for each county and list each base station's pertinent information, which is readily available from the NCGS website: http://geodeticsurvey.nc.gov/Pages/CORS-and-GNSS.aspx	RALEIGH DOT CORS ARP (NCRD) The reference position used by the National Geodetic Survey (NGS) is NAD 83(2011). NAD 83 (2011) position of Antenna Reference Point (ARP) of the geodetic antenna: - Latitude: 35 45 49.50795 N - Longitude: 78 34 44.39448 W - Ellipsoid Height (2011): 51.789 meters - NAVD 88 Orthometric Height: 85.04 meters - Receiver: Trimble NetR5 GNSS - Antenna: Trimble Zephyr GNSS Geodetic II
Approximate distance from the base station used for differential correction	20-30 miles
Coordinate system used by GNSS Receiver(s)	Geographic (Latitude/Longitude): - Degrees Minutes Seconds (DMS) - Decimal Degrees (DD) NC State Plane (Zone 3200): - Feet - Meters
Unit of Measure	Feet or Meters
Datum used by GNSS Receiver(s)	WGS84
Altitude reference system	Height Above Ellipsoid (HAE) or Mean Sea Level (MSL) – if MSL was used, then indicate which geoid model was used
Average percent of vegetative cover	20%
General location where the coordinates were recorded (if applicable)	Front door of main building Intersection of driveway and main road Approximate center of parcel As close to the smokestack as possible
Type of offset used (if applicable)	15' right offset from road centerline
Collection speed/mode	Stationary Walking Moving bicycle Moving motorized vehicle

5.9.2. Metadata: Feature

> **Documentation in each feature's attributes of a GIS layer of the quality of GPS positional information used to create that feature.**

The second type of GNSS metadata is dependent upon the software and hardware product(s) used to collect and process the GNSS data. Therefore, it is not feasible to specify a complete set of GNSS quality attributes that are universally supported. However, since the vast majority of North Carolina state and local government agencies use Trimble brand GNSS hardware and software for their mapping-grade GNSS data collection, this GNSS standard advises that all GNSS-collected GIS datasets should include as many of the GNSS quality attributes that are readily available from Trimble GPS systems. The Trimble Pathfinder Office software supports retention and export of the GNSS quality attributes to the final GIS file format for each feature as listed in Figure 12 and Table 3. The majority of mapping and survey-grade GNSS

Figure 12. The "General Attributes" export settings to select as listed in the Trimble Pathfinder Office software package.

receivers and software packages should support collection and export of many, if not all, of the GNSS quality attributes available for "All Feature Types" (Figure 12 and Table 3).
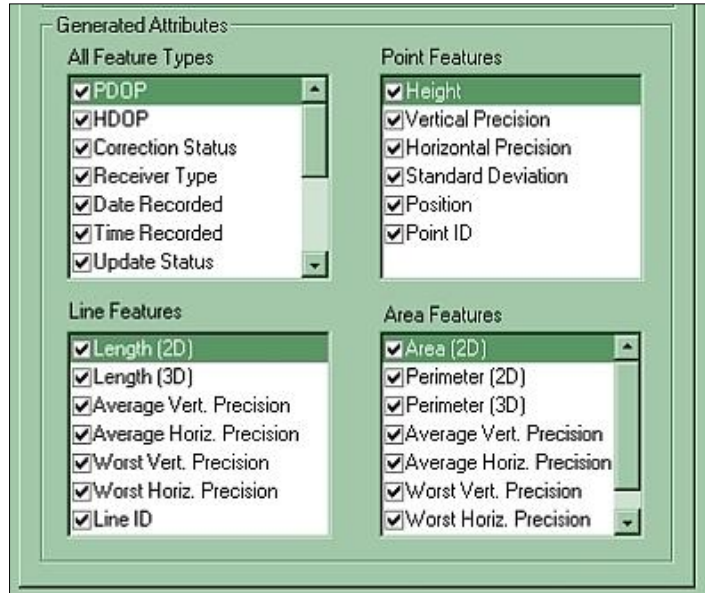
Table 3: The GNSS quality attributes that Trimble Pathfinder Office can export from a GNSS file for all feature types as well as additional attributes that can be exported for point, line, and area features.

Feature type	Exportable attribute	
All feature types:	• PDOP • Horizontal Dilution of Precision (HDOP) • Correction Status • Receiver Type • Date Recorded • Time Recorded • Update Status	• Feature Name • Data File Name • Total Positions • Filtered Positions • Data Dictionary Name • GPS Week • GPS Second
Point features:	• Height • Vertical Precision • Horizontal Precision	• Standard Deviation • Position • Point ID
Line features	• Length (2d) • Length (3d) • Average Vertical Position • Average Horizontal Position	• Worst Vertical Precision • Worst Horizontal Position • Line ID
Area features	• Area (2d) • Perimeter (2d) • Perimeter (3d) • Average Vertical Position	• Average Horizontal Position • Worst Vertical Precision • Worst Horizontal Position • Area ID

In addition, filtering of GNSS positions during the final export (Figure 13) to a GIS format should ensure that GNSS positions that do not meet the following minimum data quality standards will be filtered out of the final GIS dataset:

- Uncorrected positions,
- Positions not using signals from at least four (4) satellites
- Positions where the PDOP and HDOP are greater than six (6).
  [Please refer to section **5.3.8. Positional Dilution of Precision**]
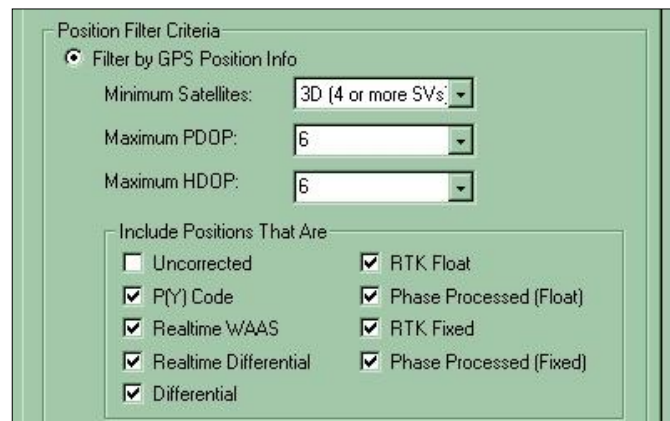

Figure 13. The "Position Filter Criteria" export settings to select as listed in the Trimble Pathfinder Office software package.

The purpose of requiring both project level GNSS documentation in the FGDC metadata and the GNSS quality information at the feature level as dataset attributes is to provide enough information about GNSS-collected GIS data layers so that both analysis and decisions based on the primary layer and any potential secondary uses of the dataset are conducted based upon the knowledge of the dataset's true accuracy.

6. Alternatives to mapping with a mapping-grade GNSS receiver

This section describes two methods for refining data collected with a non-professional GNSS receiver utilizing orthoimagery that has documented horizontal accuracy that meets or exceeds the GNSS data collection horizontal accuracy standard.

Method A: Imagery reference

The first method—what may be called "imagery reference"—is used to determine the final coordinates for geospatial features based on their locations visible and identifiable in orthoimagery. This method involves locating the area containing a feature that has been mapped using one of the following techniques:

- Collecting feature data with a non-professional-grade GNSS receiver
- Applying GNSS data that has not been differentially corrected

For geospatial features from either type of source, the following steps will produce confirmed or corrected features that meet horizontal accuracy standards. First, create a temporary "working" dataset of uncorrected GNSS data. Next, use GIS software to display the "working" dataset over orthoimagery that serves as a base map with known horizontal accuracy. For example, North Carolina statewide orthoimagery has 6-inch ground resolution and an accuracy of +/- 2.0 feet or better.

The next step is to use an editing tool in GIS to adjust the location of each feature based on the corresponding feature visible in the orthoimagery. For example, in Figure 14, a point feature collected in the field using a non-professional-grade receiver is located to the south of the intended location (representing the front entrance to a public school building). This "working" point can better represent the school location with an adjustment. An analyst would move the "before" point about 100 meters, adjacent to the apparent front entrance in the image (the "after" point or whatever placement is specified in the business rules for the dataset) and document the edit. This action refines the positional accuracy of the estimated data to match the precision of the imagery, which would bring the spatial
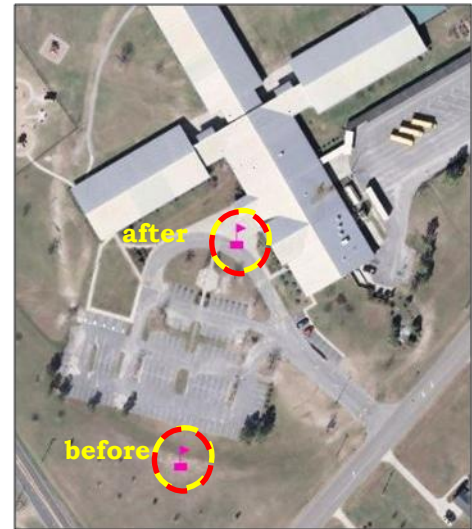
Figure 14. Imagery reference method of using aerial imagery that has a documented horizontal accuracy that meets or exceeds the GNSS data collection horizontal accuracy standard to determine the coordinates of a feature collected with a non-professional GNSS receiver (shown as the "before" point) by creating a point at the feature's actual location (shown as the "after" point).

data into compliance with accepted state mapping accuracy standards. This method typically works best for features that are represented as points, but can be used for lines and polygons as long as the features (points or areas) are visible in the imagery.

Method B: Digitizing without GNSS

The second method is to use GIS software to interactively create points over an orthoimagery base map. This method does not involve a GNSS receiver to collect field data. Instead, an analyst would display orthoimagery and any other base geographic datasets with known accuracy to use as a visual reference. Next, the analyst would then use an editing tool to "digitizes" recognizable point (e.g. wells), line (e.g. stream centerlines), and area (forest stand boundaries) features in the imagery. For example, a playground behind a school, in leaf-off conditions, has boundaries that are visible and may be represented as a new geographic feature. The horizontal accuracy of the output dataset is largely based on the horizontal accuracy of the orthoimagery along with the pixel resolution (e.g., 1 pixel = 6 inches by 6 inches), the digitizing scale (how zoomed in on the image), and the digitizing skill of the individual. For example, the 2010 North Carolina Statewide Digital Orthoimagery dataset has a horizontal accuracy of no worse than 4 feet error in any direction. If the digitizer zooms into reasonable scale (1:1000 to 1:500), that person can expect horizontal accuracies as good as or better than using differentially corrected mapping-grade GNSS which typically generates horizontal errors of no more than 15 feet.

Figure 15 displays an example of North Carolina statewide imagery that contains clearly visible features suitable for interactive data creation: a farm field with distinct vegetation (on the left), a pond (on the right), and a greenway (bottom center).

Figure 15. Digitizing without GNSS to create point, line, and/or area features. The example shows a digitized farm field area feature in the top left corner, a digitized pond area feature in the top right corner, and a digitized centerline of greenway line feature in the bottom.

The digitizing without GNSS method has several possible advantages over using GNSS:

1) If the area to be mapped is large (i.e. a county or more), this method is useful given that much more area can be covered in one digitizing session than could ever be collected by an individual using GNSS on the ground over the same time interval.

2) Many geographic feature boundaries (stream edges, tree lines, etc.) are readily apparent to the eye when viewed from above. This can make collecting these boundaries digitally very easy compared to locating and mapping them on the ground.

3) Many locations are simply too difficult to map on the ground with GNSS due to terrain, weather, vegetation, wildlife, hostile property owners, etc. This method can be used to map any location covered by the imagery.

4) Many commercial and open source GIS software packages are available with capability to utilize Methods A and B.

There are also several possible drawbacks for Methods A and B:

1) Any imagery dataset is literally a snapshot in time. If a GIS analyst tries to map a feature as it exists today, then a snapshot from 2010 may be of little use depending on how much the feature has changed over time. For example, the latest available imagery for a site may have been acquired just 1 year ago, but would not show the development that has occurred in the intervening period.

2) The feature you wish to map may not be easily discernible in the imagery due to the scale of the imagery, shadows from nearby tall objects, or being obscured by vegetation. For example, mapping narrow streams in evergreen forests can be very difficult.

3) Training is usually required to develop the skill necessary to properly identify some geographic features visible in orthoimagery.

7. Summary

The demand for more accurate and precise locational data within North Carolina state government agencies will only increase with the continued automation of locational data sets. GNSS is already the principal tool for collecting locational data used in systems, such as a computer models or a GIS, for which geographic accuracy is critical. GNSS is an important and cost-effective method for locating features too numerous or too dynamic to be mapped by traditional methods. Therefore, GNSS mapping is being recommended by many state and federal agencies as the locational data collection method of choice.

Each state agency that collects locational data must understand that there may be other users of the data (in the present and/or in the future) with even more stringent accuracy requirements than their requirements. Therefore, each state government agency that collects locational data shall:

- Ensure that their locational data collecting personnel have a strong foundation in GNSS theory and have been trained in the proper use of GNSS equipment.

- Use either mapping-grade or survey-grade receivers in their GNSS data collection efforts. Non-professional receivers are <u>not</u> adequate for <u>any</u> state authoritative locational data collecting purpose. Non-professional grade receivers can be used for navigation and non-authoritative data collection activities, if the data collected is verified that it meets or exceeds the horizontal accuracy requirements by adhering to the procedure outlined in section **6 Alternatives to mapping with a mapping-grade GNSS receiver**.

- Test their GNSS receivers for accuracy daily if geodetic horizontal control monuments are located at the place of work or near the project site. At a minimum immediately prior to and immediately following the conclusion of a project, and at a minimum monthly.

- Differentially correct GNSS data or utilize the procedure outlined in section **6 Alternatives to mapping with a mapping-grade GNSS receiver**.

- Archive the digital products representing all stages of the GNSS data collection and processing chain (e.g. uncorrected field files, base station files used for differential corrections, electronic data entry forms, corrected GNSS files, and final GIS datasets).

- Document all GNSS-derived GIS data products with appropriate forms of metadata.

These minimum GNSS data collection and data documentation standards will have four (4) important effects:

- Each state agency that collects GNSS data will know exactly what is expected from their time and effort spent to collect the locational data.
- Local, state, and federal agencies using state GNSS data can do so with confidence in its quality, because the data will have been collected, differentially corrected or verified that it meets the state horizontal accuracy standard by comparing the collected data to independent data source that meets or exceeds the state horizontal accuracy requirement, and documented according to standardized procedures.
- The state will save money by maximizing original locational data collection accuracy and documentation, which eliminates the need to recollect data.
- The use of GNSS for collecting locational data will become more prevalent in state government, because GNSS technology, training, and data documentation will be more consistent and readily accessible.

8. References

Arkansas State Land Information Board. (2001). *Standards for Collecting Mapping-grade Global Positioning System Positions*. Retrieved from: http://www.gis.state.ar.us/Docs/LAW/GPS_Standard.pdf

August, P., Michaud, J., Labash, C., and Smith, C. (1994). *GPS for Environmental Applications: Accuracy and Precision of Locational Data*. *Photogrammetric Engineering and Remote Sensing*, v. 60, no. 1, pp. 41-45.

General Statutes of North Carolina. Chapter 89C: Engineering and Land Surveying. "The North Carolina Engineering and Land Surveying Act." (1951, c. 1084, s. 1; 1975, c. 681, s.1.). Retrieved from: http://www.ncga.state.nc.us/EnactedLegislation/Statutes/HTML/ByChapter/Chapter_89C.html

Gilbert, C. (1994, April). Accuracy Specifications of GPS Data Collection Systems - Code-Based vs. Carrier-Based Systems. *Earth Observation Magazine*, pp. 57-59.

Hurn, J. (1989). *GPS - A Guide to the Next Utility*. Trimble Navigation.

Hurn, J. (1993). *Differential GPS Explained*. Trimble Navigation.

New Jersey Department of Environmental Protection. (2002). *NJDEP GPS Data Collection Standards for GIS Data Development*. Retrieved from: http://www.nj.gov/dep/gis/gpsoutstand.html

United States Department of Agriculture Forest Service, Technology Development Program. (2004). *Comparing Four Methods of Correcting GPS Data: DGPS, WAAS, L-Band, and Postprocessing*. 0471–2307–MTDC. Retrieved from: http://www.fs.fed.us/database/gps/pubs/htmlpubs/htm04712307/

United States Environmental Protections Agency. (2003). *Global Positioning Systems - Technical Implementation Guidance*. Retrieved from: http://www.epa.gov/esd/gqc/pdf/GPS-TIG_rev_2.pdf

United States National Park Service, 2004. *Field Data Collection with Global Positioning Systems Standard Operating Procedures and Guidelines*. Retrieved from: http://www.nps.gov/gis/gps/documents/FieldDataCollectionwithGPS_070204.doc

Vermont Center for Geographic Information, Inc. (2005). Vermont GPS Guidelines. In, <u>VGIS Handbook</u>. Retrieved: http://vcgi.vermont.gov/sites/vcgi/files/guidelines/partiii_section_l.pdf

Victoria (Australia) Department of Sustainability and Environment and Department of Primary Industries. (2006). *Global Positioning System Handbook: GPS Data Collection for Integration with Geographic Information Systems - Standards, Specifications and Best Practice Field Guide, Version 7.2*. (56 p.). Retrieved from: http://www.dse.vic.gov.au/__data/assets/pdf_file/0018/104661/GPSHandbookreduced.pdf

9. Glossary

9.1. Abbreviation and acronyms

Abbreviation/Acronym	Definition
C/A code	Course/Acquisition GPS code
CORS	Continuously Operating Reference Station
CSDGM	Content Standards for Digital Geospatial Metadata
dBHz	decibel hertz
DD	Decimal degrees
DGPS	Differential Global Positioning System
DMS	Degrees minutes seconds
DoD	Department of Defense
DOP	Dilution of Precision
DOT	Department of Transportation
EDT	Eastern Daylight Time
EST	Eastern Standard Time
FAA	Federal Aviation Administration
FGDC	Federal Geographic Data Committee
GICC	Geographic Information Coordinating Council
GIS	Geographic Information System
GLONASS	Global Navigation Satellite System (English translation of Глобальная навигационная спутниковая система)
GMT	Greenwich Mean Time
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRS 80	Geodetic Reference System 1980
HAE	Height Above Ellipsoid

Continued from the previous page.

Abbreviation/Acronym	Definition
HDOP	Horizontal Dilution of Precision
LPV	Localizer Performance with Vertical guidance
MiFi	Mobile Wi-Fi, WiFi, or Wifi
MSL	Mean sea level
NAD 83	North American Datum of 1983
NAS	National Airspace System
NAVSTAR	Navigation and Vehicular Satellite Timing and Ranging
NCGS	North Carolina Geodetic Survey
NDGPS	Nationwide Differential Global Positioning System
NGS	National Geodetic Survey
OPUS	Online Positioning User Service
P-code	Precise code.
PDOP	Positional Dilution of Precision
PPS	Precise Positioning Service
PPS	Precise Positioning Service
PRN	Pseudo-Random Noise
RTK	Real Time Kinematic
RTN	Real-Time Network
SA	Selective Availability
SMAC	Statewide Mapping Advisory Committee
SNR	Signal to Noise Ratio
SPS	Standard Positioning Service

Table continued from the previous page.

Abbreviation/Acronym	Definition
UERE	User Equivalent Range Error
UFCORS	User Friendly Continuously Operating Reference Station
URE	User Range Error
USCG	United States Coast Guard
UTC	Coordinated Universal Time
WAAS	Wide Area Augmentation System
WGS 84	World Geodetic System of 1984
WMS	Wide-area Master Station
WRS	Wide-area Reference Station

9.2. Definitions

Term	Definition
Carrier phase GPS	The accumulated phase of either the L1 or L2 carrier of a GPS signal, measured by a GPS receiver since locking onto the signal. Also called integrated Doppler.
Code phase GPS	GPS measurements based on the pseudo random code (C/A or P) as opposed to the carrier of that code.
Control segment	That portion of the Global Positioning System that consists of a master control station, monitoring stations, and ground antennas, which monitor and update satellite signals and upload correction data to the satellites.
Course/Acquisition (C/A) code	Also known as the civilian code. A family of PRN codes transmitted by GPS satellites. Each satellite is assigned one of 32 unique codes in the family. Each code consists of 1,023 chips and is sent at a rate of 1.023 megabits per second. The code sequence repeats every millisecond.
Cycle slip	A discontinuity in GPS carrier-phase observations, usually of an integer number of cycles, caused by temporary signal loss. If a GPS receiver loses a signal temporarily, due to obstructions for example, when the signal is reacquired there may be a jump in the integer part of the carrier-phase measurement due to the receiver incorrectly predicting the elapsed number of cycles between signal loss and reacquisition.
Differential positioning	A technique for reducing the error in GPS-derived positions by using additional data from a reference GPS receiver (i.e. a base station) at a known position.
Dilution of Precision	A dimensionless number that accounts for the contribution of relative satellite geometry to errors in position determination. DOP has a multiplicative effect on the User Equivalent Range Error (UERE). Generally, the wider the spacing between the satellites being tracked by a GPS receiver, the smaller the position error.

Table continued on the next page.

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Term	Definition
Ephemeris	A description of the path of a celestial body indexed by time (from the Latin word, ephemeris, meaning diary). The navigation message from each GPS satellite includes a predicted ephemeris for the orbit of that satellite valid for the current hour. The ephemeris is repeated every 30 seconds and is in the form of a set of 16 Keplerian-like parameters with corrections that account for the perturbations to the orbit caused by the earth's gravitational field and other forces.
Ionosphere	That layer of the atmosphere approximately 30-300 miles above the earth's surface that contains electrically charged particles (ions). These charged particles interfere with or distort transmissions of electromagnetic signals through the layer.
Multipath error	Errors caused by the interference of a signal that has reached the receiver antenna by two or more different paths. Usually caused by one path being bounced or reflected.
P-code	The Precise code. A PRN code transmitted by GPS satellites. The code consists of about 2.35 3 1014 chips and is sent at a rate of 10.23 megabits per second. At this rate, it would take 266 days to transmit the complete code. Each satellite is assigned a unique one-week segment of the code that is reset at Saturday/Sunday midnight. The P-code is currently transmitted on both the L1 and L2 frequencies.
Precise Positioning Service	The full-accuracy, single-receiver GPS positioning service provided to the United States military, its allied military organizations, and other selected agencies. It includes access to the unencrypted P-code.
Pseudorange	The range between the antenna phase centers of a GPS satellite and a receiver, measured by the receiver's delay-lock loop using either the C/A- or P-code. The range is biased by the offset of the clock in the receiver from that in the satellite and by atmospheric propagation delays.

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Term	Definition
Selective Availability	A Department of Defense policy and procedure, which was discontinued as of May 1, 2000, that introduced intentional clock noise into the GPS satellite signals to degrade accuracy in the Standard Positioning Service (SPS) (i.e. civilian service).
Space segment	The part of the whole GPS system that is in space (i.e. the satellites).
Standard Positioning Service	Also known as the civilian system. The GPS single receiver (stand-alone) positioning service available to any user on a continuous, worldwide basis. It is intended to provide access only to the C/A-code and the L1 carrier.
Static positioning	Location determination when the receiver's antenna is presumed to be stationary on the earth. This allows the use of various averaging techniques to greatly improve accuracy.
User Equivalent Range Error or User Range Error	Any error contributing to the error budget of stand-alone GPS receiver positioning, expressed as an equivalent error in the range between a user's receiver and a satellite. UEREs originate from different sources, and thus are independent of each other. The total UERE is the square root of the sum of the squares of the individual errors.

10. GNSS resources

10.1. GNSS standards from governments and organizations

10.1.1. International

- British Columbia, Canada/Ministry of Forests, Lands and Natural Resources Operations

  o *Standards, Specifications and Guidelines for Resource Surveys Using Global Positioning System (GPS) Technology*   [April 2008]

    http://www.ilmb.gov.bc.ca/risc/pubs/other/gps/gps_standard_2008.pdf

- Natural Resources Canada/Geomatics Canada/Geodetic Survey Division

  o *GPS Positioning Guide*   [July 1995]

    http://webapp.csrs.nrcan.gc.ca/GPS_Guide_e/GPS_Guide_e.pdf

  o *Guidelines for RTK/RTN GNSS Surveying in Canada*   [July 2013]

    http://webapp.geod.nrcan.gc.ca/geod/publications/pdf/Canada%20RTK_UserGuide_v1%201_EN.pdf

- Province of Victoria, Australia/Department of Sustainability and Environment & Department of Primary Industries

  o *Handbook for GPS Data Collection for Integration with GIS Standards, Specifications and Best Practice Field Guide*   [Feb 2006]

    http://www.dse.vic.gov.au/__data/assets/pdf_file/0018/104661/GPSHandbookreduced.pdf

    Note: There are 2 underscores ("_" and "_") between ".au/" and "data" in the URL.

10.1.2. Federal

- NOAA/National Geodetic Survey (NGS)

  o *User Guidelines for Single Base Real Time GNSS Positioning*   [August 2011]

    http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v2.1.pdf

  o R*eal Time Positioning - Best Methods for the Field (webinar)*   [11-09-2011]

    http://www.ngs.noaa.gov/corbin/class_description/RT_field_2011.shtml

- U.S. Army Corps of Engineers

  o *Engineering and Design: Navstar Global Positioning System Surveying (EM 1110-1-1003)*   [02-28-2011]

    http://140.194.76.129/publications/eng-manuals/EM_1110-1-1003_pfl/

- U.S. Environmental Protection Agency (EPA)/Office of Environmental Information

  o *GPS Technical Implementation Guidance*   [July 2006]

    http://www.epa.gov/esd/gqc/pdf/GPS-TIG_rev_2.pdf

- U.S. Department of the Interior (DOI)/National Park Service (NPS)

  o *Field Data Collection with GPS Standard Operating Procedures and Guidelines* [07-02-2004]

    http://www.nps.gov/gis/gps/documents/FieldDataCollectionwithGPS_070204.doc

  o *Global Positioning System Data Acquisition and Processing*   [01-28-2009]

    http://science.nature.nps.gov/im/units/nccn/assets/docs/dm_docs/NCCN_GPS_Guidelines.pdf

10.1.3. State

- Arkansas State Land Information Board

  - *Standards for Collecting Mapping Grade Global Positioning System Positions and GPS Metadata*   [8-29-2001]

    http://www.gis.state.ar.us/Docs/LAW/GPS_Standard.pdf

- Georgia Department of Transportation (GDOT)

  - *GPS Data Collection Policy*   [5-2-2013 cited NC's GPS stds]

    http://mydocs.dot.ga.gov/info/gdotpubs/Publications/8085-2.pdf

- Idaho Transportation Dept (ITD)

  - *Global Positioning System Data Collection and Documentation Standards*   [8-15-2003]

    http://itd.idaho.gov/planning/gis/maps/Standards/GPSStandards.doc

- New Jersey Department of Environmental Protection (NJDEP)

  - *NJDEP GPS Data Collection Standards For GIS Data Development*   [6-8-2011]

    http://www.nj.gov/dep/gis/GPSStandards_2011.pdf

- Texas Commission on Environmental Quality

  - *GPS: Guidelines and Information*   [11-4-2002]

    http://www.tceq.state.tx.us/permitting/water_supply/pdw/SWAP/gps/opp_8.12.html

- Texas Department of Transportation (TXDOT)

  - *Survey Manual – GPS Surveying*   [April 2011]

    http://onlinemanuals.txdot.gov/txdotmanuals/ess/gps_surveying.htm

- Vermont Center for Geographic Information (VCGI)

  - *Vermont GPS Guidelines*   [September 2005]

    http://vcgi.vermont.gov/sites/vcgi/files/guidelines/partiii_section_l.pdf

10.1.4. Organizations

- Royal Institution of Chartered Surveyors (RICS)

  - *Guidelines for the use of GNSS in land surveying and mapping*   [11-2010]

    http://www.rics.org/us/shop/Guidelines-for-the-use-of-GNSS-in-Surveying-and-Mapping-18524.aspx

    http://www.cnavgnss.com/uploads/Guidelines_for_the_use_of_GNSS_in_surveying_and_mapping.pdf

10.2. GNSS information

10.2.1. Federal

- Federal Aviation Administration (FAA)

  o *Real-Time WAAS DOP Accuracy Display*   [updated every three minutes]

    http://www.nstb.tc.faa.gov/RT_NPACoverage.htm

- National Geospatial-Intelligence Agency

  o *Office of Geomatics*   [4-30-2013]

    http://earth-info.nga.mil/GandG/

- NOAA/National Geodetic Survey

  o *Continuously Operating Reference Station (CORS) Network*

    http://www.ngs.noaa.gov/CORS/   [12-17-2013]

  o *GPS and Geodesy for Dummies: Do You Know Where You Are?*   [08-19-2007]

    http://learningcenter.nsta.org/products/symposia_seminars/stlouis07/GPS/webseminar
    .aspx

- U.S. Coast Guard NAVCEN

  o *General information on GPS*   [12-11-2013]

    http://www.navcen.uscg.gov/?pageName=GPSmain

- U.S. Dept of Agriculture/Natural Resources Conservation Service (NRCS)

  o *National Geospatial Center of Excellence (NGCE)*   [no date info on the content, but
    the social media links imply that it is current]

    http://www.ncgc.nrcs.usda.gov/products/gps/index.html

- US Department of the Interior (DOI)/National Park Service (NPS)

  o *Global Positioning Systems*   [no date info on the content]

    http://www.nps.gov/gis/gps/

- U.S. Naval Operations Center

  o *GPS Timing and Data*   [updated each second]

    http://www.usno.navy.mil/USNO/time/gps

10.2.2. State

- New Jersey Department of Environmental Protection (NJDEP)

  - *A Guide to the Basic Concepts of the NAVSTAR Global Positioning System*   [5-8-2003]

    http://www.nj.gov/dep/gis/gpsweb/train00_files/frame.htm

10.2.3. Private

- Rocco V. D'Andrea, Inc.

  - *Interactive GPS Day/Week Calendar*   [3-15-2010]

    http://www.rvdi.com/freebies/gpscalendar.html

- Samuel J. Wormley

  - *GPS Errors & Estimating Your Receiver's Accuracy*   [7-15-2010]

    http://edu-observatory.org/gps/gps_accuracy.html

  - *DGPS Resources*   [12-18-2009]

    http://www.edu-observatory.org/gps/dgps.html

10.3. Online GNSS-related magazines

- *GeoInformatics*   [updated daily]

    http://www.geoinformatics.com/

- *GIM International*   [updated daily]

    http://www.gim-international.com/

- *GPS World*

    http://gpsworld.com/   [updated daily]

- *Inside GNSS*

    http://www.insidegnss.com/   [updated daily]

- *Point of Beginning*   [updated daily]

    http://www.pobonline.com/

- *Professional Surveyor*   [updated ~daily]

    http://www.profsurv.com/

- *Spatial Source*   [updated daily]

    http://www.gisuser.com.au/

10.4. Free mission planning software

- Trimble GNSS Planning Online   [almanac updated daily]

  http://www.trimble.com/GNSSPlanningOnline/#/Settings

- Trimble Planning Software v2.9   [Aug 2010]

  http://ww2.trimble.com/planningsoftware_ts.asp

  Note: This software requires the current almanac, which can be downloaded from either:

  - *NAVCEN* (http://www.navcen.uscg.gov/?pageName=gpsAlmanacs)

  - *Trimble* (ftp://ftp.trimble.com/pub/eph/almanac.alm)

10.5. Commercial GNSS software
10.5.1. Field computer software

- ESRI ArcPad

  http://www.esri.com/software/arcgis/arcpad

  Note: Mobile field mapping and data collection software

  - Extensions for ESRI ArcPad or ArcGIS mobile

    – Trimble Positions Software Suite

      http://www.trimble.com/mappingGIS/trimblepositions.aspx

      Note: Integrates Trimble's field solutions/data verification into the ArcGIS environment

    – Trimble GPSCorrect Extension for ESRI ArcPad

      http://www.trimble.com/mappingGIS/gpscorrect.aspx

      Note: Provides the ability to log GNSS data for post-processing

- Leica Zeno Field & Office

  http://www.leica-geosystems.us/en/Leica-Zeno-Field-Office_79643.htm

  Note: Original equipment manufacturer (OEM) version of ArcPad that provides GNSS raw data logging for post-processing

- Trimble TerraSync

  http://www.trimble.com/mappingGIS/TerraSync.aspx

  Note: Field GIS data collection and maintenance with seamless GNSS control in the field

10.5.2. Desktop software

- Leica Zeno Field & Office

    http://www.leica-geosystems.us/en/Leica-Zeno-Field-Office_79643.htm

    Note:Provides the ability to post-process GNSS data within ArcGIS Desktop

- Trimble GPS Pathfinder Office

    http://www.trimble.com/mappingGIS/PathfinderOffice.aspx

    Note:Provides the ability to post-process, manage, and export GNSS data

- Trimble GPS Analyst Extension for ESRI ArcGIS

    http://www.trimble.com/mappingGIS/gpsanalyst.aspx

    Note:Provides the ability to post-process GNSS data within ArcGIS Desktop

10.6. Government software

- NOAA/National Geodetic Survey

    o *Geodetic Toolkit*

        http://www.ngs.noaa.gov/TOOLS/

    o *Geodetic software*

        http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml

10.7. GPS/GNSS receivers

> Note: Several of the following GPS/GNSS receivers could be placed in more than one accuracy category depending on the data collection method utilized)

10.7.1. Sub-foot accuracy mapping-grade

- ikeGPS

    o ikePro (http://www.ikegps.com/ikegps/ikepro/), but only in combination with a Septentrio APS-3X Pak (http://www.ikegps.com/ikegps/high-accuracy-tools/)

- Leica

    o Leica CS25 GNSS

        http://www.leica-geosystems.us/en/Leica-CS25-GNSS_101857.htm

- Spectra Precision

    o MobileMapper 100

        http://www.spectraprecision.com/products/gis-mobile-mapping/mobilemapper-100/

- SX Blue (only the RTN or OmniStar enabled series)

    o SXBlue III GNSS

        http://sxbluegps.com/product/sxblue-iii-gnss/

    o SXBlue III-L GNSS

        http://sxbluegps.com/product/sxblue-iii-l-gnss/

    o SXBlue III GPS

        http://sxbluegps.com/product/sxblue-iii-gps/

- Trimble

    o Trimble Pro 6H

        http://www.trimble.com/mappingGIS/pro6.aspx

    o Trimble Pro 6T

        http://www.trimble.com/mappingGIS/pro6.aspx

    o Trimble Geo 6 Series (Geo XH)

        http://www.trimble.com/mappingGIS/geo6.aspx

10.7.2. Sub-meter (1 - 3 feet) accuracy mapping-grade

- Trimble
  - GPS Pathfinder ProXRT

    http://www.trimble.com/mappingGIS/pathfinderproxrt.aspx

  - Geo 7 Series

    http://www.trimble.com/mappingGIS/geo-7-series.aspx

  - Geo 6 Series (Geo XT)

    http://www.trimble.com/mappingGIS/geo6.aspx

  - GeoExplorer 5 Series

    http://www.trimble.com/mappingGIS/geo5.aspx

- Leica
  - Leica Zeno 10 & Zeno 15

    http://www.leica-geosystems.us/en/Leica-Zeno-10-Zeno-15_79645.htm

- Spectra Precision
  - MobileMapper 120

    http://www.spectraprecision.com/products/gis-mobile-mapping/mobilemapper-120/

  - MobileMapper 10

    http://www.spectraprecision.com/products/gis-mobile-mapping/mobilemapper-10/

10.7.3. Sub-5 meter (3 - 15 feet) accuracy mapping-grade

- Trimble

  o Juno 5 Series Handheld

    http://www.trimble.com/mappingGIS/juno5.aspx

  o Juno 3 Series

    http://www.trimble.com/mappingGIS/juno3.aspx

  o Juno SD

    http://www.trimble.com/mappingGIS/junoS.aspx

  o Juno SA

    http://www.trimble.com/mappingGIS/junosa.aspx

  o Nomad G Series

    http://www.trimble.com/mappingGIS/nomadg.aspx

  o Yuma 2 Rugged Tablet

    http://www.trimble.com/mappingGIS/yuma2_rugged_tablet.aspx

- Leica

  o Leica Zeno 5

    http://www.leica-geosystems.us/en/Leica-Zeno-5_99189.htm