

**Geographic Information Coordinating Council
Statewide Mapping Advisory Committee**

**Statewide
Global Positioning System (GPS)
Data Collection and Documentation Standards**

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1. Executive summary

Due to the increasing use of Global Positioning System (GPS) 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.

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 GPS theory and have been trained in the proper use of GPS equipment.
- Use either mapping-grade or survey-grade receivers in their GPS data collection efforts. Because, recreational-grade receivers are not adequate for any state locational data collecting purpose.
- Test their GPS receivers for accuracy every six (6) months to identify faulty receivers for repair or disposal.
- Differentially correct GPS data.
- Archive the digital products representing all stages of the GPS data collection and processing chain (e.g. uncorrected field files, base station files used for differential corrections, electronic data entry forms, corrected GPS files, and final GIS datasets).
- Document all GPS-derived GIS data products with appropriate forms of metadata.

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

- Agencies that collect GPS data will know exactly what is required
- Agencies that use state GPS 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 GPS will become more prevalent in state government

2. Position statement

This document is an update to the minimum standards that were adopted in December 1999 to be used by all state agencies and their contractors using Global Positioning System (GPS) 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. GPS will be the principal tool for collecting locational data used in systems (such as computer models and geographic information systems) for which horizontal geographic accuracy is critical. GPS is an important and cost effective method for locating features too numerous or too dynamic to be mapped by traditional methods. Therefore, GPS is being recommended by many state and federal agencies as the locational data collection method of choice.

There are three components to GPS.

1. The Space Component which consists of the GPS satellites.
2. The Control Component which consists of a system of tracking stations located around the world.
3. The User Component which consists of the GPS receivers and the user community.

GPS receivers or units fall into two categories: Recreational 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 or recreational-grade receivers, but is focused on the use of professional mapping-grade receivers. The choice of a GPS receiver depends upon the intended use and the accuracy requirement of the GPS locational data.

- Recreational-grade GPS 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, because these receivers operate in autonomous point positioning mode without the GPS-derived positions being differentially corrected in either real-time or post-processing. These GPS receivers are the least accurate of all the grades.
- “Enhanced” recreational-grade GPS receivers that have been equipped to operate in a differential GPS (DGPS) mode with added modules can in most instances meet state standards.
- Mapping-grade GPS receivers have the capacity for higher accuracy (sub-foot to five meters horizontal accuracy) and are designed to facilitate data collection for a GIS program. Mapping-grade GPS units use differential correction for high accuracy.
- Survey-grade GPS 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 or recreational-grade GPS activities. Agencies involved in locational data collection must decide whether or not their projects require survey-grade accuracy (i.e., +/- 1 cm). Surveying activities are governed by strict standards beyond the scope of this document. This document defines standards for on-ground field collection using GPS and does not address aerial GPS data collection or control. These standards apply to current GPS technology. The standards will require periodic review and possible revision as GPS technologies evolve.

There are five (5) main uses for GPS 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:** Providing control for map production and attaching coordinates to features, attributes, and metadata
- **Timing:** Providing precise timing

GPS techniques are one of the primary tools for locating features on the earth's surface. In North Carolina, government agencies, academic institutions, and private companies are using GPS 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 GPS, such features had to be located with surveying equipment, aerial photographs, or satellite imagery. Now with GPS, these features can be located by a single operator using hand-held equipment. However, the accuracy of data collected using GPS 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 GPS receivers**
- **Differentially correct the GPS derived locational data**

Note: Recreational-grade receivers are NOT adequate for this type of data acquisition.

Recreational and professional GPS 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 of less than 5 meters for mapping of 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, the vertical accuracy from a GPS observation is 2-3 times less 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 GPS data collection and data documentation standards will have four important effects:

1. Agencies collecting GPS 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 GPS 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 GPS for collecting locational data will become more prevalent in state government because GPS technology, training, and data documentation will be more consistent and more readily accessible.

The Geographic Information Coordinating Council (GICC) supports the development and adoption of standards for the successful collection, exchange, and use of locational data. GPS data collection standards are necessary, so that state agencies and their contractors have minimum specifications for collecting GPS data. Contractors should be in compliance with General Statute Chapter 89C (Engineering and Land Surveying), when applicable, with respect to the collection of GPS data.

GPS data documentation in the form of metadata is required to provide data users with specific information about the lineage of a data set, so it can be used with full knowledge of its source, quality, and content. Adequate metadata is required for the appropriate, responsible, and defensible use of any geographic data set. The GICC has adopted the FGDC "*Content Standards for Digital Geospatial Metadata*" (CSDGM):

<http://fgdc.er.usgs.gov/metadata/contstan.html>

3. Background on GPS

The Global Positioning System (GPS), which is a satellite based positioning and navigation 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.

The GPS system consists of the following three segments:

Space: The constellation of 29 (as of February 6, 2006) NAVSTAR satellites that orbit the earth twice a day at an altitude of approximately 20,200 km (12,500 miles)¹.

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

Users: GPS 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 GPS 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. Future satellites will provide a third frequency (L5), a civilian code on L2, and a military code on all signals. Additional information on GPS modernization can be found at the following URL:

<http://www.navcen.uscg.gov/gps/modernization/default.htm>

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. GPS 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 GPS receiver uses the process of trilateration to determine its position.

¹ 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, 29 satellites were in orbit.

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:

- **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 GPS receiver, which results in derived distant errors.
- **Positional Dilution of Precision (PDOP) value:** The satellite position geometry index for precision (Figure 2): Optimum locational data configuration (low PDOP) where the GPS satellites are spread out; and Poor locational data configuration (high PDOP) where the GPS satellites are bunched together.

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). Differential GPS involves the use of a stationary receiver, referred to as a base station, that continuously records satellite measurements at a fixed and known location. Since the base station 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 GPS antenna. This error correction factor information can be either:

- Broadcasted by a radio transmitter or transmitted via telephone for real-time differential correcting by specially equipped GPS receivers with a radio link or cell phone data link, respectively.
- Stored on an Internet server for GPS users to download the data and do their differential correcting procedure later on a computer by post-processing.

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

- For real time differential correcting, the roving receiver applies the broadcasted or transmitted differential corrections to its GPS range observations as they are collected in order to remove errors in the ranges and improve the accuracy.

- For post-processing differential correcting, the differential corrections are retrieved over the Internet and applied to stored GPS range observations that have been downloaded from the roving receiver to a computer equipped with post-processing software that removes the errors in the ranges and improves 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 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 a network of GPS base stations. Due to the fact that NCGS is continually adding new base stations, users are advised to contact NCGS or view a current listing on the “GPS Base Stations in North Carolina” web page at the following URL:

<http://www.ncgs.state.nc.us/basestation.html>

The quality of the GPS receiver also has a significant impact on positional accuracy. Survey-grade receivers are the most expensive and produce data of the highest accuracy. Mapping-grade receivers (listed in section 3. “Mapping-grade receiver levels”) are mid-range in price and provide sufficient accuracy for most locational and GIS applications.

Data obtained using recreational-grade receivers, the least expensive type of receiver, is the least accurate. Some recreational-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 recreational-grade GPS receivers. The horizontal accuracy of such “enhanced” recreational-grade GPS systems can in most instances meet the “within 5 meters 95% of the time” state standard.

Note: **The enhanced 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 recreational-grade GPS unit up to mapping-grade standards begins to approach that of lower-end mapping-grade GPS units. It is questionable whether this approach to acquiring GPS equipment is a sound investment. For more information, Internet resources are listed in section 8.13.

Without differential correction, the accuracy of any GPS 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 differential GPS 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: GPS 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	± 1 cm	± 1 cm
Mapping	Yes	± 1-5 m	± 1-5 m
Enhanced Recreational	Note ¹	Note ²	OPUS-GIS ³

Note¹: Requires external hardware device or built in data collection capacity.

Note²: Requires external radio beacon or built-in capability to receive range corrections.

OPUS-GIS³: The mapping-grade version, which is being developed by the National Geodetic Survey (NGS), of the automated On-line Positioning User Service (OPUS) that differentially corrects GPS data submitted by users and then emails the corrected files back to each user. For more information on OPUS, please visit the following URL:

<http://www.ngs.noaa.gov/OPUS/>

4. Mapping-grade receiver levels

This section provides a list of mapping-grade GPS receivers, which were available at the time of this document's publication, at the following levels of accuracy:

- 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 (i.e with a beacon) or after the data is collected by post-processing.

Disclaimer: NCGS has not tested each of the following listed GPS receivers, and therefore cannot verify any manufacturer's stated accuracy level for a receiver. Furthermore, the following listings do not constitute an endorsement of any specific GPS product by NCGS, nor does it intentionally exclude any available mapping-grade receiver. Rather, the following lists only exist to provide examples of the different levels of mapping-grade GPS equipment available at the time of this document's publication.

4.1. Sub-foot mapping-grade

- Trimble Pathfinder ProXH
<http://www.trimble.com/pathfinderproxh.shtml>
- Trimble GeoXH units
<http://www.trimble.com/geoxh.shtml>
- CMT HP-GPS-L4
<http://www.cmtinc.com/fieldcmp/hpgpsl4.html>

4.2. Sub-meter (1 - 3 feet) mapping-grade

- Trimble ProXT
<http://www.trimble.com/proxt.shtml>
- Trimble GeoXT
<http://www.trimble.com/geoxt.shtml>
- Leica GS20
http://www.leica-geosystems.com/corporate/en/products/gps_systems/lgs_4502.htm
- CMT ALTO-G12
<http://www.cmtinc.com/fieldcmp/alto.html>

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

- Trimble GeoXM
<http://www.trimble.com/geoxm.shtml>
- Thales Mobile Mapper CE
<http://products.thalesnavigation.com/en/products/product.asp?PRODID=1021>
- Thales Mobile Mapper Pro
<http://products.thalesnavigation.com/en/products/product.asp?PRODID=1043>
- CMT MC-GPS and March II units
<http://www.cmtinc.com/fieldcmp/march.html>
- Surveylab Ike
http://www.surveylab.co.nz/Detailed_ike_information/Specifications.html
- GENEQ SXBlue
<http://www.geneq.com/catalog/en/sxblue.html>

5. Best practices for GPS use

The best practices for using GPS technology include

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

5.1. Purchasing

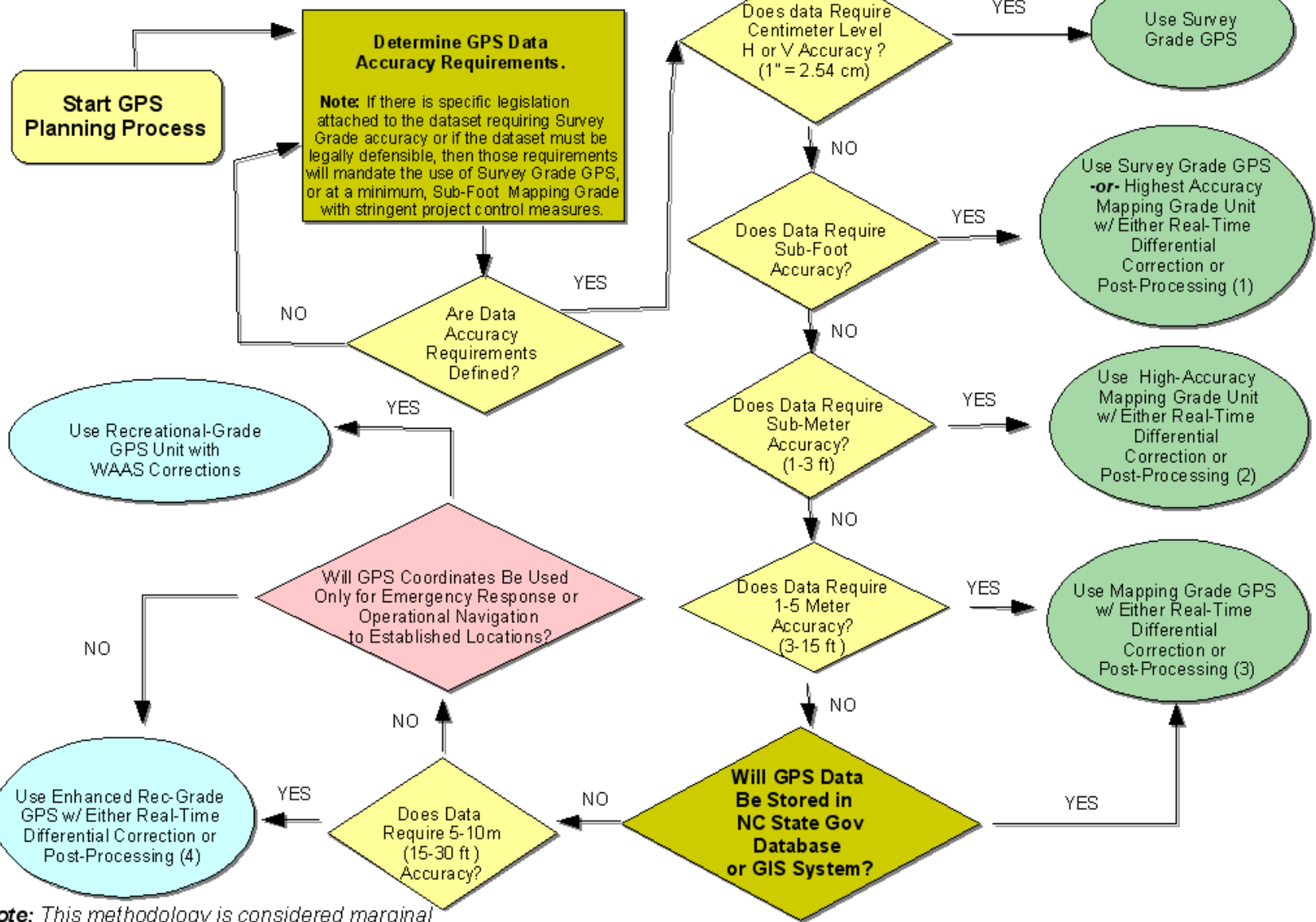
State government agencies are encouraged to coordinate their purchases of GPS technology with NCGS. The NCGS staff are aware of the latest developments in the technology and the relative specifications between product offerings of the various GPS vendors.

5.2. Using the most appropriate grade of receiver

To select the most appropriate GPS receiver grade, answer the questions in the GPS receiver selection decision tree (Figure 1).

State of North Carolina GPS Data Collection Standards

GPS Receiver Selection Decision Tree Diagram



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 1. 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, and thus a 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. 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. Note: An elevation mask is the setting to exclude satellites below a certain angle from the horizon. In this case, satellites below 15 degrees will NOT be used by the GPS receiver.

5.3.4. Datum

NAD 83, the state legislated datum

5.3.5. Ellipsoid

GRS 80

5.3.6. Satellites

Minimum of four (4) satellites.

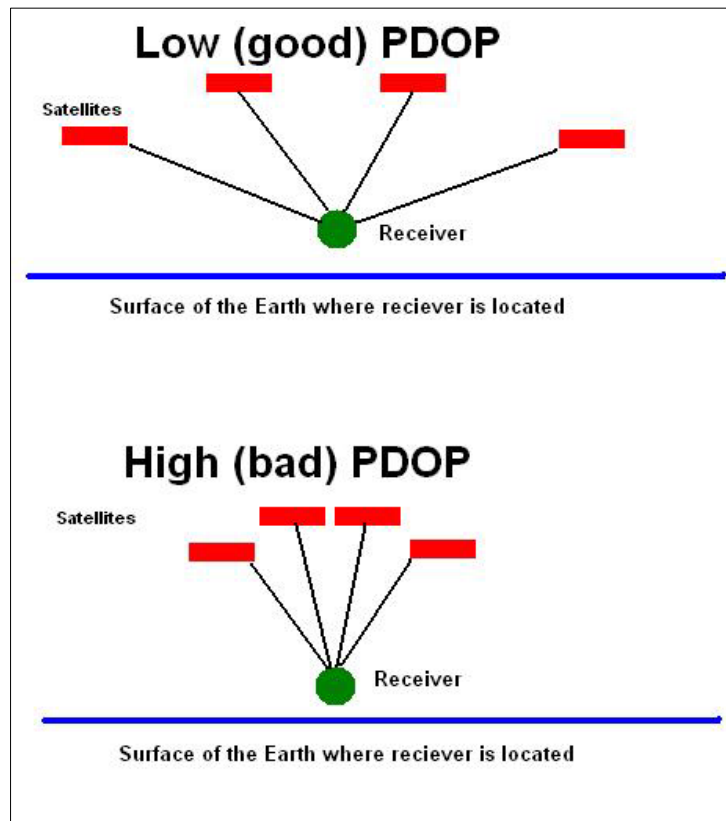
5.3.7. Signal to Noise Ratio (SNR)

Four (4)

5.3.8. Positional Dilution of Precision (PDOP)

Less than six (6). The Positional Dilution of Precision (PDOP) is satellite position geometry index for precision referring to how close or far apart the satellites are from one another in the sky (Figure 2).

Figure 2. A diagram showing the satellite position geometry index for precision, Positional Dilution of Precision (PDOP): Low PDOP (Good location data configuration) where the GPS satellites are spread out in the sky (top image); and High PDOP (bad location data configuration) where the GPS satellites are bunched together in the sky (bottom image).



5.4. Mission planning

GPS mission planning is an effective method for GPS users to determine the optimal time to perform field data collection. Two of the most important factors in obtaining the highest accuracy in your GPS data are having 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 GPS data. Furthermore, these high PDOP conditions are exacerbated in mountainous terrain, heavy forest cover, or urban canyon situations, because satellite signals are being 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).

Free software programs are available that will allow GPS users to perform mission planning for their data collection projects. Most modern GPS processing software also includes an integrated mission planning module. It is important to note that a GPS mission planning software requires a GPS almanac file (i.e. GPS satellite orbit information) that is current (i.e. within two weeks of the current date). In addition, a GPS receiver uses an almanac file to determine approximately where the satellites are relative to the local sky.

Current almanac files may be obtained directly from a mapping-grade GPS receiver. Note: The GPS receiver should track satellites for at least 15 minutes before the user transfers the almanac file to ensure that the file is complete. It is also possible to download almanac files from the following sources:

- NCGS base station web page (<http://www.ncgs.state.nc.us/basestation.html>)
- U.S. Coast Guard's NAVCEN web page (<http://gps.gov/gps/almanacs.htm>)
- Certain GPS manufacturers' websites

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

5.5. Processing data

5.5.1. Processing data settings

5.5.1.1. Units

US Survey Foot. The NC General Statutes require US Survey Foot for English to metric conversion whereby one (1) meter is equivalent to 3.280833333 feet.

5.5.1.2. Coordinate system

North Carolina State Plane, the state legislated coordinate system (GS 102).

5.5.1.3. Vertical datum

North American Vertical Datum of 1988

5.5.2. Timely post-processing of GPS data

GPS data may be corrected by two methods:

- Real time corrections from a DGPS radio beacon, NCGS Real Time Kinematic (RTK) Network, or a satellite correction service provider, such as Omnistar.
- Post-processing by downloading GPS base station files and using desktop software to perform the differential corrections after the data has been collected.

In order to post-process, the software needs GPS base station correction files, which can be downloaded from the following NCGS web page:

<http://www.ncgs.state.nc.us/basestation.html>

It is important for GPS users to not delay differentially correcting their uncorrected field files (i.e. stockpiling them for en masse processing), but rather to download the necessary base station correction files and perform the differential correction process on a daily or weekly basis, because NCGS only posts GPS correction files for a period of a few weeks due to space constraints on the web server.

If a GPS user delays post-processing and then later discovers that the necessary correction files are no longer available from the NCGS website, that user may download archived base station correction files from the National Geodetic Survey (NGS) from the following web page:

<http://www.ngs.noaa.gov/CORS/>

Note: GPS users must be aware that NGS utilizes a different reference datum [NAD 83 (2011)] than NCGS (NAD 83/86), which means that North Carolina GPS users must perform a datum shift in the processing to correctly use these archived correction files. Users who need assistance with this process should contact NCGS. Please note that this situation of NGS and NCGS using a different reference datum should be resolved by February 2007 when NGS will have finished its National Adjustment project and released the NAD 83/National Spatial Reference System (NSRS) datum.

In addition to performing post processing of data collected by GPS receiver, real time differential GPS can be performed using the following systems:

- NCGS Real Time Kinematic (RTK) Network
- Nationwide Differential Global Positioning System (NDGPS)
- Commercial service providers, such as Omnistar

5.5.3.2. Nationwide Differential Global Positioning System (NDGPS)

The Nationwide Differential Global Positioning System (NDGPS) provides differential corrections that, if received, can yield a horizontal accuracy of 1-3 meters (m) at the 95% confidence level, and therefore 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 GPS receiver's real-time settings with the following cascading search protocol:

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

Therefore, the user will still need to post-process the collected GPS field data to ensure that each collected GPS position has been differentially corrected. Basically, when used for mapping, the real-time corrections can provide a good map, but this map may have an undeterminable number of positional errors. Alternatively, when NDGPS is used for navigation, the correction signals allow the operator to navigate to known points at the 1-3 m horizontal accuracy level.

The purpose of the NDGPS is to provide accurate positioning and location information to meet surface transportation navigation needs (e.g. emergency response units, positive train control, harbor navigation, 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 from farming to surveying to mapping to scientific applications.

The system 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, Hawaii, and Puerto Rico.

Although the system is led by the USCG, it is an interagency collaborative with the following partners:

- Federal Highway Administration
- Federal Railroad Administration
- National Oceanic and Atmospheric Administration
- U.S. Air Force
- U.S. Army Corps of Engineers
- Office of the Secretary of Transportation
- State, county, and local governments

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.

In North Carolina, there is an NDGPS tower site in New Bern and in Greensboro, which provides double coverage in the eastern half of the state and single coverage as far west as Hickory (Figure 4). To achieve double coverage throughout the entire state, the USCG is installing a site in Dandridge, Tennessee and is planning to install a site in Polk County.

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 GPS vendors, to either the site's broadcast transmitting frequency or its broadcast site ID. For example, with the two North Carolina sites:

- New Bern (294 KHz/ID 771)
- Greensboro (303 KHz/ID 824)

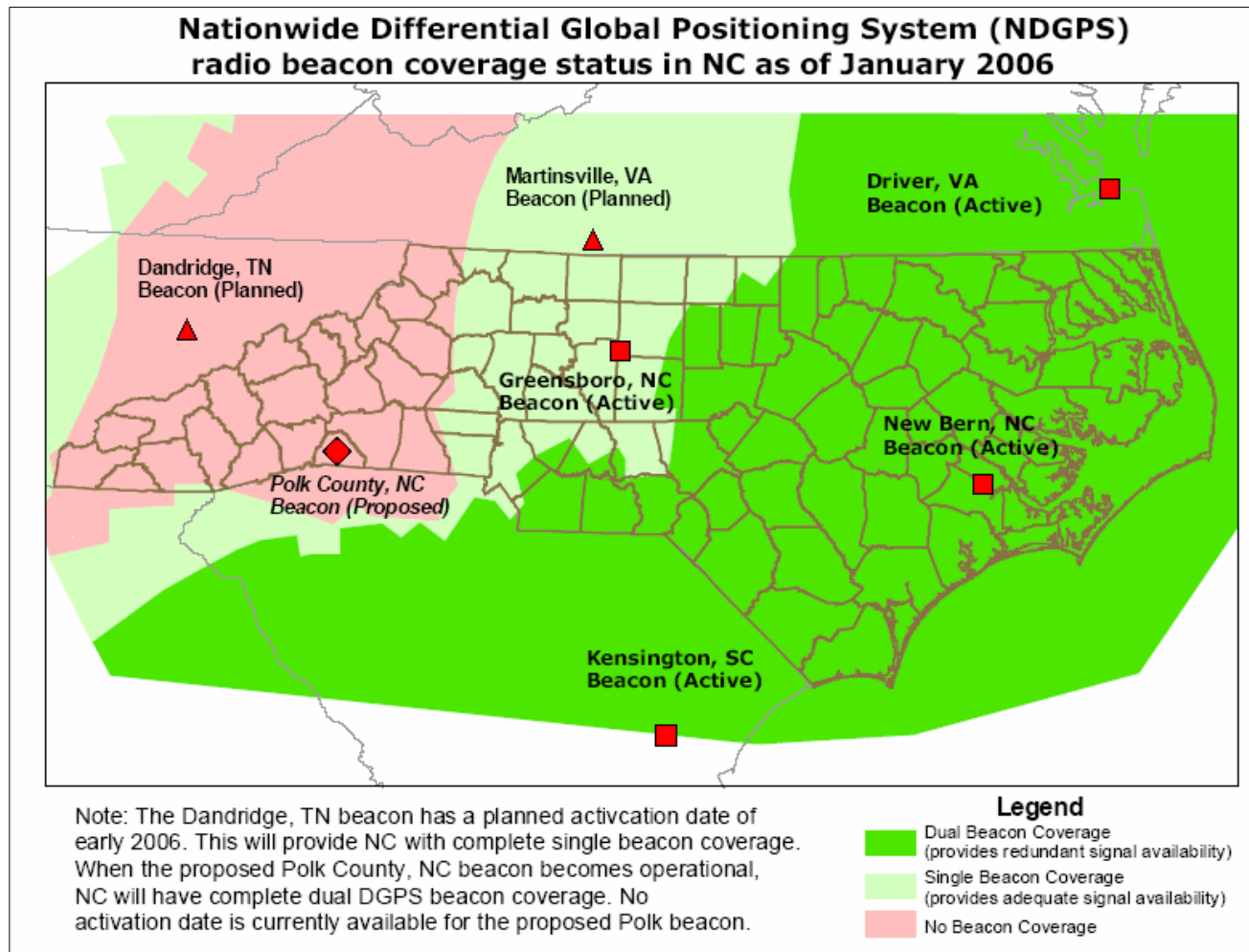


Figure 4. The Nationwide Differential Global Positioning System (NDGPS) radio beacon coverage status map of North Carolina showing: dual beacon coverage in dark green; single beacon coverage in light green; and no beacon coverage in pink. In addition, active beacons are marked with a square, planned beacons are marked with a triangle, and the proposed beacon is marked with a diamond.

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.

Note: This standard will be reviewed in the future with advances in GPS receiver technology and the integration of a third WAAS satellite for North America in the fall of 2006.

Note: Certain high quality mapping receivers, such as the Trimble GeoXT, can yield post-processed levels of accuracy with WAAS. Yet, since this differential correction procedure is dependent on receiving a highly interruptible radio signal corresponding to each collected GPS position, a high quality mapping receiver user must set the GPS 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.

Therefore, even these high quality mapping receiver users will still need to post-process the collected GPS field data to ensure that each collected GPS position has been differentially corrected. Basically, when used for mapping, the WAAS real-time corrections can provide a good map, **but this map may have an undeterminable number of positional errors**. Alternatively, when WAAS is used for navigation, the correction signals allow the operator to navigate to known points.

WAAS is being 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 can not provide the positional accuracy to meet FAA's navigation requirements for accuracy, availability, and integrity. WAAS tackles each of these requirements accordingly:

- Positional accuracy 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 (LPV) to most of the continental U.S.

The system utilizes a network of precisely-located ground reference stations positioned across the continental U.S., Alaska, Hawaii, and Puerto Rico; with additional stations being installed in Canada and Mexico. These stations collect and process GPS satellite data and send this

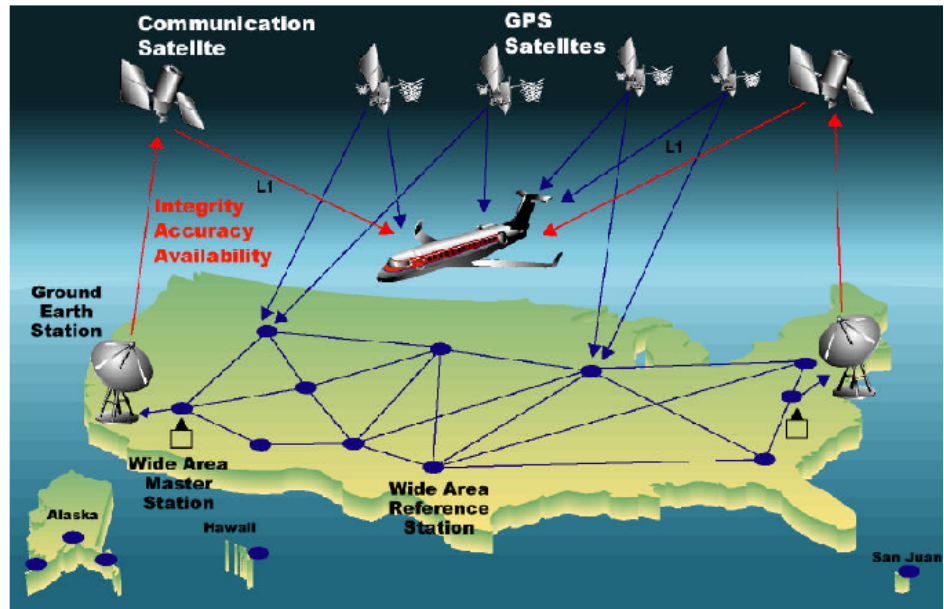


Figure 5. The basic design of the Wide Area Augmentation System (WAAS) showing the ground reference stations receiving GPS signals, which are sent to either of the two master stations, which calculates correction signals and transmits them to that station's corresponding communication satellite to be broadcasted for airplane navigation purposes.

data to either of the two (2) master stations, which calculates GPS correction messages and then sends these messages to the station's corresponding geostationary satellite to be broadcasted for airplane navigation using the same L1 frequency as the GPS satellites (Figure 5).

As for mapping and navigating on the ground, the GPS receiver must have a clean line-of-sight to one of the geostationary WAAS satellites to receive the signals and be a WAAS enabled GPS 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 mapping in the field. Although North Carolina is one of the states located closest to the WAAS satellite for the eastern U.S. (Figure 6), the satellite always resides relatively low in the southeastern sky at 40° elevation due to being positioned at an elevation of 35,845 km (22,224 miles) in a geostationary orbit at 0° N and 53° W (i.e. near the Brazilian border with French Guiana and Suriname).

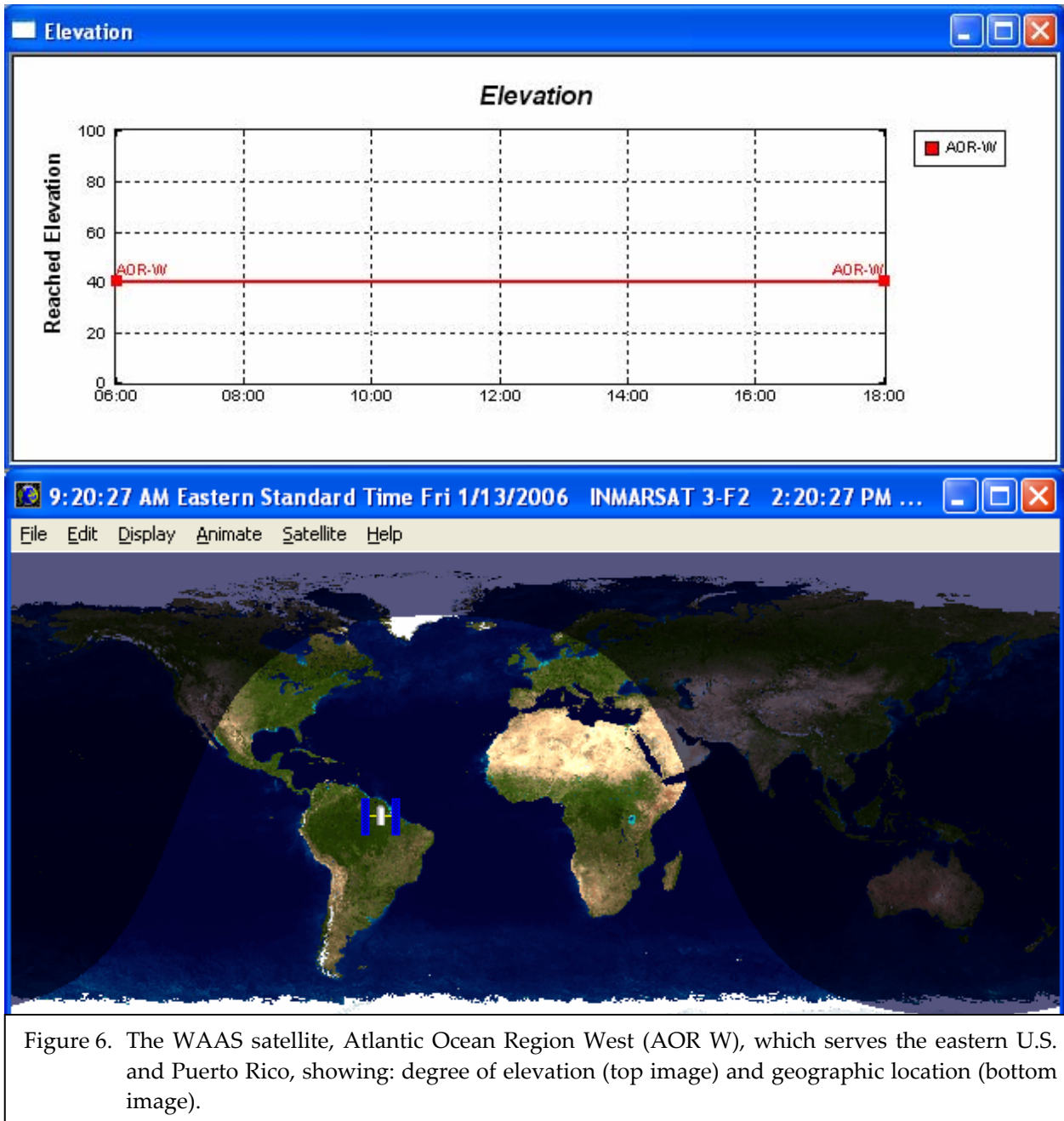


Figure 6. The WAAS satellite, Atlantic Ocean Region West (AOR W), which serves the eastern U.S. and Puerto Rico, showing: degree of elevation (top image) and geographic location (bottom image).

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

5.6. GPS records retention and accessibility

It is strongly recommended that GPS data collectors archive (i.e. safely backed up on tape, CD, or DVD in an organized manner) all phases of the data used to create either a GIS data layer or GPS coordinates stored in a relational database. The GPS data files should be easily retrievable if questions about the processing methodology ever arise. Retaining the raw GPS 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) GPS filed data files
- GPS 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 GPS datasets

5.7. Equipment and procedure testing

To ensure that faulty GPS receivers can be identified for repair or disposal, all GPS 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) epochs (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 GPS 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 web site at the following URLs:

- [Digital County Maps \(http://www.ncgs.state.nc.us/digitalmaps.html\)](http://www.ncgs.state.nc.us/digitalmaps.html)
- [NCGS Database \(http://www.ncgs.state.nc.us/searcher.html\)](http://www.ncgs.state.nc.us/searcher.html)

Each agency that uses GPS 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 GPS” course is available from NCGS and other organizations for the benefit of the GPS user. This course covers the basics of GPS theory, field receiver operation, differential correction, and data documentation. It is recommended as a first step in the training process for new users of GPS technology.

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

5.9. GPS data documentation (metadata)

Data collected using GPS 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 GPS 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://fgdc.er.usgs.gov/metadata/csdgm/02.html>

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

- 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 (Note: Please read pages 28 – 30 for a detailed explanation).
- Documentation in each feature’s attributes of a GIS layer of the quality of GPS positional information used to create that feature (Note: Please read pages 31 – 32 for a detailed explanation).

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 Federal Geographic Data Committee (FGDC) metadata record for the final GIS dataset. This documentation should include the following information:

- The type of receiver(s) used to collect the GPS 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 GPS data collection
- The differential correction methods applied to the raw data, including type of correction, software name and version used
- The GPS base station(s) used for differential correction of GPS data
- The approximate distance of the base station from the target GPS data
- The projection or coordinate system used
- The datum used
- The units of measure used
- The altitude reference system (HAE or MSL, if MSL define geoid)
- The estimated percentage of vegetative cover (i.e. canopy) over feature locations
- The part of the feature where coordinates were recorded (general perimeter, center line, center point, shoulder of road/river, centroid of parcel, driveway entrance, 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 GPS data collection.

Occasionally, project restrictions or unavoidable circumstances may necessitate GPS receiver settings or collection methods outside of those recommended by the State of North Carolina's GPS standard. When this occurs, the actual GPS 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 GPS 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 this information is captured.

Table 2: A standard metadata checklist.

Requirement	Example
Receiver Type (s) used	<i>Manufacturer & Type:</i> Trimble GeoXM Trimble Pocket GPS Thales Mobile Mapper CMT March II
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 GPS Collection	Between 1/15/05 and 3/15/05
GPS correction methodology utilized	Code Phase Post-Processed Differential using Trimble's Pathfinder Office 3.1 software, including appropriate levels of detail in the metadata process steps. Other options might include: <ul style="list-style-type: none"> • Code Phase Real Time Differential (list correction source, e.g. CORS beacon, OmniStar, WAAS) • Carrier Phase / Real Time Kinematic • Carrier Phase / Static • Carrier Phase / Fast Static

Table continued on the next page.

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Requirement	Example
<p>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://www.ncgs.state.nc.us/basestation.html</p>	<p>Raleigh (RALR) The reference position used by NGS is a NAD_83 POSITION (EPOCH 2002.0). NAD 83/86 position of L1 phase center of geodetic antenna</p> <ul style="list-style-type: none"> • Latitude: 35 47 12.85682 • Longitude: -78 38 19.42264 • Ellipsoid Height (Epoch 2002): 143.092 meters (+/- 0.05 meters) • NGVD 29 Orthometric Height: 176.22 meters (+/- 0.02 meters) • NAVD 88 Orthometric Height: 175.95 meters (+/- 0.02 meters) • Receiver: Trimble 4700 • Antenna: L1/L2 with ground plane
<p>Approximate distance from the base station used for differential correction</p>	<p>20-30 miles</p>
<p>Coordinate system used by GPS Receiver(s)</p>	<p>Geographic (Latitude/Longitude):</p> <ul style="list-style-type: none"> • Degrees Minutes Seconds (DMS) • Decimal Degrees (DD) <p>NC State Plane (Zone 3200):</p> <ul style="list-style-type: none"> • Feet • Meters
<p>Unit of Measure</p>	<p>Feet or Meters</p>
<p>Datum used by GPS Receiver(s)</p>	<p>WGS84</p>
<p>Altitude reference system</p>	<p>HAE (Height Above Ellipsoid) or MSL (Mean Sea Level) – if MSL is used, indicate which Geoid Model was used</p>
<p>Average percent of vegetative cover</p>	<p>20%</p>
<p>General location where the coordinates were recorded (if applicable)</p>	<p>Front door of main building Intersection of driveway and main road Approximate center of parcel As close to the smokestack as possible</p>
<p>Type of offset used (if applicable)</p>	<p>15' right offset from road centerline</p>
<p>Collection speed/mode</p>	<p>Stationary Walking Moving Bicycle Moving Motorized vehicle</p>

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 GPS metadata is dependent upon the software and hardware product(s) used to collect and process the GPS data. Therefore, it is not feasible to specify a complete set of GPS quality attributes that are universally supported. However, since the vast majority of North Carolina state and local government agencies use Trimble brand GPS hardware and software for their mapping-grade GPS data collection, this GPS standard advises that all GPS-collected GIS datasets should include as many of the GPS quality attributes that are readily available from Trimble GPS systems. The Trimble Pathfinder Office software supports retention and export of the GPS quality attributes listed below to the final GIS file format for each feature. The majority of mapping and survey-grade GPS receivers and software packages should support collection and export of many, if not all, of the GPS quality attributes available for "All Feature Types" (Figure 7).

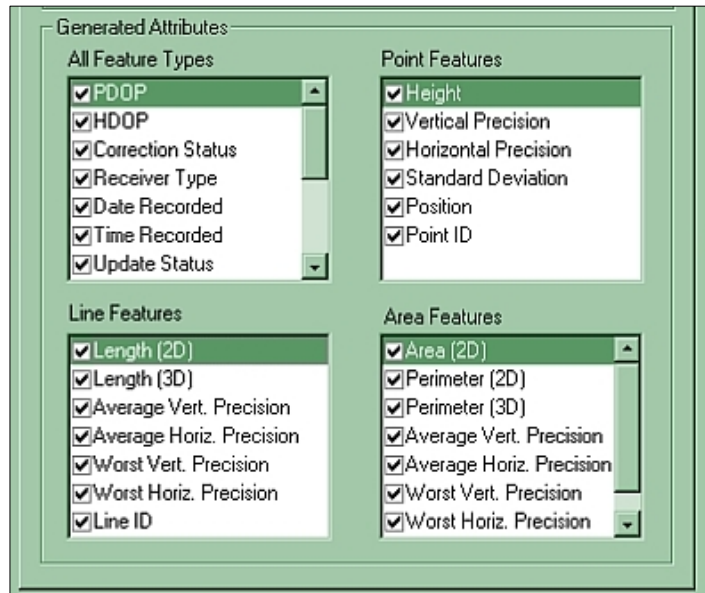


Figure 7. The "General Attributes" export settings to select as listed in the Trimble Pathfinder Office software package.

Pathfinder Office supports these GPS quality attributes for All Feature Types:

PDOP, 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, and GPS Second.

Pathfinder Office supports these additional attributes for Point Feature Types:

Height, Vertical Precision, Horizontal Precision, Standard Deviation, Position, and Point ID

Pathfinder Office supports these additional attributes for Line Feature Types:

Length (2d), Length (3d), Average Vertical Position, Average Horizontal Position, Worst Vertical Precision, Worst Horizontal Position, and Line ID.

Pathfinder Office supports these additional attributes for Area Feature Types:

Area (2d), Perimeter (2d), Perimeter (3d), Average Vertical Position, Average Horizontal Position, Worst Vertical Precision, Worst Horizontal Position, and Area ID.

In addition, filtering of GPS positions during the final export to a GIS format should ensure that GPS 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 Horizontal Dilution of Precision (HDOP) are greater than six (6).

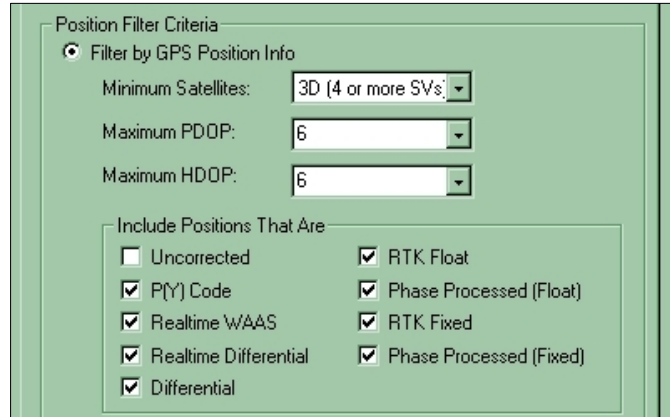


Figure 8. The “Position Filter Criteria” export settings to select as listed in the Trimble Pathfinder Office software package.

The purpose of requiring both project level GPS documentation in the FGDC metadata and the GPS quality information at the feature level as dataset attributes is to provide enough information about GPS-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. 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. GPS is already the principal tool for collecting locational data used in systems (such as computer models and geographic information systems) for which geographic accuracy is critical. GPS is an important and cost effective method for locating features too numerous or too dynamic to be mapped by traditional methods. It is therefore 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 GPS theory and have been trained in the proper use of GPS equipment.
- Use either mapping-grade or survey-grade receivers in their GPS data collection efforts. Because, recreational-grade receivers are not adequate for any state locational data collecting purpose.
- Test their GPS receivers for accuracy every six (6) months to identify faulty receivers for repair or disposal.
- Differentially correct GPS data.
- Archive the digital products representing all stages of the GPS data collection and processing chain (e.g. uncorrected field files, base station files used for differential corrections, electronic data entry forms, corrected GPS files, and final GIS datasets).
- Document all GPS-derived GIS data products with appropriate forms of metadata.

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

- Each state agency that collects GPS 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 GPS data can do so with confidence in its quality, because the data will have been collected, differentially corrected, 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 GPS for collecting locational data will become more prevalent in state government, because GPS technology, training, and data documentation will be more consistent and readily accessible.

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8. Glossary

8.1. Acronyms

Acronym	Definition
C/A code	Course/Acquisition GPS code
DGPS	Differential Global Positioning System
DOP	Dilution of Precision
FAA	Federal Aviation Administration
FGDC	Federal Geographic Data Committee
GIS	Geographic Information System
GPS	Global Positioning System
HAE	Height Above Ellipsoid
MSL	Mean sea level
NAD 83	North American Datum of 1983
NAVSTAR	Navigation and Vehicular Satellite Timing and Ranging
NCGS	North Carolina Geodetic Survey
NGS	National Geodetic Survey
OPUS	Online Positioning User Service
P-code	Precise code.
PDOP	Position Dilution of Precision
PPS	Precise Positioning Service
RTK	Real Time Kinematic
SA	Selective Availability
SNR	Signal to Noise Ratio
URE	User Equivalent Range Error
SPS	Standard Positioning Service
USCG	United States Coast Guard
WAAS	Wide Area Augmentation System
WGS 84	World Geodetic System of 1984

8.2. Definitions

Term	Definition
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.
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.
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.

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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 10 ¹⁴ 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.
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).

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Term	Definition
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	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. Also known as user range error (URE). UERE errors 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.

9. GPS web links

9.1. GPS standards from other organizations

- USDA Forest Service GPS Data Accuracy Standard Proposal Powerpoint
http://www.fs.fed.us/database/gps/gps_standards/gps_data_std_kc.ppt
- USDA Forest Service GPS to GIS Procedural Handbook & Reference Guide, Version 7.0 Includes GPS Analyst:
http://www.fs.fed.us/database/gps/gps2gis/gps_gis_v7-0.pdf
- US National Park Service Field Data Collection with GPS S.O.P (2004)
<http://www1.nature.nps.gov/im/units/ermn/Reports/Cooperator/NPSGpsStds.pdf>
- DOI/Bureau of Land Management GPS Data collection guidelines
<http://www.blm.gov/nhp/efoia/wo/fy01/im2001-186attach1.pdf>
- US EPA: GPS Technical Implementation Guidance
<http://www.epa.gov/oei/pdf/GPS-TIG.pdf>
- Idaho GPS Standards
<http://itd.idaho.gov/planning/gis/maps/Standards/GPSStandards.doc>
- Vermont GPS Guidelines
http://www.vcgi.org/techres/standards/partiii_section_1.doc
- New Jersey Department of Environmental Protection GPS Standard
<http://www.nj.gov/dep/gis/gpsoutstand.html>
- Georgia DOT GPS Standards
http://www.dot.state.ga.us/DOT/plan-prog/transportation_data/qualityassurance/documents/GPS_Standard_v4.0.pdf
- Arkansas GPS Standards
http://www.gis.state.ar.us/Downloads/ASLIB/gps_standards.pdf
- Oregon DOT GPS Standards
http://www.oregon.gov/ODOT/TD/TDATA/rics/docs/gps_standards.pdf
- Texas DOT GPS Handbook
http://manuals.dot.state.tx.us/dynaweb/colsysre/gps/@Generic__BookTextView/81;cs=default;ts=default
- Texas Commission on Environmental Quality: Operating policy and procedure for GPS technology
http://www.tceq.state.tx.us/permitting/water_supply/pdw/SWAP/gps/opp_8.12.html

- City of Sarasota, FL GPS Standards
http://gis.co.sarasota.fl.us/PDF/gps_procedures.pdf
- Richland County, SC GPS Standards
<http://www.richlandmaps.com/redirect.asp?htmlpage=www.richlandmaps.com/standards/gps.html>
- Oakland County, MI GPS Standards
<http://www.co.oakland.mi.us/maps/assets/docs/GPSStandards.pdf>
- British Columbia, CA GPS Standards
http://ilmbwww.gov.bc.ca/bmgs/gsr/specifications/resource_gps/bc%20specifications%20-%20gps%20resource%20mapping%20release%203.0.pdf
- Natural Resources Canada GPS Guidelines (1995)
http://luna.geod.nrcan.gc.ca/GPS_Guide_e/GPS_Guide_e.pdf
- Province of Victoria (Australia) Handbook for GPS Data Collection for Integration with GIS Standards, Specifications and Best Practice Field Guide
[http://www.land.vic.gov.au/CA256F310024B628/0/311F3E48EE0204AFCA257110001EFCDE/\\$File/GPS+Handbook+v7.2.pdf](http://www.land.vic.gov.au/CA256F310024B628/0/311F3E48EE0204AFCA257110001EFCDE/$File/GPS+Handbook+v7.2.pdf)
- World Health Organization GPS data collection standards
http://www.who.int/health_mapping/resources/GIS_guidelines_data_collection.pdf
- GPS/Location Markup Language (GPSml) draft v 0.5 for submission to W3c from Chaeron Corporation
<http://www.chaeron.com/gps.html#GPSml>

9.2. US Federal Government GPS web resources

- National Geodetic Survey Homepage
<http://www.ngs.noaa.gov/>
- US Coast Guard NAVCEN DGPS Service Homepage
<http://www.navcen.uscg.gov/dgps/default.htm>
- National Geospatial Intelligence Agency - Office of GEOINT Sciences
<http://earth-info.nga.mil/GandG/>
- US Naval Operations Center GPS Timing and Data Homepage
<http://tycho.usno.navy.mil/gps.html>
- USDA Forest Service GPS Homepage
<http://www.fs.fed.us/database/gps/>
- USDA Forest Service Tested Accuracies for Commonly Used GPS Receivers (12/03)
http://www.fs.fed.us/database/gps/gps_standards/GpsAccuracyStd.pdf
- US National Park Service GPS Homepage
<http://www.nps.gov/gis/gps/>
- US National Park Service GPS Training Materials
<http://www.nps.gov/gis/gps/gps4ics.html>
- US National Park Service GPS for GIS Workflow
<http://www.nps.gov/gis/gps/gps4gis/>
- US National Park Service GPS Unit & Project Needs Assessment
<http://www.nps.gov/gis/gps/gps4gis/assessing.html>
- US National Park Service GPS Applications and Tools
http://www.nps.gov/gis/gps/tech_app.html
- US National Park Service ArcPad Customizations
<http://www.nature.nps.gov/im/units/mwr/gis/APCustomization/>
- US National Park Service GPS Toolbox
<http://www.nps.gov/gis/gps/aksogps/>
- US National Park Service Metadata Template for GPS-Collected Data
http://imgis.nps.gov/templates/gps_metatemplate.xml
- US Dept. Agriculture NRCS GPS Homepage
<http://www.ncgc.nrcs.usda.gov/products/gps/index.html>
- US Dept. Agriculture Forest Service Performance Testing Results for GPS Receivers
<http://www.fs.fed.us/database/gps/gpsusfs.htm>

9.3. Other GPS informational material

- Interactive GPS Day/Week Calendar
<http://www.rvdi.com/freebies/gpscalendar.html>
- Wisconsin DNR: Comparing GPS Systems & Tools
http://www.dnr.state.wi.us/maps/gis/documents/gps_tools.pdf
- ForestPal: GPS Comparisons
<http://www.forestpal.com/GPS.html>
- David L. Wilson's GPS Accuracy Web Page
<http://users.erols.com/dlwilson/gps.htm>
- Sam Wormley's GPS Errors & Estimating Your Receiver's Accuracy
http://edu-observatory.org/gps/gps_accuracy.html
- Sam Wormley's DGPS Resources
<http://www.edu-observatory.org/gps/dgps.html>
- German GPS Receiver Selection Tool (translated by Google)
http://translate.google.com/translate?u=http%3A%2F%2Fwww.vollmer-roosen.de%2FRoosen%2FNavig2%2Fmain.php&langpair=de%7Cen&hl=en&ie=UTF-8&oe=UTF-8&prev=%2Flanguage_tools
- English Help Page for the German GPS Receiver Selection Tool
<http://www.gps-practice-and-fun.com/navig2.html>
- Trimble Whitepaper: Collecting Quality GPS Data in a Canopy Environment
<http://gis.esri.com/library/userconf/proc02/pap0266/p0266.htm>
- Getting field GPS Data into ArcMap - King County WA GIS
http://www.metrokc.gov/gis/kb/Documents/AM_GPS.pdf
- Integrating GPS and GIS for Forest Resources (streaming video course)
http://www.ruraltech.org/video/2005/acrvview/lecture_20/Default.htm#nopreload=1&autostart=0
- James Madison University online GPS tutorials
<http://www.maic.jmu.edu/sic/gps/main.htm>
- Community Based GIS with ArcPad
<http://www.uoregon.edu/~schlossb/arcpad/>
- Real-Time WAAS DOP Accuracy Display
<http://www.nstb.tc.faa.gov/npa.html>

- Differences between GPS manufacturer's stated accuracy ratings
http://www.eomonline.com/Common/Archives/1996jun/96jun_gps.html
- GPS Accuracy and Limitations
http://www.earthmeasurement.ca/GPS_accuracy.html
- Minnesota DNR - CMT March II Tutorial
<http://thoreau.dnr.state.mn.us/mis/gis/tools/arcview/Training/WebHelp/Courses/GPS/CMT/intro.html>
- CMT - Intro to GPS (CMT)
<http://www.cmtinc.com/gpsbook/>

9.4. Online GPS-related magazines

- GPS World
<http://www.gpsworld.com/gpsworld/>
- Point of Beginning
<http://www.pobonline.com/>
- PE&RS
<http://www.asprs.org/publications/pers/index.html>
- Earth Observation
<http://www.eomonline.com/currentissues.php>
- GeoInformatics
<http://www.geoinformatics.com/asp/default.asp?language=1>
- Position
http://www.gisuser.com.au/POS/pos_frame.html
- Professional Surveyor
<http://www.profsurv.com/newpsm/>
- GIM International
<http://www.gim-international.com/>

9.5. Free mission planning software

- Trimble Planning Software
<http://www.trimble.com/planningsoftware.html>
- NOAA NGS Skyplot
<http://www.ngs.noaa.gov/gps-toolbox/skyplot.htm>

9.6. Commercial GPS software

9.6.1. Field computer software

- Trimble TerraSync
<http://www.trimble.com/terrasync.shtml>
- ESRI ArcPad
<http://www.esri.com/software/arcgis/arcpad/index.html>
- Trimble GPSCorrect Extension for ESRI ArcPad (Note: This extension is required to differentially correct data collected with ArcPad!)
<http://www.trimble.com/gpsccorrect.shtml>
- TopCon TopSurv
http://www.topconpositioning.com/index.html/session_id/5a417277e1be92ea1785540945442592/screen/software/category_id/id43b58f062afca8.06277100/category_ids/193
- TDS Solo Field
http://www.tdsway.com/products/solo_field
- SDC CartoPac
<http://www.spatialdatatech.com/Products/CartoPac/>
- CyberTracker
<http://www.cybertracker.co.za/>

9.6.2. Desktop software

- Trimble Pathfinder Office
<http://www.trimble.com/pathfinderoffice.shtml>
- Trimble GPS Analyst Extension for ESRI ArcGIS
<http://www.trimble.com/gpsanalyst.shtml>
- Converter from Trimble Data Dictionary to ArcPad Forms
<http://www.elecddata.com/gps/trimgis.html#DDF>
- TopCon Tools
http://www.topconpositioning.com/index.html/session_id/5a417277e1be92ea1785540945442592/screen/software/category_id/id43b58f08bb4ec6.66939732/category_ids/185
- TDS Solo Office
http://www.tdsway.com/products/solo_office
- CMT PC-GPS
http://www.cmtinc.com/software/pcgis38_05.html
- Leica GIS DataPRO
http://www.leica-geosystems.com/corporate/en/ndef/lgs_4506.htm
- Thales Mobile Mapper Office
<http://products.thalesnavigation.com/en/products/product.asp?PRODID=984>
- MacGPS Pro - connect a GPS to your Mac
<http://macgpspro.com/>
- GPSy - Macintosh GPS/GIS mapping program
<http://www.gpsy.com/>

9.7. GPS software reviews

- Cybertracker vs ArcPad
<http://www.cybertracker.co.za/Cybertracker%20vs%20ArcPad.pdf>
- PDA Street Routing Software comparison
<http://www.pocketgps.co.uk/compareomatic/index.php?TempID=21>

9.8. Free and/or open source GPS/geodetic software

- National Geodetic Survey Geodetic Toolkit
<http://www.ngs.noaa.gov/TOOLS/>
- NOAA GPS Toolbox
<http://www.ngs.noaa.gov/gps-toolbox/>
- National Geodetic Survey Free Software
http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml
- RINEX Conversion Software
<http://www.helenav.nl/rinex.htm>
- Free GPS Software
<http://www.gisdevelopment.net/downloads/gps/>
- PocketGpsLib - Free OpenSource GPS Library for Pocket PC
<http://gps.iter.dk/>
- Open Source GPS software and interface descriptions
<http://www.topology.org/soft/gps.html>
- Open Source GPS Links
<http://home.earthlink.net/%7Ecwkelley/>
- The GPS Toolkit, GPSTk for Linux
<http://gpstk.sourceforge.net/papers/linuxjournal/>
- Cetus GPS for Palm OS
<http://www.cetusgps.dk/>
- Cetus GPS Documentation Book
<http://book.cetusgps.dk/v12b/index.html>
- Chuck Taylor's NMEA Server
<http://home.hiwaay.net/~taylorc/gps/nmea-server/>
- GPSd: a GPS service daemon for Linux
<http://gpsd.berlios.de/>
- DGPS over the Internet
<http://www.wsrcc.com/wolfgang/gps/dgps-ip.html>

9.9. GPS hardware links

- Master List of GPS Equipment Manufacturers, provided by the Canadian Space Geodesy Forum
<http://gauss.gge.unb.ca/manufact.htm>
- GPS-PDA Cables
<https://www.bluehillsinnovations.com/store/index.php?action=category&id=3>

9.10. Sub-foot accuracy mapping-grade

- Trimble ProXH
<http://www.trimble.com/proxh.shtml>
- Trimble GeoXH
<http://www.trimble.com/geoxh.shtml>
- CMT HP-GPS-L4
<http://www.cmtinc.com/fieldcmp/hpgpsl4.html>

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

- Trimble ProXT
<http://www.trimble.com/proxt.shtml>
- Trimble GeoXT
<http://www.trimble.com/geoxt.shtml>
- Thales Mobile Mapper Pro
<http://products.thalesnavigation.com/en/products/product.asp?PRODID=1043>
- Leica GS20
http://www.leica-geosystems.com/corporate/en/products/gps_systems/lgs_4502.htm
- CMT ALTO-G12
<http://www.cmtinc.com/fieldcmp/alto.html>
- TopCon GMS 110
<http://www.topcongps.com/hardware/gms110.html>

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

- Trimble GeoXM
<http://www.trimble.com/pathfinderproxt.shtml>
- Thales Mobile Mapper CE
<http://products.thalesnavigation.com/en/products/product.asp?PRODID=1021>
- CMT MC-GPS and March II units
<http://www.cmtinc.com/>
- Surveylab Ike
<http://www.surveylab.co.nz/>
- GENEQ SXBlue
<http://www.geneq.com/catalog/en/sxblue.html>
- GENEQ SXBlue Mapper (also requires DGSP Max Beacon or CMT's PC-GPS-GIS post-processing software)
http://www.geneq.com/catalog/en/sxblue_mapper200_400.html

9.13. "Enhanced" recreational-grade accuracy ~5-10 meter (15-30 feet)

- USDA Configuration for Garmin w/ Real-Time Beacon Receiver (Real-Time corrections only)
<http://www.3dllc.com/page.asp?pageid=3>
- DeLorme Earthmate GPS with PostPro Software (also requires Blue Logger and Bluetooth PowerPack)
<http://www.delorme.com/professional/xmapgps.asp>
- Navtek Differential Garmin GPS Kits
<http://www.navtechgps.com/supply/difsys.asp>

9.14. GPS hardware reviews

- TDS Recon Handheld Computer 7/05
http://www.pocketnow.com/index.php?a=portal_detail&t=reviews&id=667
- Recreational-grade GPS Comparisons
<http://www.pocketgps.co.uk/item-menu.php?idSubCat=7>
- Magellan Meridian Platinum (Recreational-grade)
<http://www.pocketgps.co.uk/magellanmeridianplatinum.php>
- Delorme Earthmate Blue Logger 8/04 (quasi-Rec-Grade)
http://www.pocketnow.com/index.php?a=portal_detail&t=reviews&id=465
- Mobile Tech GPS Reviews
<http://www.mobiletechreview.com/tips/GPS/index.htm>
- GPS Receiver Information, Software, and Hardware Reviews of Garmin, Lowrance, Magellan and other GPS Receivers
<http://gpsinformation.net/>

9.15. Recreational GPS software, reviews, and other links

- PocketPC GPS and Navigation Software Listings
<http://www.gpsinformation.org/dale/PocketPC/wince.htm>
- GRINGO (GPS RINEX Generator) for 12-channel Garmin GPS receivers
<http://www.nottingham.ac.uk/iessg/gringo/>
- Byonics - GST-1 GPS Sentence Translator for Earthmate
<http://www.byonics.com/gst-1/>
- Minnesota DNR Garmin Software
<http://www.dnr.state.mn.us/mis/gis/tools/Arcview/extensions/DNRGarmin/DNRGarmin.html>
- Minnesota DNR Garmin Extension Training
<http://thoreau.dnr.state.mn.us/mis/gis/tools/arcview/Training/WebHelp/Training.htm#DNRExt/dnrgarmin43/GPSIntro.htm>
- GPSMapEdit - create raster backdrops for use in your Garmin
<http://www.geopainting.com/en/>
- Garmin GPS format abandons NMEA and goes (more) proprietary
<http://www.oreillynet.com/pub/wlg/5745>
- DGPS on Garmin Receivers
<http://www.gpsinformation.org/dale/dgps.htm>
- Garmin Recreational GPS Units Give Pseudorange and Carrier Data
<http://gpsinformation.net/pseudorange.htm>
- GRINGO PostProcessor for Garmins
<http://www.nottingham.ac.uk/iessg/gringo/>
- Information on GPS navigation and a lot of other GPS uses
<http://www.gps-practice-and-fun.com/>
- Rec Grade GPS Information Resources
<http://www.gpsinformation.net/>
- Poor Man's DGPS - Why you need not bother
<http://gpsinformation.net/main/poordgps.htm>
- Covert GPS Vehicle Tracking Systems
<http://www.covert-gps-vehicle-tracking-systems.com/>
- Dale DePriest's GPS and Navigation Website
<http://www.gpsinformation.org/dale/>

9.16. Developer-level GPS technical material

- CodeGuru - Writing your own GPS Applications: Part 1
<http://www.codeguru.com/vb/mobile/pocketpc/article.php/c8079/>
- CodeGuru: Writing Your Own GPS Applications: Part 2
http://www.codeguru.com/Csharp/Csharp/cs_data/tutorials/article.php/c8875__4/
- Obtaining raw GPS data from some Garmin units
<http://artico.lma.fi.upm.es/numerico/miembros/antonio/async/>
- NGS RINEX 2.1 Format documentation
<http://www.ngs.noaa.gov/CORS/instructions2/>
- NMEA 0183 and GPS: Decoding the NMEA 0183 standard in your GPS Software Project
<http://www.scientificcomponent.com/nmea0183.htm>
- Peter Bennett- GPS & NMEA Site
http://vancouver-webpages.com/peter/idx_nmeaprogram.html
- Glenn Baddeley - GPS - NMEA sentence information
<http://home.mira.net/~gnb/gps/nmea.html>
- GPS components for .NET and PocketPC Developers
<http://www.gpsdotnet.com/>
- NMEA-183 Ver 2.0 GPS Sentence Compatibility
<http://gpsinformation.net/main/nmea3.txt>