

Global Positioning System (GPS) Data Collection Guidelines

[Mapping Grade GPS]

Suffolk County, New York

DRAFT
April, 2008

Purpose

The goal of this document is to provide a means of quality control and accuracy documentation of Geographic Information System (GIS) data sets created with Global Positioning System (GPS) technology. It is geared primarily for the mapping grade GPS user.

These GPS data collection guidelines seek to accomplish the following objectives:

- (1) Establish methodology for collecting GPS data for use in a GIS;
- (2) Provide guidelines for reporting metadata about GPS collected data and methods/means used to collect such data;
- (3) Supply GPS users with definitions of GPS terms and abbreviations; and
- (4) Eliminate or reduce known and potential systematic errors.

This document was developed by the Suffolk County, Long Island GPS Sub-Committee; chaired by M. Ross Baldwin. A large amount of material and formatting for this document was obtained and used with permission from the GPS Standards Subcommittee within the Standards & Data Coordination Work Group of the NYS GIS Coordination Program (www.nysgis.state.ny.us) and the “VT GPS Guidelines” document, written by the Vermont Center for Geographic Information's Technical Advisory Committee, led by Mike Brouillette.

(http://www.vcgi.org/techres/standards/partiii_section_l.doc)

*A special thanks to James Gormley for compiling the GPS Quick Reference Guide.

While these guidelines are generally intended to improve the quality of GPS-collected data, following these guidelines does not guarantee that any suggested combination of hardware and methods will insure a prescribed accuracy. A myriad of factors influence GPS data quality—many of them not under the direct control of the user. Guidelines alone cannot substitute for experience and judgment in the field. Specifications should balance the needs for accuracy against the resources available for the project.

The user of these guidelines should understand that GPS technology is rapidly changing. Users of this document require training and a base knowledge of GPS software and hardware. The GPS technology is constantly evolving, necessitating the evolution of these guidelines. In order to maintain the accuracy of these guidelines, this document will be reviewed and updated as necessary.

In February 2006, the NYS GIS Coordination Program, through the NYS Office of Cyber Security & Critical Infrastructure Coordination (CSCIC), presented a three hour workshop introducing GIS practitioners to the basic concepts, functionality, accuracy issues and processes of data collection via GPS, demonstrating the integration of GPS data into a GIS, and illustrating how positional error within GPS data may affect the results of a GIS project. Additionally, a DVD of this workshop was created and may be of interest to the readers of this document. This DVD is available upon request from the NYS GIS Clearinghouse.

Survey, Professional Licensure and Use of GPS

The Global Positioning System (GPS) and Geographic Information Systems (GIS) have been a great benefit to all levels of government. These two technologies have and will continue to change the way governments manage land records, infrastructure, emergency response, and planning, to name a few. Many of these GIS data layers are built and maintained by GIS consultants or government employees.

Some decisions, regulations, ordinances, and law enforcement require government officials to base their decision on information, data, or maps provided by State Licensed Professionals.

Licensed Land Surveyors commonly use Survey Grade GPS when performing boundary and topographic surveys. Through the New York State Education Law, the State of New York governs the Profession of Land Surveying, which this document will not address.

Users should familiarize themselves with and adhere to New York State Education Laws 7203 and 7209, which define the professions of engineering and land surveying as well as set guidelines. In the interest of public health and safety, 7203 and 7209 set standards, respectively, by stating ²:

“The practice of the profession of land surveying is defined as practicing that branch of the engineering profession and applied mathematics which includes the measuring and plotting of the dimensions and areas of any portion of the earth, including all naturally placed and man- or machine-made structures and objects thereon, the lengths and directions of boundary lines, the contour of the surface and the application of rules and regulations in accordance with local requirements incidental to subdivisions for the correct determination, description, conveying and recording thereof or for the establishment or reestablishment thereof.”

AND

“No official of this state, or of any city, county, town or village therein, charged with the enforcement of laws, ordinances or regulations shall accept or approve any plans or specifications that are not stamped”.

More information about these New York State Education laws can be found online at <http://www.op.nysed.gov/pefaq.htm>.

² “NYS Education Law, Article 14,” 23 Jan. 2007 <<http://www.op.nysed.gov/article145.htm>>

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GPS QUICK REFERENCE GUIDE

I. Mapping Grade GPS:

- Critical Settings
 - **Position Mode:** Recommended manual 3D mode (requires 4 satellites)
 - **Minimum Satellites:** This guideline recommends 4
 - **Elevation Mask:** It is recommended that a mask of 15 degrees be applied (It may be appropriate to increase the Elevation Mask when collecting data in valleys or urban areas)
 - **Signal to Noise Ratio (SNR) Mask:** Varies from GPS receiver Manufacture. Users should consult the user manual to obtain the SNR Mask.
 - **Position Dilution of Precision (PDOP):** the user should stop data collection when PDOP is greater than 6
 - **Logging interval:** Collection rate should be equal to or a multiple of the sampling rate of the base station use in post-differential correction e.g., 1, 5, 10, 15, or 30 seconds
 - **Minimum Positions:** For Point data this Guideline recommends that the user set the default data collection rate to one second and the minimum number of positions to 30.
 - **Carrier Mode:** allows a receiver to collect carrier phase data used for surveying purposes. SHUT CARRIER MODE OFF.
 - Reference System:
 - Datum: It is recommended that Datum be North American Datum from 1983 (AKA: NAD 83)
 - Projection: New York State Plane
 - Units of Measure: Feet
- **The Suffolk County GIS Technical and User Committees adopted New York State Plane NAD 83 Feet
- Mission Planning
 - Users Should be aware of Known Satellite Outages, PDOP, and local Obstructions to the sky and change the receiver settings and plan data collection times accordingly
 - Number of Channels
 - The more channels that a receiver has the greater the potential accuracy for the data collection points will be. This guideline recommends that the receiver have the capacity to track 12 channels
 - Data Collection
 - External Antenna: It is recommended that an external antenna be used when collecting data in wooded or urban areas and anywhere where obstructions to the sky occur.
 - Data Dictionary Design: It is recommended that a Data dictionary be used but not editable in the field.
 - Data Download: The data should be downloaded from the receiver to a computer or network as soon as possible
 - Post Processing: Recommended even when using a real time correction method

- Base Station: It is recommended that users use a single reference station throughout the duration of the data collection project (For Projects that cover more than 30 miles it might be appropriate to use more than one).
- Quality Control
 - Pre Collection Test: It may be necessary to collect “test” points for users who are unfamiliar with the GPS Equipment.
 - Use of Ancillary Data: Orthophotography, Internet mapping options, Street centerline data, etc.
 - Control Points: USGS Monuments, or any other feature with a known GPS location
 - Users should review data collected to determine if collection procedures established during Mission Planning were Followed
- Important Variables that affect GPS Accuracy:
 - Multipath error
 - Atmospheric
 - Distance From Base Station
 - Selective Availability
 - Noise (SNR)
 - Receiver Default Setting
 - Data Points Collected per feature
 - Differential Correction

II. Recreation Grade GPS:

- Since most recreation grade GPS receivers are championed as an easy out of the box data collection solution, the default settings set by the manufacturer will be optimal for most occasions.

SECTION A - GUIDELINES

I. EXPLANATION OF GEOGRAPHIC INFORMATION SYSTEMS AND GLOBAL POSITIONING SYSTEMS

A. Geographic Information System

In its simplest form, a Geographic Information System (GIS) is an electronic map used to display data based on its geographic location; in its more complex form, it becomes a powerful analytical tool with millions of pieces of data that are related geographically and can be displayed in a format that allows the user to make the inter-relationships between the data visually understandable.³

B. Global Positioning System

The Global Positioning System (GPS) consists of a constellation of 24 satellites that orbit the earth twice a day (making one revolution approximately every 12 hours) at an altitude of approximately 124,000 miles. The GPS satellite navigation system was initiated by the U.S. Department of Defense in the 1970's for military purposes. When the system is at full operational capacity, there are 24 operational satellites. This number changes periodically as satellites are commissioned (put into operation) and decommissioned (removed from operation). At the time of this writing, 31 satellites were in orbit. These satellites broadcast radio signals, containing satellite position and precise time data, twenty-four hours a day. These signals enable anyone with a GPS receiver to determine a geographic location.

The GPS system consists of three distinct segments: the space segment, the ground segment and the user segment.⁴ The space segment, known as the Navigation Satellite Timing And Ranging (NAVSTAR) constellation, consists of the GPS satellites, which transmit signals on two phase-modulated frequencies (L1 - 1575.42 MHz and L2 - 1227.60 MHz). These transmissions are carefully controlled by highly stable atomic clocks inside the satellites. The satellites also transmit a navigation message that contains, among other things, orbital data for computing the positions of all satellites. The ground segment, also called the control segment, consists of a Master Control Station located near Colorado Springs, Colorado, and several monitoring stations located around the world. The purpose of the control segment is to monitor satellite transmissions continuously, to predict the satellite ephemeris, to calibrate satellite clocks, and to update the navigation message periodically. The user segment simply stands for the total GPS user community. The user will typically observe and record the transmissions of several satellites and will apply solution algorithms to obtain position, velocity, and time.

Two signals are broadcast continuously by each satellite, one for use by the military, and the other for civilian use. The latter is referred to as Standard Positioning Service. The basis of GPS technology is precise information about time and position. To determine a horizontal location on earth, signals from at least three satellites are required. A minimum of four satellite signals are needed for determination of vertical position.

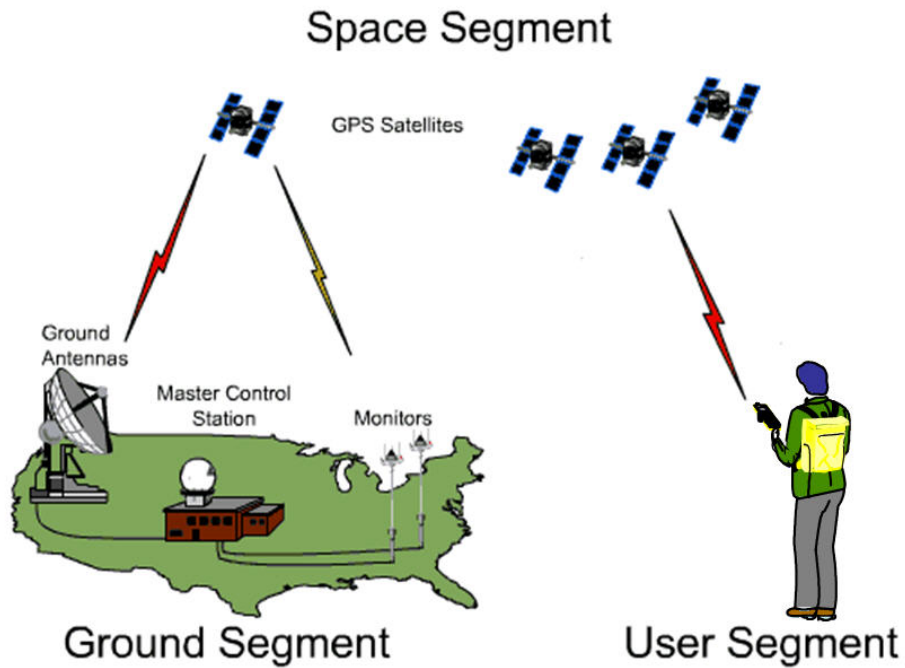
GPS receivers calculate the distance to each satellite by measuring the time interval between the transmission and the reception of a satellite signal. Once the distance measurements of at least three satellites are known, the method of trilateration can be used to determine the position of the GPS receiver. GPS can be used worldwide, 24 hours a day and in all types of weather. While positional accuracy can be very high, it does vary, depending on the type of GPS receiver, field techniques used, post-processing of data, and error from various sources.⁵ For further information, reference Section **A.V.A** about [SOURCES OF ERROR](#) and Section **A.IV** about [DATA COLLECTION & PROCESSING METHODOLOGY](#).

³ "NYS Office for Technology – Policy," 20 Dec. 2006 <http://www.oft.state.ny.us/policy/tp_9618.htm>

⁴ Alfred Leick, *GPS Satellite Surveying*, Second Edition (1995), 60

⁵ "North Carolina - Statewide Global Positioning System (GPS) Data Collection and Documentation Standards, Version 3," 20 Dec. 2006, <<http://cgia.cgia.state.nc.us/gicc/>>

C. Illustration of the Three GPS System Segments⁶



⁶ "GPS Control Segments." 20 Dec. 2006, <http://www.mitrecaasd.org/proj_images/satnav/segment.gif>

II. CATEGORIES OF GPS RECEIVERS

A. Recreational Grade

Accuracy within five to twenty meters. These GPS receivers usually do not have the ability to "post-process" collected data, but usually have the ability to perform real time correction using Wide Area Augmentation System (WAAS). GPS receivers can be used to navigate to a specific area and/or compile uncorrected GPS data; using associated third party software to convert the collected data directly into GIS supported data formats.

B. Mapping Grade

Accuracy from sub-foot to five meters. These GPS receivers have the ability to log raw GPS data, enabling these GPS-collected data to be post-processed utilizing desktop GPS software and allowing locations to be refined or corrected to a higher level of precision than inherent in the raw data.⁷ This category of GPS receiver also has the ability to communicate with a base station, store attributes of features, use a data dictionary and upload data from the GPS device to a PC.

C. Survey or High Accuracy Grade

These include instruments with associated software that can achieve one-centimeter relative accuracy. These are used by land surveyors primarily for boundary, topographic, geodetic surveys, photogrammetry, and other activities requiring high accuracy. Specialized training is needed to use this equipment.

⁷ Depending upon the model, corrections may occur as broadcast real time adjustments (WAAS or Coast Guard Beacon) or by post processing.

D. Categories of GPS Receiver Comparison Table

RECREATIONAL GRADE	MAPPING GRADE	SURVEY GRADE
Primary Uses		
Navigation; hunting; fishing; camping; backpacking; hiking; data collection	Resource mapping; navigation; GIS data collection	resource mapping; site mapping; land surveying; navigation; vertical measurement
Horizontal Data Accuracy		
5 to 20 meter	Sub-foot to 5 meter (real-time or post-processing correction)	Centimeter level (<i>real-time OR post-processed corrections, with a survey control network</i>)
Vertical Data Accuracy		
Not used to collect vertical data	2 to 15 meter (<i>2 to 3 times less accurate than horizontal data</i>)	< 2 cm (<i>real-time correction</i>) < 1 cm (<i>post-processed corrections with a survey control network</i>)
Differential Correction Options		
- Most do not have post-processing capabilities - Real-time correction (WAAS) in most GPS receivers	- Post-processing in all GPS receivers - Most have real-time capabilities (WAAS and/or USCG beacon additional add on)	- Real-time in some GPS receivers - Additional post-processing to improve accuracy is in all GPS receivers
Type of Features Collected		
points⁸	points, lines and polygons	points, lines and polygons
Option to Load Custom Data Dictionary with Feature Attributes		
unavailable at this time	all GPS receivers	all GPS receivers
Option to Load Custom Coordinate Systems, Projections, Datums/Spheroids		
some GPS receivers	all GPS receivers	all GPS receivers
Training Requirements		
minimal	moderate	advanced
Metadata (capability to generate metadata or extract metadata from GPS receiver type)		
minimal	moderate	advanced
Cost (circa 2006)		
\$200 to \$500	\$2,500 to \$12,000	\$5,000 to \$50,000

⁸ Additional software needed to generate lines and polygons

III. CHOOSING THE RIGHT TOOL FOR THE JOB

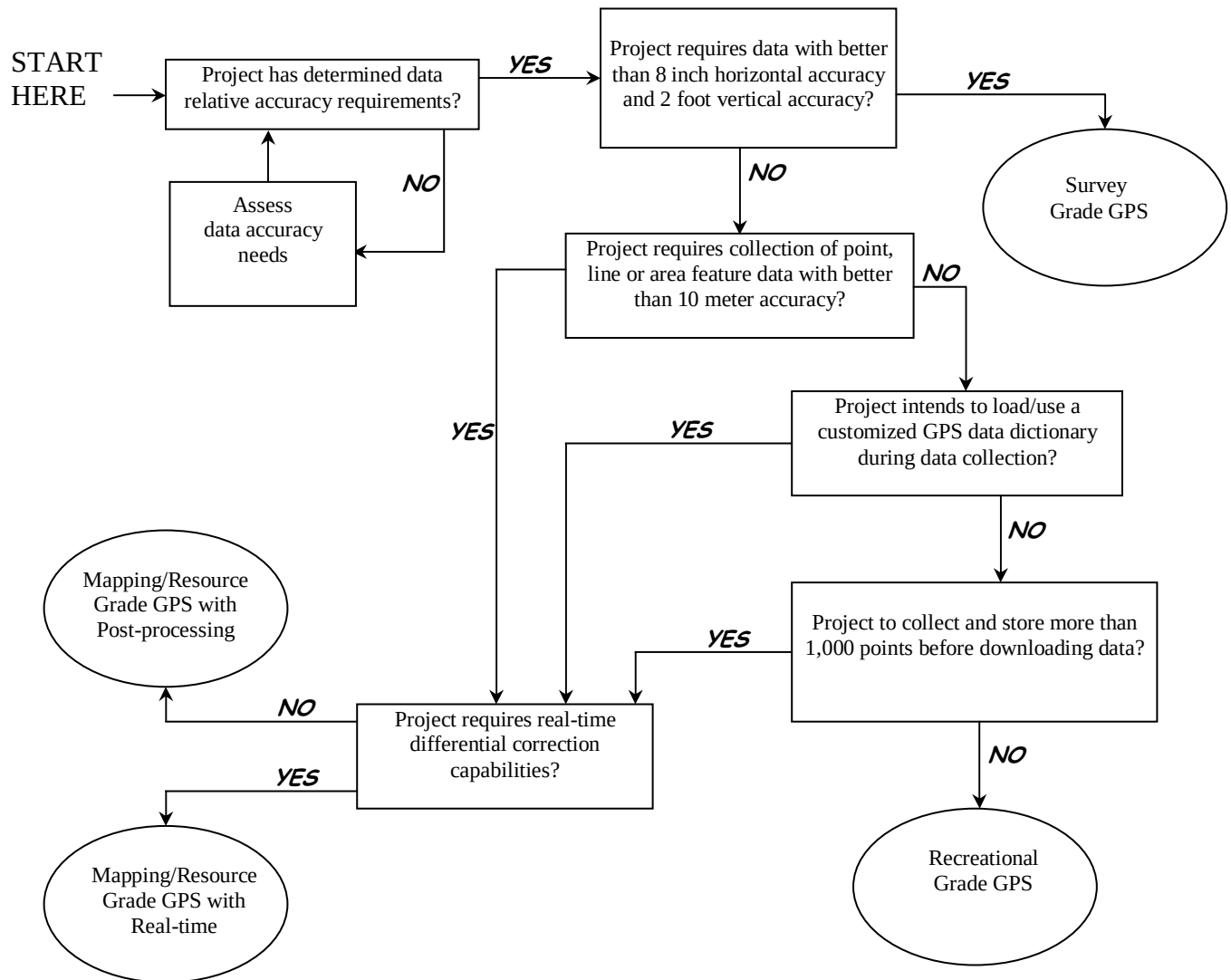
Based on the parameters established in mission planning, the user should choose a GPS receiver that meets or exceeds those requirements. Resources (e.g. staff, hardware, software) must also be sufficient to support the use and maintenance of the selected data collection tool. Therefore, choosing the right GPS receiver for a specific project requires serious consideration of the following:⁹

- Identify and use existing data collection procedures or standards.
- Anticipate use of the feature location and attribute data to be collected.
- Project data accuracy requirements for the data to be collected.
- Available resources to support data collection and processing activities.
- Type, number, and other characteristics of features to be located.
- Characteristics (e.g., rural vs. urban, remote vs. nearby) of the data collection site.
- Identify and use existing feature location or attribute data.
- Type of feature attribute data to be collected
- How the features to be located will be represented (i.e., as points, lines, or polygons)

⁹ “Vermont Center for Geographic Information VT GPS Guidelines,” 20 Dec. 2006
<http://www.vcgi.org/techres/standards/partiii_section_1.doc>

A. Decision Tree

The decision tree is intended to help users select an appropriate GPS receiver grade particular to their GPS data collection project. This is only a general guide, however, and you must also consider several other factors as noted above before making your final choice!¹⁰



¹⁰ "WI-DNR. Comparing GPS Tools," - <<http://www.dnr.state.wi.us/maps/gis/gps.html>>

B. Other Characteristics to Consider

In addition to the ability to set defaults and differentially correct data using a specific GPS receiver, users should also consider the following additional receiver characteristics before choosing a GPS receiver for your project. Nearly every new receiver surpasses the minimum configuration requirements noted below for their class and this trend is likely to continue in the future. While survey, mapping/resource and recreational-grade receivers share many of these characteristics, our suggestions pertain to mapping/resource-grade receivers.

1.) *Number Of Channels*

GPS receivers track the signals from satellites via “channels”, with the signals from one satellite occupying one channel on the receiver. A 3-channel GPS receiver tracks the signals from up to three satellites at one time, while a 12-channel receiver tracks the signals from up to twelve satellites at one time. The more channels a receiver has, the more likely that it will continue uninterrupted collection of data if the parameters (e.g., PDOP) of one of the satellites fall out of optimal range. A GPS receiver with twelve channels has a greater ability to track the “best” while continuing to seek out other satellites with more optimal parameters. Therefore, this Guideline **recommends that GPS receivers have the ability to track 12 channels.**

2.) *Memory*

The number of data points that a GPS receiver can collect and store (before you need to download the data to a computer) differs greatly between recreational and mapping/resource systems. Recreational grade receivers can only collect and store data for less than 1,000 points - and users do not usually download these data for further processing or analysis. Therefore, memory requirements of recreational grade receivers are of less concern. You must, however, consider how the field conditions of your project may influence the memory requirements of your mapping/resource GPS receiver. Larger data sets require more memory. Remote field locations may require larger files to be collected between downloading opportunities. Attribute data requirements may take up considerable storage space. Needs for higher accuracy usually means more data needs to be collected, increasing storage needs. Many GPS units have memory slots to expand onboard memory.

❖ **How many features will be located?**

More features may require more memory to minimize the number of data downloads you need to perform.

❖ **How large are the line or area features to be located?**

Long linear features (e.g., trails) or polygon features with very large areas (e.g., forest stand boundaries) may require more memory to store all collected data. In addition, a GPS receiver that lets you open and append data to existing files will minimize the number of total files you need to create and compile for one feature.

❖ **How remote are the features to be located?**

Remote features may require more memory in order to minimize the number of trips made to the field to capture them. Without adequate memory the only alternative is to return to the office numerous time to download data or bring a laptop into the field for downloading.

❖ **Will a customized data dictionary be loaded on the receiver?**

The use of data dictionaries is highly recommended (unless using ArcPad), and they take up memory!

❖ **What are your data accuracy requirements?**

More memory may be needed to capture and store the larger volume of data needed to support higher data accuracy requirements.

This Guideline recommends that your mapping/resource grade GPS receiver have a **minimum 2Mb of memory**. This amount of memory should allow for the loading of a custom data dictionary and the ability to collect data for 8 hours while using a one second sampling interval in all but the most demanding situations. Additional memory is an option with most receivers.

3.) *External Antenna*

GPS satellite signals can be received from any direction. For best results the antenna must have a clear view of the sky. Satellite signals do not penetrate metal surfaces, buildings, tree trunks, or similar objects. In addition, signals are weakened when they penetrate tree canopies, glass, or plastic. GPS receivers have an internal antenna that is sufficient for general use in clear sky areas away from buildings. Most resource/mapping grade receivers also have the option of an external antenna. An external antenna is very useful in situations where the internal antenna may be blocked by the user, an obstruction or where a stable platform is desired. These are also useful mounted on top of a vehicle. The internal antenna is disabled when an external antenna is used so that signals are not received from both antennas. External antennas generally increase the amount of “signal gain” and the ability to operate in demanding environments, e.g., tree canopy or narrow river valleys, at a minor cost of additional battery drain.

Mounting an antenna on a pole mount raises the antenna above obstructions and limits multipath signal degradation from reflected signals. The ground plane is established at the antenna height. An external antenna mounted on a vehicle should be mounted on a metal surface to establish a ground plane rather than on a plastic or fiberglass camper shell to limit multipath. It is important to properly secure the external antenna’s cable to the GPS receivers the connection cannot become dislodged by an obstruction or when walking through brush.

An external antenna is recommended when collecting data in wooded or urban areas where the sky is partially obscured and when acquiring data with a vehicle.

4.) *GPS Power Source*

Battery capacity, charging systems and battery replacement should be considered. GPS receivers run on electricity, so it is important to have a good battery supply available in the field. Important parameters include: the ability to work in a range of temperatures, all day working capacity and rapidly rechargeable. The ability to utilize a 12v adaptor of a vehicle socket will provide an endless power when conducting mobile GPS work. There are a number of different battery types, e.g., lithium, ni-cad that come in a variety of voltage and Wattage. One useful measure in comparing batteries is the “Amp-hours” rating.

5.) *Data Dictionary Design (ESRI ArcPad not applicable, uses ArcPad Forms)*

A data dictionary is a menu of standard feature attributes (i.e., data elements) loaded on a GPS receiver that is used to simplify and standardize data collection of geographic features in the field when recording descriptive information. Individual geographic features are represented by multiple coordinate pairs known as “fixes” that are captured according to the sampling interval of the receiver. The data dictionary defines the fill requirements, default values, and valid codes/values (domain values) for each attribute. This approach minimizes the effort of entering in descriptive text via the

keypad, prevents misspelled entries and improves data consistency, e.g., different fields operators might otherwise assign different values to the same feature(s). Once a company or department defines a data dictionary it can be used repeatedly to standardize data collection and ensure quality control of attributes and their domain values. Some receivers are limited to a single dictionary while others can store multiple ones. Other limitations worth assessing are: character maximum length for the feature name, attribute name and menu attributes; maximum character length for a character string; maximum character length for a user code and maximum character length for comments.

6.) *Critical Settings*

Traditionally, the user had full control over all of the “critical settings” that affect the quality of captured data. Increasingly, these settings are being pre-defined by manufacturers in an attempt to make receivers easier to use. While this may be desirable most of the time, it is useful to have the choice to control them manually. Invariably you will find yourself one day in a deep river valley at dusk coming to the conclusion that a point captured with a lower PDOP threshold is better than no point at all. Critical settings include:

- ❖ Logging interval - time between “positions”;
- ❖ Minimum positions - minimum number of positions required to log point feature;
- ❖ Minimum time - ensures acquisition of carrier phase information to calculate higher accuracy features
- ❖ Position mode - driven by accuracy needs. Options are: “2D” (x,y), Manual 2D/3D, or 3D (x,y,z);
- ❖ Elevation mask - prevents GPS receiver from using satellites not visible by the base station;
- ❖ Signal-to-noise ratio (SNR) mask - prevents receiver from recording positions with low signal quality;
- ❖ PDOP mask and switch - prevents receiver from logging inaccurate positions due to poor satellite geometry.

IV. DATA COLLECTION AND PROCESSING METHODOLOGY

*Methodology refers to the techniques a user should apply prior to and while collecting data with a GPS receiver. It should be noted that not all of these options are applicable to all recreational grade GPS receivers.

A. Mission Planning

For the purpose of this document, Mission Planning is a broad overview of planning a project to establish what the purpose is, what the data will be used for and who will be using them. All these factors will help determine the proper equipment and methods to be used.

1.) *Satellite Availability & Known Outages*

Before collecting data, the user should be aware of the theoretical satellite availability. Most GPS software has the ability to provide a theoretical estimate of satellite availability at a certain geographic location, on a certain day, at a specific point in time. This information is often displayed in a variety of methods, including graphs, charts and diagrams, and skyplots, which display the satellite constellation over a location.

The United States Coast Guard maintains a website that generates a digest of known or forecasted GPS satellite outages. This digest is called the Notice Advisory to NAVSTAR Users (NANU) and lists the times when specific GPS satellites will be unstable or not available for use. This information can be used in the mission planning utility when considering which satellites will be available on a specific day. For information about how to subscribe to the NANU email list, visit the following webpage: http://www.navcen.uscg.gov/gps/gps_news_090905.htm

2.) *Position Dilution of Precision (PDOP)*

The user should plan their data collection at times when there is optimum satellite availability (four or more) and when the satellites are in an appropriate configuration to produce an acceptable (lower) PDOP value. Data collection can be planned to exclude poor (higher) PDOP times. PDOP values should be reviewed daily as satellite geometry changes constantly. Most GPS desktop software has the capability of providing graphics indicating the number of satellites available over the course of a day at a specific location as well as the PDOP values.

3.) *Local Obstructions of the Sky*

The user should consider performing field reconnaissance in advance of data collection to identify local obstructions of the sky, including urban canyon, forest canopy, etc., that can affect results.

B. GPS Receiver Configuration

It is recommended that the following values be set on the GPS receiver prior to field data collection. These values are subject to the accuracy requirements of specific projects. The values below may be modified depending on GPS receiver model. Additionally, the user should consult the manufacturers' guidelines for optimal GPS receiver configuration recommendations.

1.) *Position Dilution of Precision (PDOP)*

Most GPS receivers allow you to set a maximum acceptable Position Dilution of Precision (PDOP). The PDOP is a statistical indicator of the geometry among the satellites being observed—it is an important indicator of position accuracy. Since a GPS position is the calculated intersection of measurements from multiple satellites, GPS data are more accurate if the satellites are evenly distributed in all quadrants around and above the receiver. The ideal geometry of the satellites which will produce the lowest PDOP is to have three satellites at 15 degrees above the horizon and evenly distributed, separated horizontally by 120 degrees with a fourth satellite directly overhead. Since the GPS system was designed to maximize coverage over temperate regions of the globe, this theoretical ideal isn't even possible in the current configuration of satellite orbits.

GPS receivers calculate PDOP from the distribution of usable satellites in the sky at the moment of data collection. Receivers search for and use the combination of available satellites that will

produce the lowest “dilution of precision”, within the threshold setting specified by the user. **This Guideline recommends that you set your GPS receiver to stop collecting data when the PDOP is over 6.**

2.) *Signal to Noise Ratio (SNR) Mask*

Setting the value of the SNR mask higher will help minimize noise error. Varies from GPS receiver manufacturer; each manufacturer has their own recommendations; user must refer to their specific user manual.

3.) *Elevation Mask Angle*

As mentioned above, the distribution of satellites above the horizon is used to calculate PDOP. Most GPS receivers let you set a minimum “elevation mask angle” to ensure that the GPS receiver only tracks and uses satellites that are positioned a specified distance above the horizon. Setting this value too low could allow the receiver to collect data from satellites not being tracked by the base station having an adverse impact on post-processing efforts. Also, data from satellites that are low on the horizon are “noisy” due to increased atmospheric refraction. The elevation mask setting is a minimum threshold; it is very likely that local topography and obstacles blocking the horizon, such as vegetation or buildings, are likely to constrain the “effective” minimum elevation to something higher than the mask. **This Guideline recommends that you set the minimum elevation mask angle on your GPS receiver to 15° or greater.**

4.) *Data Collection Rate (Sync Rate)*

The number of readings you collect for a feature affects the accuracy of GPS data. The user can specify the minimum number of position fixes and the interval at which fixes are stored, based on your project’s data accuracy requirements. There is an obvious relationship between the number of points you collect and the rate at which you collect them. A collection rate of one fix per second will yield 30 points in 30 seconds, whereas, it would take 150 seconds to record 30 points if the rate is one per five seconds. In general, the more readings you record, the more accurate a feature’s location will be with the caveat that GPS data accuracy does not significantly improve after a “threshold” number of points are collected. In addition, the collection rate should be equal to, or a multiple of, the sampling rate of the base station to be used in post-differential correction, e.g., 1, 5, 10, 15 or 30 seconds. Refer to [Table IV-1 Static Data Collection – Suggested Duration and Number of Fixes](#) for suggested collection rates and collection durations.

For point data, this Guideline recommends that you set the default data collection rate to one second and the minimum number of position to 30. When collecting line or polygon features the rate may vary between one and five seconds depending on your speed of ground travel

5.) *Datum*

GPS receivers are designed to collect GPS positions relative to the WGS-84 datum, however the user has the option of designating into which datum the data will be displayed. Users must have an understanding of the datum in which the GIS project is developed.

*For most GIS applications, the WGS-84 datum is similar to the NAD-83 datum, however NAD-27 is significantly different from the NAD-83 datum. Most manufacturers allow the user the option of *displaying* the data being collected in most datum’s. Various software exists that allow for the transformation of data from one datum to another. Refer to Appendix B for more information on datum transformation.

6.) *Projection*

It is recommended that data being collected with GPS be displayed on the GPS receiver in the New York State Plane projection:

State Plane New York Long Island feet

Users should have an understanding of the projection the data are being collected in and the projection in which the GIS project is in. GPS receivers are designed to collect data and perform real-time correction in an unprojected geographic coordinate system (latitude/longitude). Most manufacturers allow the user the option of displaying the data being collected on the GPS receiver in most projections.

*Refer to Appendices C for maps of the State Plane Zone.

7.) *Units of Measure*

Users should be aware of the units of measure that are commonly used with each projection. The State Plane projections can be published in US Survey Feet or meters. Users should also be aware of the International Foot unit of measurement, which is different than the more commonly used US Survey Feet.

Users should have an understanding of the units of measure in which the data can be displayed on the GPS receiver. Some manufacturers allow the user the option of displaying the data being collected in different units of measure (e.g. US Survey Feet, International Feet, Miles, Meters, etc.).

When collecting data with a GPS receiver, the geographic location is represented as a coordinate pair (e.g. 42.8123N, 75.8066W). The positional coordinate pair can be displayed in some common formats:

Latitude/Longitude - Degrees/Minutes/Seconds (DMS)

A latitude or longitude might be written as 43° 5' 20", where the single quotation (') represents minutes and the double-quotation symbol (") represents seconds.

Latitude/Longitude - Decimal Degrees (DD)

The same coordinate would be written as 43.088889°.

Latitude/Longitude - Degrees and decimal minutes

The same coordinate would be written as 43° 5.333333'.

UTM 18 extended North (meters)

The same coordinate would be written as (4740283N, 434057E).

State Plane New York Central (US feet)

The same pair would be written as (312608N, 313525E).

US National Grid

The same pair would be written as (18T WN 7125315437)

Conversion of a coordinate pair between any of these three formats can be performed with a relatively easy formula found within existing tools. Additionally, calculators and mathematical formulas on the Internet allow translation of one coordinate pair (i.e. latitude/longitude) in any of these formats into another format for that same location. Refer to Appendix B for a list of useful websites.

C. GPS Data Download and Processing

The data download process varies by GPS receiver manufacturer so the user should refer to their specific user manual for instructions.

D. Quality Control

*Data should be reviewed to determine if procedures established during mission planning were followed.

High resolution orthophotos, such as those available through the New York Statewide Digital Orthoimagery Program (NYSDOP), can be used to determine if there are gross errors (i.e. does not meet the accuracy standards defined in mission planning of a project) in the GPS data by comparing the GPS data positions to the high resolution orthoimagery. It may be necessary to recollect data if the original data do not meet project needs. NYSDOP has been producing orthoimagery since 2001 with high-resolution orthoimagery available statewide outside New York City for viewing and downloading.¹¹ More information about the New York State Digital Orthoimagery (DOI) Program can be found at the following webpage:

<http://www.nysgis.state.ny.us/gateway/orthoprogram/index.cfm>

The SCTM digital parcel map should only be used to determine if there are gross errors in the GPS data as well. The SCTM is best used for generalizations and as a reference.

After conducting quality control and if your positional requirements are not met, it may be necessary to recollect the data.

E. Data Collection

1.) *GPS Receiver Antenna*

In order to minimize loss of GPS satellite lock, users should, whenever practicable, orient the GPS antenna skyward; and in the case of handheld GPS receivers avoid signal blockage by their upper body and head. In addition, when recording the location of tall features (e.g. trees, utility poles) it is a good practice to approach the feature from the south, positioning the GPS receiver antenna on the south side of the feature. This recommendation is due to the fact that, in the northern hemisphere, GPS satellites are not present in the northern sky except at very high elevations above the horizon (i.e. > 70 degrees).

2.) *Prohibit Data Dictionary Editing*

It is recommended to prohibit the editing of the data dictionary in the field in order to ensure uniformity in the data attributes being collected.

3.) *Data Download*

It is recommended to download the collected data from the GPS receiver to a local computer as soon as possible after returning from the field to minimize the risk of losing the data on the GPS receiver due to battery failure, inability to store additional data or overwriting existing data.

4.) *Post-Processing*

It is recommended that users employ post-processed differential correction as part of their GPS data management workflow as soon as practicable after downloading data from a field device. Three key benefits to adhering to this approach are:

- Rapid identification of reference stations that are out of service or are experiencing communication interruptions
- Avoidance of encountering a condition where reference station files are no longer available because they have been deleted from the provider's server

¹¹ "NYS GIS Clearinghouse - Digital Orthoimagery Program," 12 February 2007
<<http://www.nysgis.state.ny.us/gateway/orthoprogram/index.cfm>>

- Compliance with a standardized workflow procedure that delivers data in its final form swiftly, allowing for archiving of raw field and intermediate data files, and promoting streamlined and simplified file management

5.) *Base Station*

The user should determine the quality of the base station being used. It is recommended for the novice GPS user that only NOAA/NGS published base stations be used.¹² Advanced GPS users may have the ability to establish their own base station and should consult the manufacturers' guidelines for their specific hardware for instructions.

*It is **recommended** to utilize a single reference station for all project specific post-processed differential correction activities, with the exception of projects that cover a large area (e.g. several thousand square miles) or long (30 miles or more) "strand" or linear mapping projects. This technique will promote data registration uniformity by inducing identical systematic errors (if any) across the full breadth of your data sets. In addition, metadata documentation will be simplified and differential correction parameters will be homogeneous across the entire project data set.

**The most commonly used Base Stations for Long Islanders include NYCI, NYRH, CTDA (Conn.)

V. GPS ACCURACY CONSIDERATIONS

A. Sources of Error

*In order to effectively gather precise/accurate data, it is necessary to understand potential sources of error that can affect GPS data quality

1.) *Multipath*

Errors caused by reflected GPS signals arriving at the GPS receiver, typically as a result of nearby structures or other reflective surfaces (e.g. buildings, water). Signals traveling longer paths produce higher (erroneous) pseudorange estimates and, consequently, positioning errors.

The user should be aware that multipath errors are not detectable or correctable with recreational grade GPS receivers. Some mapping grade GPS receivers as well as most or all survey grade GPS receivers have antennas and software capable of minimizing multipath signals.

2.) *Atmospheric*

GPS signals can experience some delays while traveling through the atmosphere. Common atmospheric conditions that can affect GPS signals include tropospheric delays and ionospheric delays.

Tropospheric delays have the capability of introducing a minimum of 1-meter variance. The troposphere is the lower part (from ground level to 13 km) of the atmosphere that experiences the changes in temperature, pressure, and humidity associated with weather changes. Complex models of tropospheric delay require estimates or measurements of these parameters.¹³

Unmodeled ionospheric delays have the potential to introduce significant (i.e. >10 meter) positional error. The ionosphere is the layer of the earth's atmosphere generally ranging from 50 km to 500 km above the earth's surface. During periods of heightened solar activity, charged particles (ions) in the ionosphere impede GPS signal transmission. Specific phenomena that do affect the GPS signal quality include periods of high solar activity (e.g. solar flares). The

¹² "CORS Data," 20 Dec. 2006 <<http://www.ngs.noaa.gov/CORS/Data.html>>

¹³ "Global Positioning System Overview," 20 Dec. 2006 <<http://www.colorado.edu/geography/gcraft/notes/gps/gps.html>>

ionospheric model transmitted in the GPS signal compensates for approximately 50% of this delay. The balance must be resolved through differential correction.¹⁴

Weather conditions, including cloud cover and precipitation, generally do not affect the GPS receivers' (hardware) capability of collecting accurate data. However, cold temperatures near and below freezing could affect the GPS receiver LCD screen and battery life.

3.) Distance from Base Station

While differential correction will increase the quality of the data, accuracy is degraded slightly as the distance from the base station increases. Users should use the nearest base station to where the data is being collected. With the implementation of the NYS CORS Base Station Network (see Appendix E) across the State, the density of base stations is increasing. This network should be sufficient to provide differential correction for GIS users in most situations.

4.) Selective Availability (SA)

SA is the intentional degradation of the GPS signals by the Department of Defense (DOD) to limit accuracy for non-U.S. military and government users. The potential error due to SA is between 30 to 100 meters.¹⁵ SA is presently turned off, but the DOD reserves the right to turn it back on at any time and in specific geographic theaters.

5.) Noise

Noise error is the distortion of the satellite signal prior to reaching the GPS receiver and/or additional signal "piggybacking" onto the GPS satellite signal. All three grades of GPS receivers are capable of suffering from noise error. The amount of error due to noise cannot be determined.

*You can ensure that the quality of your data is high by understanding the numerous factors that can affect GPS data quality, including:

- ❖ Conditions in the ionosphere and atmosphere (e.g., solar flares)
- ❖ Number of available satellites and their geometry and health
- ❖ GPS receiver default settings (e.g., PDOP, mask angle)
- ❖ Signal interference (e.g., multipath errors) by obstacles such as buildings and trees
- ❖ Number of data points collected for a feature
- ❖ How and if data are differentially corrected
- ❖ Base station used for differential correction

By using appropriate data collection and processing techniques users can minimize much of the error associated with these factors. Obviously, some factors are beyond user control, e.g., solar flares or satellite characteristics. However, the right tool and its proper use can minimize these sources of error and make your GPS data as accurate as possible.

B. Default Settings That Affect GPS Data Accuracy

Many GPS receivers let you set data collection constraints that disallow data collection unless certain minimum operating thresholds are met. The following discussion introduces the most commonly available constraints that are under the user's control. The user should note that the recommendations given below are intended to support accuracy in the 0.5 to 2 meter range. It should also be stated that the trade-off between accuracy and productivity (and cost) is embodied in any choice of operating constraints. *The user should employ data collection constraints that meet the accuracy needs of the project.*

¹⁴ Alfred Leick, *GPS Satellite Surveying*, Second Edition (1995), 303

¹⁵ "Global Positioning System Overview," 20 Dec. 2006 <<http://www.colorado.edu/geography/gcraft/notes/gps/gps.html#SA>>

1.) *Position Dilution of Precision (PDOP)*

2.) *Elevation Mask Angle*

3.) *Number of Points Collected Versus Data Collection Rate*

4.) *Data Collection Under Difficult Conditions*

Topography, buildings, and vegetative canopy are among the most frequently encountered obstacles to GPS signal reception. Signals can be blocked completely, the signal strength can be reduced (analogous to static on a radio), or signals can bounce off nearby objects and contribute to position inaccuracies (multi-path). A full discussion of this topic is beyond the scope of this Guideline. We offer some practical approaches to addressing this condition here.

Experienced users recognize that GPS data collection conditions are seldom ideal. It is this same experience that teaches these users to enter the field prepared for poor conditions. The following general strategy offers some guidance, but its successful implementation relies heavily on the experience and judgment of the user.

The most successful strategy is to “be prepared”. In the case GPS data collection, this means entering the field with knowledge of the conditions you are likely to encounter and knowledge of the “ideal” satellite times for minimizing the impact of difficult conditions. Data collection on a north slope or in a steep stream valley may dictate that GPS can only be collected at certain times of the day when a sufficient number of satellites are available above the topographic “obstacles”. Most GPS software allows the user to predict the positions of all the satellites at any time of the day and users can enter the field with this information, allowing them to make decisions about when to attempt data collection or how long to wait at a particular location for favorable satellite availability.

Vegetative canopy is more likely to reduce the strength of (rather than completely obstruct) the incoming signal. If choosing the time of day is an option, plan to collect data when satellites are plentiful and high in the sky. Alternately, you may be able to raise your antenna into or above the canopy for better signal reception or plan your data collection for “leaf-off” conditions. Yet another option with some receivers is to collect an “offset” position; that is, GPS data are collected some distance off the desired position, but a compass bearing and estimate of distance to the actual point are also collected. Post-processing the position with the offset information “projects” the collected data to the actual location from the offset location.

C. Differential Correction to Improve GPS Data Accuracy

Differential correction removes certain types of error from GPS data, and can occur back in the office (post-processing) or as you are collecting data in the field (real-time). Post-processing these corrections is a little more accurate than real-time differential correction because the individual fixes and the corresponding base station corrections are perfectly time- synchronized, whereas, real-time corrections introduce a time delay between the correction data and the position.

Both methods of correction work by comparing satellite signals received by the receiver with those received by a base station, which is fixed over a highly accurate, surveyed point. Base station correction values are calculated and then applied to the rover data to increase their accuracy to 5 meters or less, depending on the GPS receiver grade.

Both post-processing and real-time differential correction require that the base station and receiver are able to record data from the exact same satellites. In addition, the base station should be within 100 miles of the field data collection site to maximize the effectiveness of the post-processing. When differentially correcting GPS data you must decide which method will best support your project needs, and if your project resources are

adequate to support the selected technique. The major differences between the post-processing and real-time are related to equipment cost and time sensitivity to accessing corrected data. The extra equipment needed to attain real-time can add to cost of a system but comes with the advantage of access to the corrected data in real-time. Generally speaking, unless you have a specific need for the enhanced location accuracy provided by real-time differential processing in the field, it is easier and more economical to go the post-processing route in Vermont. The topography and dense vegetative cover in Vermont can adversely impact radio and direct satellite link signals. The characteristics of post-processing and real-time differential processing are described in more detail below.

1.) Post-Processing Differential Correction

This type of differential correction occurs back in the office, after you have downloaded raw GPS data from the receiver on to a computer. Special software (specific to the GPS receiver!) is used to apply correction values calculated from base station data to the rover data. The ease of this process has steadily improved over the years and is not difficult to learn.

In most cases, you can download free base station data from an Internet site operated by the National Geodetic Survey (<http://www.ngs.noaa.gov/CORS/>). For Long Island, there are a number of base stations to choose from. Please refer to Appendix D and E for a map and list of available sites. A list of community base stations is available on Trimble's website (<http://www.trimble.com/trs/findtrs.asp>). You can also set up a temporary base station for a specific project, but this requires additional effort and may involve security issues if the receiver is to be unattended in a remote location. To ensure the best accuracy possible for field data ensure that your collection rate, e.g., 1 fix per second is a factor of the sampling rate of the available base station data. For example, if the closest base station has a 5 second sampling rate do not set your collection rate to 2 or 3 seconds, rather, set it to 1, 5, 10, 15 or 30 seconds etc.

Most base stations do not store one second interval data for more than a month so do not wait to acquire this data after a field collection effort!

GPS equipment with post-processing functionality is generally less expensive than systems with real-time functionality, because less hardware is required (i.e., there is no need for a real-time beacon receiver). However, today's resource grade receivers often come with both capabilities, and this is becoming the standard receiver configuration.

2.) Real-time Differential Correction

Some recreational and mapping/resource grade GPS receivers have real-time differential correction functionality (also known as Differential GPS or DGPS). Real-time differential correction occurs in the field, and requires another piece of equipment (either separate from or integrated into the GPS receiver) to receive correction values from a GPS base station via radio signals or direct satellite link, and automatically apply these data to adjust GPS rover data as they are being collected. Systems with a built-in satellite link provide real-time capabilities anywhere in the world.

The real-time corrections are based on an extrapolation of the derived base station corrections computed at some time in the past. This extrapolation is a result of the small time lag between the time the satellite information is collected and stored by the base station; a correction is computed and finally transmitted to the GPS receiver. The time lag between the simultaneous reception of satellite signals by the base station and GPS receiver and the receipt of the correction transmission to the receiver is known as RTCM-Age (Radio Technical Commission for Maritime Services). Most units have the ability to set the limit on RTCM-Age that will be used by the receiver to calculate the real-time position. With the removal of Selective Availability the RTCM-Age can be longer than before without adverse results, e.g., a meter every few minutes. The *recommended* settings are as follows, relative to the desired target accuracy.

Target Accuracy (95%) using Real-Time GPS	Suggested Maximum RTCM-Age
1m	15 seconds
2m	30 seconds
5m	60 seconds
10m	90 seconds

Table IV-1: Suggested Maximum RTCM Correction Age Settings

Another type of real-time differential correction is the Wide Area Augmentation System (WAAS), developed by the Federal Aviation Administration to aid the avionic application of GPS. Though many recreational grade receivers are now WAAS capable, the signal is highly susceptible to blockage from topographic relief and vegetation and is not as accurate as post processing. To avoid questioning if your data has been enhanced through the use of WAAS **always post process your data for the best results!** See APPENDIX F - WIDE AREA AUGMENTATION SYSTEM (WAAS) OVERVIEW for more information.

Three types of receivers are used to receive base station correction data:

- ❖ external real-time radio link receiver
- ❖ real-time radio link receiver built into the GPS receiver
- ❖ direct satellite link built into the GPS receiver (i.e., correction data are transmitted from the base station up to a communications satellite and then back down to the receiver)

In order to help secure accurate results, it is important that the base station transmitting the radio signals carrying the correction values be within 100 miles of the field data collection site. A map of Nationwide Differential GPS (NDGPS) sites that broadcast corrections can be found at <http://www.navcen.uscg.gov/dgps/coverage/EastCoast.htm>. Radio signals carrying correction data can be received from base stations more than 100 miles from the field data collection site, but results are inconsistent and use of these correction data are not recommended for real-time differential correction. Post-processing is also recommended when base station radio signals are blocked by terrain.

D. Quality Control and Reporting

Quality Control (QC) and Quality Assurance (QA) procedures ensure reliability in GPS survey results and instill confidence in the data. Whereas QC procedures are undertaken by the GPS Contractor to ensure accuracy and completeness of the data produced throughout the data collection effort, QA procedures are the responsibility of the Contracting Agency to ensure the GPS data are accurately imported into existing map databases once received. QC procedures are discussed here. QA and auditing procedures are outlined in *Section A.V.E - Quality Assurance and Audit*. Once again, it is important to stress that QA/QC specifications should be considered very carefully and balanced against the needs of the project. They will almost always add something to the cost.

*It is always good practice to follow Quality Control and Quality Assurance procedures internally as well.

1.) Validation and Quality Control

Requiring Contractors to submit a small “trial run”, or validation survey, in order to pre-qualify for responding to a GPS survey contract is a logical place to start controlling the process of creating high quality, reliable data. These surveys provide insight into a Contractors technical capabilities and ability to assess a project and plan the data collection and processing efforts accordingly. If poor results are received in a Contractors validation survey, it may have a bearing on how the actual project will be conducted. Reviewing Contractor credentials to determine their success in conducting past GPS work is **highly recommended**.

2.) Quality Control (QC)

The primary QC method is to ensure that parameters associated with field data capture were followed. Many of the procedures outlined in *Sections A.V.C - Differential Correction to Improve GPS Data Accuracy* above and *A.V.D.3 - Recommended Data Collection Methods* below detail field procedures, processing methods and specifications that help control GPS data quality.

Additional, specific QC procedures that help ensure GPS survey data is as reliable and accurate as possible are detailed below:

i. PDOP Masks

Not all GPS receivers have settings that enforce that no data be collected when Position Dilution of Precision (PDOP) values are too high. Ideally, PDOP values are logged for each position fix for verification. When the receiver isn’t capable of this, PDOPs can be computed afterwards with most manufacturers’ software. Whenever possible, it is suggested that the following QC parameters be output: solution standard deviations, residuals, variance factors, etc. The capabilities of commercial software that offer these outputs vary by manufacturer.

• 2D vs 3D

Most mapping/resource grade GPS receivers allow the user to set data collection to be either two-dimensional (2-D) or three-dimensional (3-D) and correspondingly, how many satellites are required. 2-D positions need three satellites and 3-D positions need at least four. 3-D positions are more reliably accurate than 2-D ones and it is *recommended* that only 3-D positions be collected. Occasionally, difficult site locations and conditions may limit satellite availability and force a 2-D position. When the rover files are exported from the desktop GPS software it is *highly recommended* that the option to export the position type attribute be enabled to allow for ready identification of 2-D or 3-D positions, or alternatively, only 3-D, corrected positions should be accepted.

• Digital Imagery Comparison

An alternative to re-observing points, when accuracy validation isn’t a project requirement, is the use of the New York State Digital Orthophotography Program. By planning ahead and capturing field points that are readily identifiable on the “orthos”, e.g., road intersections, distinct driveways etc. it is possible to compare the field point onscreen with the imagery to gain a general sense of the field data accuracy without re-observation. Although the “orthos” are quite accurate, (1:5000 source scale) remember that accuracy is a relative term and that the imagery you’re using as a frame of reference to compare field points does contain a certain amount of error. According to the U.S. National Map Accuracy Standards¹⁶, the horizontal accuracy for 90% of points at the 1:5000 scale is approx. 2.5m (8ft). Due to the unpredictable nature of accuracy, this means that a point lining up perfectly with the corresponding point on the image can still be off by the error of the source imagery, i.e., 2.5m.

¹⁶ http://www.oh.nrcs.usda.gov/technical/gis/natl_map_accuracy.html

- Re-Observation
The best method of assessing the accuracy of a GPS survey is by re-observing a portion of the original positions using the same receiver and settings. This topic is fully discussed in [Section B.III.A. Re-Observation](#). Re-observing points is a good way to verify that your collection effort is on the right track, however, it is only absolutely necessary if you are trying to prove your data meets a certain accuracy.
- Use of other ancillary data (parcels, benchmarks, streets, etc)
- Benchmarking to Established Monuments
A benchmark is an established and documented field location with known coordinates. One can occupy a benchmark, collect GPS data and compare the collected position to the “published” position. However, the accuracy noted for one GPS point against a benchmark, regardless of a benchmark’s coordinate accuracy, does not apply to other points in a typical GPS data collection survey. Instead, the utility of this comparison may be limited to simply ensuring the receiver’s critical settings have proper values and that it isn’t malfunctioning. Benchmarking should never be a substitute method for re-observation to estimate the accuracy of a survey.

3.) *Recommended Data Collection Methods*

The three main types of features in Geographic Information Systems (GIS), e.g., points, lines (arcs), and polygons (areas), are all based on individual points or vertices. The definition of a line or polygon feature is affected by the proximity of the points to each other under certain conditions. Just how close the points should be is discussed in more detail below. Most mapping/resource grade receivers and their software are capable of capturing all of these features while recreational grade receivers are not.

GPS data can be collected in one of two ways, first by remaining stationary over a point or while moving “dynamically” over a line or edge of a polygon feature. These data collection methods are called “static” or “dynamic” modes, respectively. Points can be the result of a single positional fix or an average from many positional fixes, each taken at intervals from one second (the minimum) to the highest setting allowed by the receiver (a maximum of 30 seconds is practical). The combined impact of the number of fixes and sampling interval on the accuracy of an averaged point is less pronounced for point features than for line or polygon features captured dynamically. While capturing features dynamically is an efficient, acceptable means of data capture it requires consideration of additional factors in order to maintain the desired accuracy.

This section defines data collection methods and suggested field methods and GPS receiver settings to achieve target accuracies.

i. Static Point Features

“Static point features are normally surveyed by grouping a number of individual position fixes to produce an averaged single position. Examples of static point features are: a project location, culvert, bridge, cabin etc. A static point feature has a start and an end time, and usually includes attributes describing the feature. The post-processing software will average all individual position fixes to compute a single position for the feature and attach any attributes for export to a GIS or mapping system.

The largest errors in Differential GPS (DGPS) positions are usually due to multipath and signal attenuation caused by nearby objects such as foliage, reflecting surfaces, etc. While the antenna is moving, these errors tend to be random (more or less), but significant systematic errors can occur at a stationary antenna. Multipath on L1 pseudoranges occurs in cycles of 6-10 minutes (theoretically). If the antenna is kept over a point for a full multipath cycle, the errors

should average out and accuracies of a few meters may be attainable under forest canopy. However, requiring a 10-minute occupation time at point features may not be practical, or necessary if the project's accuracy target is lower. It is important that enough data is collected to be able to detect systematic multipath at static point features. In most cases, 45 - 60 seconds of observations is sufficient for an experienced user post-processing the data "to detect multipath trends in a point feature. Note that this time period is enough to usually *detect* multipath effects, however, it may not be enough to ensure accurate and reliable feature coordinates from the remaining fixes once the multipathed fixes are deleted. In this case the feature would have to be re-surveyed in the field.

This averaging improves positional accuracy and minimizes random measurement "noise" and multipath effects. In theory, accuracy continues to improve as more data is averaged, however there is a point of diminishing returns after a number of minutes of recording. *It is recommended that at least 30 fixes be averaged for every static point observed, regardless of the project's accuracy.*

Both the number of individual position fixes and the length of occupation will affect the accuracy for a point feature. There are two minimum conditions that must be met. The operator must stay for at least the minimum time *and* have at least the minimum number of position fixes recorded. Under marginal observing conditions, the operator may have to stay for a longer time to meet the minimum fix requirement."¹⁷

The table below details the minimum number of fixes and sampling rate recommended to achieve the desired relative target accuracy detailed in Section B: Accuracy Standards. Relative target accuracies listed presume a mapping/resource grade GPS receiver collecting data under good site conditions, e.g., no obstructions, and favorable critical values, e.g., PDOP, SNR, small baseline error etc. and where all data is post-differentially corrected or acquired via "real-time" correction.

Note! This table is only a guideline and no field tests were conducted to determine these values. Due to the large selection of mapping/resource grade GPS receivers on the market it would be virtually impossible to assess them all.

Relative Target Accuracy	Suggested Data Collection Duration	Suggested Number of Fixes	Sampling Interval
< 1.0 m	15 minutes (900s)	180	5 s
1.0 m	10 minutes (600s)	120	5 s
2.0 m	8 minutes (480s)	96	5 s
5.0 m	5 minutes (300s)	60	5 s
10.0 m	1 minute (60s)	60	1 s
20.0 m	.5 minutes (30s)	30	1 s

Table IV-2 Static Data Collection – Suggested Duration and Number of Fixes

ii. Linear Features - Dynamic Mode

Line features are formed from a number of individual GPS position fixes and similar to point features they have a start and end time and associated attributes. The two modes of collecting linear features are dynamic traverses and point-to-point traverses.

¹⁷ British Columbia Standards, Specifications and Guidelines for *Resource Surveys Using GPS Technology*. pp. D-35

“Dynamic Traverses are analogous to “stream-mode” digitizing of a line. The Field Operator guides the antenna along the linear feature to be mapped while collecting GPS position fixes at a specified time interval. This time interval will be chosen based on the resulting distance between position fixes, which includes consideration of the traveling speed, feature complexity, and tracking environment. It is important that position fixes be recorded at all significant deflections in the linear feature. Static point features can be added to record features along the line (e.g. a culvert along a stream survey). The individual position fixes are connected to form the linear feature. The line can be smoothed and generalized later in mapping / GIS software.

Resource surveys can be done on foot by a Field Operator wearing a GPS backpack, from the air via helicopter or fixed-wing aircraft, and by vehicle (truck, quad, snowmobile, bike, boat, etc). These surveys can be very productive, but are only suitable if the feature is easy to identify and the vehicle can accurately guide the antenna over the feature at all times. These surveys must also conform to the fix spacing limits set by the contracting entity (e.g. a position fix every 25m). Also, the speed of the vehicle may affect how accurately the feature can be followed. The speed limits defined in the following sections are based on the speed that can safely be flown in a helicopter (from interviews with pilots familiar with GPS mapping). During some road surveys there may be safety reasons to increase the vehicle speed limit (e.g. so as not to impede vehicles on an active road), but for most surveys, 50 km/h (30 mph) is a practical upper limit.

During dynamic linear positioning the data recording rate should be set according to the fix spacing desired which is related to the vehicle speed. For example, if a road is to be surveyed at 10m fix spacing and the vehicle speed is 35 km/hr (~20 mph), then the data collector must be capable of recording one fix per second. Note that some GPS systems claims a one-second recording rate, but can only sustain this when tracking less than 5 satellites.

The following table shows examples of various fix spacing for different traveling speeds and recording rates.”¹⁸

Example Modes Of Transportation	Speed (m/s)	Data Collection Rate (s) And corresponding Point Separation (m)
Walking	1.4m/s (5km/h or 3mph)	@1.0s separation = 1.4m @5.0s separation = 7.0m
Bike	4.2m/s (15km/h or 10mph)	@1.0s separation = 4.1m @5.0s separation = 21m
Vehicle – slow	8.3m/s (30km/h or 18mph)	@1.0s separation = 8.3m @5.0s separation = 42m
Vehicle – fast	17m/s (60km/h or 35mph)	@1.0s separation = 17m @5.0s separation = 84m

Table IV-3 Dynamic Traversing - Speed & Data Rate vs. Point Separation¹⁹

iii. Linear Features - Point-to-Point Mode

Point-to-Point Traverses entail capturing individual points, i.e., a “traverse point”, that collectively defines linear features. No fixes are logged between points and once averaged the points are converted into a linear feature by either the GPS desktop or CAD / GIS software. The

¹⁸ British Columbia Standards, Specifications and Guidelines for *Resource Surveys Using GPS Technology*. pp. D-36

¹⁹ British Columbia Standards, Specifications and Guidelines for *Resource Surveys Using GPS Technology*. pp. D-41.

operator should acquire an overview of the features to be captured in order to log key inflection points in the features. Point-to-point traverse may not be more accurate than dynamic traverses under forest canopy but are more practical under certain circumstances. Practicality may prevent a dynamic traverse, e.g., a river or other impassible topographic features and the accuracy target may render delineation of minute details unnecessary. Another advantage is the ability to use offsets when logging these points to overcome obstacles or improve satellite reception, e.g., reducing multipath interference from forest canopy when delineating a tree stand. Offsets are described below.

iv. Linear Features - Hybrid-mode

Individual “nestled” point features can be recorded while a separate feature is being logged by a dynamic traverse, e.g., a spring or cabin along a trail. This is extremely useful in improving the efficiency of the capture effort where multiple features can be captured in a single effort but when the point feature has an accurate location or may be readily identifiable on a digital Orthophotography. This can provide an additional QC checkpoint for the linear feature especially in situations where forest canopy may be affecting the target accuracies.

v. Polygon Features

Polygon (area) features are essentially linear features that close, e.g., connect at their endpoints. These can be collected explicitly as polygons or as linear features that are later processed into polygons using CAD/GIS software. For simple features in open areas with good satellite reception it may be more straightforward to collect the features as polygons.

For more complicated or large features where reception may be an issue, logging linear features can be more versatile logistically for two reasons; A) A single line segment representing the polygon can be saved midway along the traverse to capture other linear features in the vicinity; and B) Collecting multiple segments guards against losing the entire feature due to loss of signal, lack of storage space or battery power. In either case linear features are saved whereas a polygon feature will close between the original position and last available position.

Whichever approach is chosen it is *highly recommended* that one approach be adopted and followed for consistency throughout a project.

vi. GPS Events

An additional method for logging point features is the “GPS Event”, “Nested Point”, or “quickmark”. Using the “time stamp” ingrained in every position fix, the quickmark is interpolated from stored GPS fixes taken before and after the mark. These are not substitutes for static point features because they are only based on individual fixes, not averaged positions. They are useful in defining general reference points or when the GPS antenna can’t remain stationary over a point feature, i.e., during collection efforts while using a car. They will not work if signals to the antenna are blocked at the instant the mark is taken.

To gain a sense of how accurate the event times must be in relation to the speed of travel the following tables depicts different accuracies at different times and assumes the quickmark be accurate to one-half of the target accuracy. “For example, if the accuracy specification is 10m and the traveling speed is 50km/h (14m/s), Event times must be accurate to one half of 10m divided by the speed (i.e. 5m divided by 14m/s = 0.36 seconds).”²⁰

²⁰ British Columbia Standards, Specifications and Guidelines for *Resource Surveys Using GPS Technology*. pp. D-38

Desired Network Accuracy	Receiver Speed	Required GPS Timing Accuracy
1.0 m	5km/h (1.4m/s)	0.36 seconds
	30km/h (8.3m/s)	0.06 seconds
	60km/h (17m/s)	0.03 seconds
	100km/h (28m/s)	0.02 seconds
2.0 m	5km/h (1.4m/s)	0.72 seconds
	30km/h (8.3m/s)	0.12 seconds
	60km/h (17m/s)	0.04 seconds
	100km/h (28m/s)	0.04 seconds
5.0 m	5km/h (1.4m/s)	1.80 seconds
	30km/h (8.3m/s)	0.30 seconds
	60km/h (17m/s)	0.15 seconds
	100km/h (28m/s)	0.09 seconds
10.0 m	5km/h (1.4m/s)	3.60 seconds
	30km/h (8.3m/s)	0.60 seconds
	60km/h (17m/s)	0.30 seconds
	100km/h (28m/s)	0.18 seconds

Table IV-4 Desired Point Accuracy vs. Speed & Timing Accuracy²¹

vii. Point and Line Offsets

Offsets allow the capture of points without having to directly occupy them. Using a bearing and distance measure the GPS receiver applies an adjustment to its present location to derive the offset. The accuracy of the offset is subject to the accuracy of the bearing, the distance measure and reference GPS position but if the antenna is no longer under canopy as a result of the offset, accuracy can improve. Some receivers are sophisticated enough to allow for a digital laser range finder that calculates both distance and bearing to the feature and automatically feeds this information into the GPS receiver to calculate the offset. Offsets are desirable under field conditions where physical access or satellite obstacles, e.g., forest canopy and safety concerns prevent direct occupation of the feature. It can also be more efficient to log features this way, e.g., logging fire hydrants from a vehicle mounted GPS antenna.

The power of offsets comes with the responsibility to manage them properly in order to avoid the introduction of error. All manually entered measurements that help compute offsets must be done correctly and a thorough understanding of magnetic and true azimuths, inclination angles, and slope and horizontal distances is required to ensure accuracy.

Receivers supporting offsets usually allow input measurements to be reviewed and edited to remedy any incorrect entries. For points acquired by receivers without offset capabilities, offsets can still be calculated if measurements are recorded and used in concert with CAD/GIS software.

viii. Point Offsets

The following procedures are recommended when using point offsets:

- ❖ Only use a single Azimuth measurement for the entire project, i.e., magnetic or true north. For projects covering large geographical areas multiple magnetic declination values may be required. The value(s) used should be documented.
- ❖ All azimuth measurements should be made relative to the GPS antenna.

²¹ British Columbia Standards, Specifications and Guidelines for *Resource Surveys Using GPS Technology*. pp. D-39

- ❖ Measuring the azimuth value from both the offset location and from the actual feature location helps to improve the accuracy of the value.
- ❖ The accuracy of distance measurements directly affects an offsets overall accuracy. Distances measured on an incline must be adjusted from slope to horizontal distance. For receivers that accept an inclination angle the horizontal distance is automatically calculated.
- ❖ All compasses are affected by natural and man-made attractions so all efforts should be made to prevent these sources of magnetic distortion from influencing azimuth readings.

The magnetic declination value used in the survey should be present in the project report along with methods employed to measure distance, direction and inclination. Before offset coordinates are calculated the magnetic declination value must be applied. Setting the declination in the field compass allows a direct reading of true azimuth but it is also possible to apply the declination to magnetic azimuth values after the fact. The best source of magnetic declination in the United States is the National Geophysical Data Center's Geomagnetism home page and values can be computed using their on-line [Magnetic Declination Calculator](#). The accuracy of the predicted magnetic declination is variable and local anomalies can exist.

The following table associates the effects of compass precision and offset distance. Both analogue and digital compasses are affected by magnetic declination and local variations.

Compass Instrumentation	Compass Precision	Declination & Variation Uncertainty	Offset Distance	Offset Point Uncertainty (approximate)
Standard Compass e.g. Silva Ranger (15T)	2.0°	1.0°	25m	1.0m
			50m	2.0m
			100m	3.9m
Precise Compass e.g. Suunto KB-14D	1.0°	1.0°	25m	0.6m
			50m	1.2m
			100m	2.5m
Digital Compass e.g. MapStar, Laser Atlanta	0.3° - 0.5°	1.0°	25m	0.6m
			50m	1.1m
			100m	2.3m

Table IV-5 Offset Accuracy vs. Instrumentation Precision & Offset Distance²²

ix. Linear Offsets

For linear offsets digitized in a dynamic traverse, maintaining a constant offset distance from the feature is essential, particularly when collecting data from a vehicle when both speed of travel and practical safety concerns can affect the offset distance. Keeping the offset distance small, i.e., less than 5m, in dynamic traverses can help minimize error. When linear offsets are digitized in a static traverse each offset can be managed individually and does not necessarily have to be a constant value.

4.) *Advanced Data Processing*

This section is provided for users wishing to go the extra mile in validating the accuracy of their data and when required by an audit. When more than four satellites are available for determining a

²² British Columbia Standards, Specifications and Guidelines for *Resource Surveys Using GPS Technology*. pp. D-41

positional fix extra, i.e., “redundant” information is available to the receiver that yields what is called an “over-determined” solution. Redundant information can make the data more accurate because there are more satellites to choose from in calculating the position and it also provides additional statistical information. This information comes in two forms, e.g., solution variances and observation residuals and can be used for quality control assessment with desktop software capable of processing it. At present, most desktop software shipped with mapping/resource grade GPS units aren’t capable of processing this information but this may change in the future.

i. Filtering

Some manufacturers of GPS systems utilize a variety of techniques for interpolating, filtering and estimating GPS data in their software. Details on these techniques are too involved for this document and they will simply be referred to collectively as “filtering”. For these manufacturers the functionality is always implemented in the desktop software but not always in the receiver. This determines whether the filtering can be applied dynamically in the field or only during post-processing. Some receivers have a corresponding receiver setting allowing the user to pick different modes of data collection, e.g., walking, driving, flying etc., while others provide no such controls to the user. Filters and their settings used should be noted in the project report, when applicable.

Filtering works by assessing points that surround the point being re-computed, e.g., previous and subsequently logged points. Points that are too far apart for the time elapsed to have been acquired by a pedestrian (remember everything is “time stamped” in GPS) can be identified as incorrect, i.e., an outlier, and deleted.

ii. Data Editing, Smoothing and Generalizing

Post-differentially corrected or real-time differential data is considered to be “original corrected” GPS data and should be retained in the project archive previous to any edits to provide an opportunity to review the level of noise in the GPS traverse as well as any major errors. In cases where critical parameters are changed or special processing controls applied in either post-processing efforts or part way through a survey (avoid this whenever possible) to produce originally corrected data, e.g., a different elevation mask or outlier deletion criteria, they should be noted in the project report.

Most point, linear and polygon features are edited or generalized in some way to remove apparent errors from individual points caused by a poor acquisition environment or user error. Editing individual points collected as either static point features or in point-to-point traverses (to form a linear feature) can be done automatically by desktop GPS or CAD/GIS software where individual fixes meeting certain criteria are deleted and the position is recomputed. One of these criteria is the standard deviation value.

The goal of most edits to linear or polygon features is to find the best representative line or “best-fit” line using the GPS positions as a guide. These lines are created in a variety of ways: 1) Manually drawing a line over the GPS position fixes in CAD/GIS software commonly referred to as “heads-up digitizing”; 2) Sequentially connecting each positional fix to form the line; or 3) Deleting outliers. Some of these edits can be done automatically in GIS software.

Regardless of the method there is a certain amount of subjectivity involved by the data processor and this makes it all the more important that they have adequate experience and training to complete the job successfully. Asking a green technician to determine which fixes are outliers, to interpret the “best-fit” line for complex features or those with “noisy” data is simply not reasonable or acceptable as the majority of errors in traverses are due to insufficient interpretation. Ultimately, if the data is too complicated to interpret with an acceptable level of confidence, it must be reacquired.

E. Quality Assurance and Audit

Whereas Quality Control procedures are undertaken by the GPS Contractor to ensure accuracy and completeness of the final products, Quality Assurance (QA) procedures are the responsibility of the Contracting Agency to ensure the final products are properly integrated into their existing map databases. The QA procedures may be detailed in a contract but are primarily intended for the Agency's benefit. It is recommended that Audit procedures be outlined in the contract to inform the Contractor how the delivered data will be assessed. The following sections are intended to provide an overview of QA concepts and auditing data submitted by the Contractor and are highly recommended for use by the Agency to ensure data integrity and accurate integration of the data into existing database. When data sets of extreme value or sensitivity, e.g., emergency services, are involved these QA procedures may not be detailed enough and further research should be conducted. Note that only relative accuracy is covered by these guidelines. See [Section B: Accuracy Standards](#).

1.) Quality Assurance & Accuracy Requirements

The process of Quality Assurance (QA) entails integrating data acquired from the Contractor into existing database and ensuring that they are complete, correct, and meet the target accuracies detailed in the contract. Failing to implement QA processes can create doubt as to data integrity and may make users justifiably reluctant to invest large amounts of time and energy based on unknown source data. While it has always been the responsibility GIS users to understand data limitations it is also the responsibility of both the Contractor and Agency to ensure integrity in the data they create.

Target accuracies that the data must meet and how these values are reported is detailed in [Section B: Accuracy Standards](#). Reviewing this section will help interpret the following sections.

As all features are ultimately comprised of point features, it is possible to apply standard statistical methods to each individual position averaged from numerous fixes and have them output from the desktop GPS software. Including the raw GPS data as a requirement in the data deliverables allows these values to be recreated if not originally generated by the Contractor. If more than the minimum number of fixes was collected for a feature it is possible to remove a number of outliers in order to recreate the averaged point and improve the points *relative* accuracy, e.g., reduce the standard deviation. An averaged point with a low spread of individual fixes and therefore a low standard deviation does not guarantee an increase in absolute accuracy. See the [General Concepts and Definitions](#) in Section B: Accuracy Standards for a discussion on relative vs. absolute accuracy.

i. Assessing Linear Features

The method for assessing linear and polygon features is identical. Linear features captured via static or dynamic traverses usually have their individual point fixes edited to remove "blunders", i.e., obvious errors or outlier points, to produce a smooth or generalized "best-fit" line.

Visually comparing the "best-fit" line with the original GPS position fixes onscreen provides an insight into data quality by allowing the differences between these individual fixes and the final line to be explicitly viewed. Printing these data out at even a smaller scale for review is impractical due to the time and volume of paper it would require.

The easiest way to do this is to create a buffer equal to the relative target accuracy around the best-fit line and view in concert with the raw data in a GIS.

Fixes far from the final line are likely the result of poor satellite geometry, forest canopy or multipath errors introduced into the data. If only the minimum number of fixes were taken for each point and any show up as outliers the feature may need to be recaptured.

ii. Assessing Point Features

Assessing the quality assurance of point features is also done primarily using visual techniques, though it is entirely possible to automate the process by creating custom programs. Creating a buffer on the post-processed feature, equal to the target accuracy can be used for comparison against the original position fixes.

2.) *Quality Assurance*

Auditing and quality checking the work submitted by the Contractor is the single largest component to Quality Assurance (QA). Making sure the data received is accurate and complete before merging with existing Agency data is the first order of business and can be covered by different levels of auditing. The level and number of audits depends on available project resources, scope and mission critical nature of the data. The three levels of audit presented here are: 1) Quality Check Audit, 2) Detailed Audit, and 3) Complete Audit.

While the Contractor should clearly understand how their data is going to be audited they should not be given any information that allows them to predetermine what points or line segments will be reviewed to avoid biasing the results. Review features should be selected randomly while still representing the project as a whole.

The ascending levels of audit entail an increasing level of detail while at the same time testing a smaller percentage of the GPS data, e.g., 15%, 5%, and 1% for the respective audits, e.g., Quality Check Audits, Detailed Audits, and Complete Audits.

i. Quality Check Audit

The purpose of this audit is to verify that all deliverables detailed in the contract are submitted in full, adhere to the relative accuracy targets and digital data specifications and that field data was collected following the appropriate protocols. It is *highly recommended* that this type of audit be conducted on all projects as a primary means of verifying project objectives have been successfully completed. This basic check can be achieved by reading the project report, ensuring the completeness of all digital data and its relative accuracy through visually and/or quantitatively checking 15% of all data. This audit is geared so that technicians and those with minimal GPS experience can conduct the audit successfully.

Checking relative data accuracy by following procedures outlined in the “Assessing Linear Features” and “Assessing Point Features” noted above can provide a check on relative accuracy through comparison of the raw, individual position fixes and the final interpreted lines or averaged points. This visual review can also reveal things like the distance between position fixes and number of position fixes per point feature. The observed distance between fixes can be compared to the reported method of collection and *Section A.V.D.3.ii- Table IV-3 Dynamic Traversing - Speed & Data Rate vs. Point Separation* to check for continuity between the report and the data.

The procedures below outline a Quality Check Audit²³:

- ❖ Centralize all submitted data and materials.
- ❖ Create a review directory in the existing project directory, e.g., “QAQC”.
- ❖ Copy all submitted digital files to the directory.

²³ British Columbia Standards, Specifications and Guidelines for *Resource Surveys Using GPS Technology*. pp. D-79

- ❖ Review project report.
 - o review dates of milestones (i.e. field survey, post processing, mapping).
 - o review equipment, personnel, etc.
 - o specifically note data capture parameters (i.e. elevation masks, DOP limits, data collection duration, etc.).
 - o note any anomalies.
- ❖ Review field notes.
 - o note any anomalies that may not have been caught in mapping.
 - o review established reference markers, map ties, etc.
- ❖ Review digital files visually.
 - o overall view looking for large blunders.
 - o verify relative accuracy standards for point and line features.
 - o verify spacing of reference markers, etc.
 - o verify spacing or number of position fixes on line and point features.
 - o verify offsets and supplemental traverses.
 - o verify map datum and translations.
- ❖ Review digital files using automated methods if available.
- ❖ Review hard copy output for completeness and presentation.
- ❖ Verify that other returns are complete (particularly digital files).

ii. Detailed Audit

The next level of QA is the detailed audit and it essentially equals the level of detail the Contractor should have invested in Quality Control checks before submitting the data. In addition to the procedures outlined above in the Quality Check audit, the detailed audit includes the re-processing of the raw data and a review of the parameters used in data collection efforts and Quality Assurance procedures.

This level of audit requires a thorough understanding of GPS concepts and practical experience is essential. If a separate consultant is hired to perform these audits they must be unaffiliated with the Contractor originally conducting the survey. This requires both GPS post-processing and CAD/GIS software be available and they should have the capacity to assess quality control measures such as solution variances (standard deviations) and observation residuals in the data. The GPS receiver and software used must be capable of storing pseudorange data to permit the generation of these measures.

The re-processing of the data should follow procedures outlined in sections IV.2 Differential Correction to Improve GPS Data Accuracy and IV.3.D Advanced Data Processing for checking 15% of all data. The original GPS base station data should be reused unless the Contractor setup their own field reference base station, in which case the nearest CORS base station data should be used in re-processing.

iii. Complete Audit

The highest level of audit is the re-survey of a small portion of the Contractor's work. The original contractor should not do the work in order to ensure objectivity of the test. The re-survey test should not include features originally re-observed by the Contractor in order to expand the scope of points re-observed and to provide a separate value of relative accuracy. This value should compare to the original relative accuracy determination and can prove useful in official situations where courts or appeal boards etc. are involved.

As with the Detailed Audit work must be done by qualified personnel or independent consultants and both GPS post-processing and CAD/GIS software be available.

iv. Other Audit Procedures

Other possibilities for audits include using equipment and skilled in-house personnel available to the Agency contracting the work as either a substitute or compliment to the Detailed or Complete Audits. The Quality Check Audit should always be conducted. This is advantageous when the Agency lacks certain GPS equipment and experience but has traditional surveying resources and skills that can successfully fulfill the audit requirements in certain situations, i.e., when project is in proximity to a known benchmark or reference. Tools such as theodolites and (digital) laser range finders can locate features with a very high degree of *absolute* accuracy though this approach may be limited to more open areas free of obstacles and forest canopy. Traditional methods can also accurately determine areas for polygon features. While these methods can register the boundaries to the VSC with a tie-in to a known horizontal benchmark, this isn't necessary for comparing the area values.

*Subject to data target accuracy other techniques are also possible such as overlying the GPS data with digital data of a known accuracy for visual comparison, e.g., digital Orthophotography from the Vermont Mapping Program.

SECTION B – ACCURACY STANDARDS

I. INTRODUCTION

This section provides a means to classify the estimated accuracy of different GPS data capture efforts. It is a resource for entities contracting out GPS data collection, responding Contractors or individual users alike. It is supported by the Guidelines section and provides a common reference for use in classifying different surveys by data precision and relative accuracy. In turn, these common accuracy classes support the Specifications section that details how a target accuracy can be achieved.

The level of accuracy desired for each feature type has a direct impact on the time and cost associated with achieving that accuracy so it is recommended when contracting out GPS data collection that the desired accuracy be carefully considered in the scoping of the project.

Accuracy standards specify the **relative** accuracy of positions while *specifications* detail how the standards can be met and what rules to follow to meet them. This section specifies positional accuracy while **Section C - Content Specifications** details how they can be met. Relative accuracy differs from absolute accuracy in that it is a measure against a relative position, e.g., a previous GPS point, vs. one that has been established through traditional surveying methods or surveying grade GPS that “ties into” an established [National Spatial Reference System \(NSRS\)](#) benchmark. The National Geodetic Survey manages the NSRS. In order to determine the true accuracy for a point taken with a resource/mapping grade GPS receiver, each point would have to be surveyed using traditional survey methods and that is beyond the scope of this document. While it is possible to acquire a GPS point on an established benchmark ever changing satellite geometry, weather conditions and terrain factors negate associating a derived absolute accuracy to other points taken in a field collection effort.

The accuracy table below provides a common reference, or positional relative accuracy standard, for use in classifying different surveys by data precision and relative accuracy. This table applies to both vertical and horizontal relative accuracy so more than one level may be selected for a particular project, especially when the fact that vertical values are generally about half as accurate as horizontal values captured by resource/mapping grade receivers. With this table users can choose the relative accuracy requirements they aspire to achieve and subsequent data users are provided with a good sense of how accurate the data is and how to use it appropriately.

ACCURACY CLASS	ACCURACY CODE	CLASS RANGE
5 decimeter	1	0.201 - 0.50 meters
1 meter	2	0.51 - 1.00 meters
2 meter	3	1.01 - 2.00 meters
5 meter	4	2.01 - 5.00 meters
10 meter	5	5.01 - 10.00 meters
20 meter	6	10.01 – 20.00 meters

Table B- 1 *Relative Accuracy Classification Standards*

II. GENERAL CONCEPTS AND DEFINITIONS

To understand positional accuracy one must look at its individual components: 1) Accuracy and 2) Precision. Whereas, accuracy is connected to the quality of a result, precision is connected to the quality of the operation used to obtain the result. For example, a measuring tape that has been crimped or stretch may measure a table top consistently too short or too long making it report low accuracy (an incorrect absolute measurement) but if the same value was returned each time then the process of measuring the table can be defined as one of high precision (see Figure B-1 below). Likewise, an x,y coordinate captured for a point by a GPS receiver reporting the same number repeatedly, but the coordinate isn't the same as the absolute coordinate for the point is defined as high precision but not highly accurate.

Accuracy is defined as the proximity of a horizontal coordinate or an elevation to the “true value”. The closer the approximate value is to the true value the higher its accuracy (see Figure B-3 below). Ultimately, only relative accuracy can be estimated because the true value or absolute value of a feature requires traditional surveying methods to acquire.

Statistically speaking, precision measures the tendency of a set of numbers to cluster around the mean of those same numbers without regard to the true value (Figure B-1). Any method that results in a number close to this mean, e.g., a GPS point, would be of higher precision.

Common ways to measure precision are via the standard deviation and the root-mean-square (RMS) methods. Many GPS applications contain an option for outputting the data with a standard deviation value for each feature. These methods produce a value that estimates the spread or dispersion of individual point fixes around their mean (averaged) or expected value, reflecting the random error in the individual fixes. These values are useful estimates of precision so long as the data is unaffected by biases due to blunders or uncorrected systematic effects. By combining precision with reliability (Quality Control procedures) or precision in the absence of bias, the distance between true and relative accuracy can be minimized to produce the best possible result.

Figure B-1: Precise but not accurate

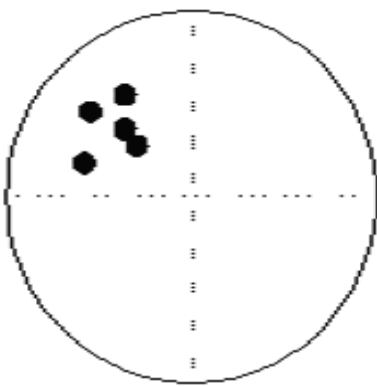


Figure B-2: Accurate but not precise

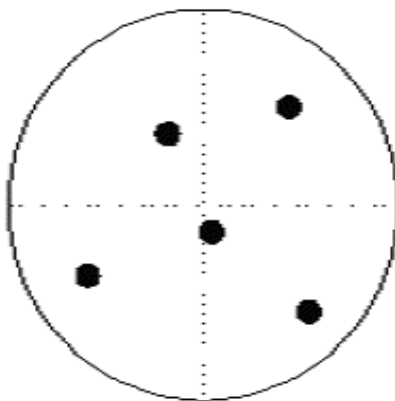
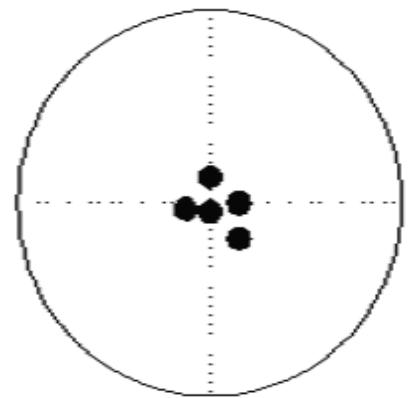


Figure B-3: Precise AND accurate



III. GPS ACCURACY STANDARDS

Before continuing acquire the following resources: 1) [Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy](http://www.fgdc.gov/standards/documents/standards/accuracy/chapter3.pdf) (<http://www.fgdc.gov/standards/documents/standards/accuracy/chapter3.pdf>); and 2) ["Positional Accuracy Handbook: Using the National Standard for Spatial Data Accuracy to Measure and Report Geographic Data Quality"](http://www.mnplan.state.mn.us/pdf/1999/lmic/nssda_o.pdf). (http://www.mnplan.state.mn.us/pdf/1999/lmic/nssda_o.pdf).

The different relative accuracy classes listed in Table B- 1 *Relative Accuracy Classification Standards* provide a common frame of reference for assessing the reliability of results in a single class of features and also between different features. In order to instill confidence in these classes it is necessary for the reported values to be validated by a process that is reproducible. While even recreational receivers have the capacity to store values that provide a measure of precision, e.g., the root-mean-square (RMS) or Standard Deviation (1 sigma) methods, these values may be unreliable means of accuracy. When a location is averaged from individual fixes over a short period, i.e., 30-seconds, the same troposphere effects and other sources of systematic error can affect all of them and impact the precision values. Alternatives to relying on these single value point measures include comparing a GPS position to a known benchmark or re-observing points at a later date when sources of systematic errors are bound to be different.

While it is possible to compare a GPS position with a known benchmark to derive an accuracy measurement, that measurement does not hold true for all points taken with the receiver at all times and under all conditions. It only holds true for that individual point, at the time it was taken and not for any subsequent point(s) acquired, e.g., taken five minutes later in a narrow river valley with a northerly aspect and under canopy. Factors affecting the accuracy of a GPS position, e.g., satellite geometry, troposphere effects, weather, topography etc., are constantly changing and short of using traditional surveying methods to survey each point using reference benchmarks, there is no way to derive the true accuracy for the entire field effort.

A more realistic way to estimate the horizontal and/or vertical accuracy attainable by an individual GPS receiver is to employ a validation procedure where test results are compared against independent control coordinates. Essentially, random points are selected from the field data and compared against an independent data set. The horizontal coordinates or vertical values for each set of points are subtracted from the independent points with the results yielding a consistent reporting value, the National Standard for Spatial Data Accuracy (NSSDA) statistic. While this statistic has a supporting national standard behind it and represents a credible, consistent approach to the issue of relative accuracy it is important to understand its limitations. The reported relative accuracy values is subject to the dynamic nature of GPS error that preclude the accuracy associated with a single point to be fully representative of other points in the same survey. This is especially true under forest canopy or areas of high topographic relief and less true in open areas of gentle terrain. Ultimately, the effort of re-observing positions only provides an indication of accuracy for the entire survey.

This approach is detailed in a set of standards created by the [Federal Geographic Data Committee](http://www.fgdc.gov/fgdc/fgdc.html)²⁴ (FGDC-<http://www.fgdc.gov/fgdc/fgdc.html>) in part three of the five part Geospatial Positioning Accuracy Standards, titled the [National Spatial Standards for Data Accuracy \(NSSDA\)](http://www.fgdc.gov/standards/status/sub1_3.html) (http://www.fgdc.gov/standards/status/sub1_3.html). The NSSDA is a reporting standard that describes the usability of data in terms of quality and accuracy, using a consistent terminology that allows for direct comparison between data sets. Fortunately, these standards have been condensed into a usable document by the Minnesota Land Management Information Center (MLMIC) titled the *"Positional Accuracy Handbook: Using the National Standard for Spatial Data Accuracy to Measure and Report Geographic Data Quality"* (see links at beginning of this section). This provides a step-by-step set of procedures that results in an accuracy statement for the data being tested and is a central resource for applying this accuracy standard.

²⁴ The FGDC develops standards to implement the [National Spatial Data Infrastructure](http://www.fgdc.gov/nsdi/nsdi.html) (NSDI - <http://www.fgdc.gov/nsdi/nsdi.html>)

A. Re-Observation

The NSSDA standard requires that a minimum of 20 check-points be tested independently of the original GPS survey. These points should be distributed throughout the geographic area of interest and be representative of the type of error likely to occur in the dataset, e.g., points under canopy, in narrow ravines, north facing locations, etc. The testing of 20 points allows for one point to fail the target accuracy threshold while allowing the remainder to be within the 95% confidence level of the target accuracy. While the ideal for this standard is to acquire the independent data set separately from the test data and that it be three times more accurate, the practical solution presented in this standard is to re-observe 20 representative points using either the same GPS receiver, or one capable of higher accuracy, if available, and the same critical settings but collecting more individual fixes.

To maximize the independence of the re-observed locations they should be taken at least one hour later than the originals and if possible, conducted by a different individual.

For the sake of clarity, the Contracting Agency should request a project report that contains either a table or spreadsheet detailing both the original and repeat measurements with a summary showing the percentage of re-observed points that were within the relative accuracy test level. To meet a relative accuracy target, 95% of the re-observed points must be within the square root of twice the relative accuracy target squared, e.g.:

Example:

Relative accuracy target: 5m

Repeat Measurement Test Level = $\sqrt{(2 \times 5^2)} = 7.1m$

QC Test: 95% of the radial distances between separate, averaged observations at the same point must be less than 7.1m to meet the relative accuracy target of 5m.

Radial distances measure the direct line distance between the original and re-observed averaged points, e.g., the mean location of the individual fixes acquired for each point.

For “network survey’s”, i.e., individual points that define a linear features like a road, whole segments of the network should be re-observed (preferably run in the opposite direction from the original survey). The two segments can be compared graphically and the separation measured to determine the relative accuracy level.

B. Determining the NSSDA

The NSSDA uses the root-mean-square error (RMSE) method to estimate positional accuracy. RMSE is calculated by squaring differences between the original and re-observed, independent coordinate values and then squaring the average value of the differences. Subsequently, the NSSDA statistic “is determined by multiplying the RMSE by a value that represents the standard error of the mean at the 95 percent confidence level: 1.7308 when calculating horizontal accuracy, and 1.9600 when calculating vertical accuracy.”²⁵

The NSSDA accuracy statistic is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value.”

²⁵ MLMIC. Positional Accuracy Handbook. pp. 8.

Reporting

This value can be reported in one of two ways, refer to either the FGDC NSSDA standard or the MLMIC's Positional Accuracy Handbook²⁶ for more details:

- 1) "Tested _____ (meters, feet) (horizontal, vertical) accuracy at 95% confidence level"; and
- 2) "Compiled to meet _____ (meters, feet) (horizontal, vertical) accuracy at 95% confidence level".

Refer to the Positional Accuracy Handbook for questions on these steps. To generate the NSSDA Statistic conduct the following steps:

1. Acquire the following resources if you haven't already: A) [Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy](http://www.fgdc.gov/standards/documents/standards/accuracy/chapter3.pdf) (<http://www.fgdc.gov/standards/documents/standards/accuracy/chapter3.pdf>); and B) "Positional Accuracy Handbook: Using the National Standard for Spatial Data Accuracy to Measure and Report Geographic Data Quality" (http://www.mnplan.state.mn.us/pdf/1999/lmic/nssda_o.pdf).
2. Determine if the test involves horizontal accuracy, vertical accuracy or both.
3. Select a set of test points from the data set being evaluated representative of both the geographical extent and likely sources of error, e.g., topography, canopy etc.
4. Select an independent data set of higher accuracy, if possible, that corresponds to the data set being tested.
5. Collect measurements from identical points from each of those two sources.
6. Calculate a positional accuracy statistic using either the horizontal or vertical accuracy statistic worksheet. (Accuracy statistic worksheets may be downloaded off the Internet from MLMIC's positional accuracy web page (<http://www.mnplan.state.mn.us/press/accurate.html>) and clicking on "Accuracy Statistic Worksheets".)
7. Add any Base Station errors that apply to the statistic before reporting it, e.g., base station accuracy or baseline error (see below).
8. Prepare an accuracy statement in a standardized report form.
9. Include that report in a comprehensive description of the data set called metadata.

C. Base Station Accuracy

The accuracy of all GPS field data benefits from post-differentially correcting the points with base station files. There are two minor elements of error involved with base stations that affect the accuracy of post-differentially corrected data; 1) baseline error; and 2) positional accuracy of the base station. The latter error is negligible, as all base stations within or in close proximity to Vermont have been surveyed to a high level of accuracy. These are part of the Continuously Operating GPS Reference Station (CORS) network, managed by the National Geodetic Survey. Nationally, CORS stations are considered to have a horizontal accuracy of 2 cm, and a vertical (ellipsoid height) accuracy of 4 cm. Base station positional accuracy becomes a more appreciable factor when a mobile GPS base station is established in the field, however, this document does not cover the use of these stations.

Baseline error is a function of an individual units rating, the distance between the GPS receiver in the field and the base station and has a direct affect upon data accuracy. Though not all receivers provide specification sheets that detail this issue, all claims of receiver accuracy must have the baseline error added to derive true receiver accuracy. This value is measured in parts per million (ppm) and generally speaking less expensive receivers generally have a higher baseline error component than their more sophisticated cousins

See the [CORS map](http://www.ngs.noaa.gov/CORS/cors-data.html) (<http://www.ngs.noaa.gov/CORS/cors-data.html>) for base station locations nationwide.

²⁶ MLMIC. Positional Accuracy Handbook. pp. 7.

Summary

To meet the relative target accuracy required by the project it is necessary to re-observe a portion of the original positions, calculate the NSSDA statistic and add the baseline error to produce the complete reporting accuracy. The only CORS base station with a one second sampling interval on Long Island is located at MacArthur Airport (ZNY1) and permits the best flexibility for field work in that it allows the GPS receiver to use any sampling interval setting (as they are all divisible by “1”). For those of you in Western Long Island and New York City the New Jersey Institute of Technology (NJ12) may be a viable site.

The CORS stations in the rest of Long Island and surrounding states are desirable where baseline errors from ZNY1 and NJ12 are larger but these stations have a sampling interval of five seconds requiring field collection efforts to either use sampling intervals in multipliers of five, e.g., 5, 10, 15 seconds etc. or to contend with interpolated results when using a one second sampling interval. Matching the GPS receiver sampling interval with that of the base station is the best way to maximize the advantage of post-differential correction and avoid the correctional base station values from being interpolated in non-multiplier increments. As base stations do sometimes “go down” and lose periods of base data, throwing off the best laid plans, one option is to always use a one second sampling interval providing: 1) your unit has ample memory; and 2) any project requirements for occupation time (vs. fixes) are still met. In other words, no one will contend more fixes acquired for a feature so long as the occupation time was adhered to.

SECTION C - CONTRACTOR SPECIFICATIONS (To aid in contracting out GPS service requests)

I. INTRODUCTION

To aid individuals, public non-profit entities and private sector companies in contracting out or responding to GPS service requests, the *Specifications* section, with support from both the guidelines and accuracy standards can be used to form the technical section of a GPS survey contract. Review of the Guidelines section is recommended prior to using the Specifications. These specifications contain the rules that convey how the data accuracy standards can be met and facilitate the standardization of data collection procedures and quality control. As previously mentioned, the Guidelines provide general background information while the Accuracy Standards establish common target accuracy classes.

These specifications are presented as a resource for contracting agencies and Contractors alike to facilitate the collection and integration of high quality GPS data into a variety of data layers where targets for horizontal accuracy are between .5 - 20m and for vertical accuracy between 1-20m. Reporting for these accuracies is at the 95% confidence level.

II. TERMINOLOGY

The following definitions and abbreviations are used in this section:

Agency	Agency, Department, Division or other entity administering the Contract.
Contractor	Corporation, firm, or individual that provides works or services to the Agency under terms and conditions of a contract.
Contract Administrator	Agency representative who has authority for issuing and managing the contract and for receiving the items or services delivered by the Contractor.
Data Processor	A trained employee of the Contractor who performs the calculations to convert raw field GPS data into processed maps / databases using DGPS procedures and QC checking / editing.
DGPS	Differential GPS (i.e. pseudorange code positioning differentially corrected either post-mission or real-time).
Dynamic-mode	Collection of GPS data while traveling along a linear feature to be surveyed (e.g. a road or watercourse).
Field Operator	An employee of the Contractor who performs the field portion of the data collection.
Geoid	The equipotential surface approximating Mean Sea Level.
GPS	Global Positioning System as operated by the United States Department of Defense (US DoD). Also called NAVSTAR.
GPS Event	A GPS Event is a single position instead of a group of positions averaged to a single position (i.e. Static survey). Events are typically used when the antenna cannot, or need not, be stationary over a point.
GPS Reference Station	A GPS receiver located at a known location collecting data continuously to be used for correcting field data (either in real-time or post-mission). Also known as a base station.
NAD27	North American Datum of 1927, based on the Clarke 1866 ellipsoid.
NAD83	North American Datum of 1983, based on the Geodetic Reference System 1980 (GRS80) ellipsoid.
NAVD88	The North American Vertical Datum of 1988; vertical control datum established in 1991
Static-mode	Collection of GPS data at a discrete point while remaining stationary.
Supplemental Traverse	Supplemental Traverses are conventional traverses (e.g. compass and tape) that are integrated with GPS surveys.
UTM	Universal Transverse Mercator projection (map projection system).

The statements in this document have been structured according to two levels of compliance:

<i>required</i>	Used to describe tasks that are deemed necessary and are good practice. Exceptions are possible, but only after <i>careful</i> consideration by the Contracting Agency.
<i>recommended</i>	Used to describe tasks that are deemed desirable and good practice, but are left to the discretion of the Contracting Agency. In some cases, cost is a large factor in recommended tasks vs. requiring them even if they are desirable.

III. GOALS

- ❖ To establish achievable levels of accuracy by task, and to classify the surveys to be performed by end specifications aimed at achieving target accuracies.
- ❖ To provide a technical document for individuals, agencies or the private sector to use in contracting GPS related services.
- ❖ To provide users with a consistent set of methods that can be used at the individual or agency level that allows results to be easily integrated.
- ❖ To qualify a GPS Contractors' equipment, methods, and employees to ensure target accuracies are achievable under various conditions.

IV. PRE-QUALIFICATION AND VALIDATION

A. Total System

It is *required* that any Contractor expecting to undertake GPS data collection be prepared to fulfill the requirements of the full "System", including: GPS hardware and software for field and office; field and GPS Reference Station receivers (when applicable); and reporting techniques. All parts of the System are to be capable of meeting the contractual specifications below.

B. Field Operator Training

It is *recommended* that Field Operator(s) be qualified through a GPS training course provided by an established and reputable company, agency or organization.

C. Data Processor/Project Manager Training

It is *required* that Data Processor/Project Manager(s) have an established track record in the planning, management and implementation of GPS projects. It is *recommended* that the background include the capture, processing and management of GPS data.

D. Contractor Validation

For large or extremely important GPS efforts it is *required* that the GPS System used prove its ability to meet the accuracy targets through a validation survey. Subsequent to determining validation accuracies and the conditions under which they were achieved, the results should apply to all subsequent fieldwork. For a large enough project the validation exercise could simultaneously provide an additional means of assessing a Contractor's proposal. However, this approach should be considered carefully as it will add an extra component to proposal estimates and may put downward pressure on proposal submittals. See Section C.V *Validation Surveys*.

V. VALIDATION SURVEYS

Due to the nature of GPS technology there is no easy way to detect outright blunders or to balance random errors homogenously throughout a survey. A skilled operator can certainly stack the odds in their favor for reducing blunders and errors but short of tying each GPS point to a known benchmark through traditional survey methods, there is no way to precisely assess accuracy. While using traditional methods to survey each point would negate the cost and efficiency advantages of using GPS, there is a middle ground solution that can be very useful in pre-qualifying GPS Contractors if the project is big enough, important enough and worth the extra costs incurred.

A sample *Contractor GPS Contractor Report* resides in *Appendix J* of this document to assist Contractors in complying with a validation survey, if required. The report contains the minimum information required but Contractors may provide additional analytical information, if practical to do so, on additional page(s). If a validation survey is not required for pre-qualification by the Contracting Agency it is still *required* for the actual fieldwork and must accompany the deliverables. Regardless, the parameters outlined in the specifications must be followed for both pre-qualification and contracted fieldwork.

A validation survey simply compares the coordinate values of points acquired by the Contractor with known values. The Contracting Agency can establish a “Test Range” with either point, line, and area features located to simulate field conditions, e.g., canopy, steep terrain etc. where Contractors acquire location that are compared to highly accurate feature coordinates acquired using traditional methods. If practical, it is *recommended* that at least two of these points be benchmarks from the National Spatial Reference System (NSRS). Horizontal and vertical values must be tested with horizontal or vertical benchmarks, respectively. Needless to say the Test Range requires qualified personnel to establish and evaluate in order to ensure that the trials are fair and scientifically defensible. When evaluating test results don’t neglect practical, non-accuracy related considerations, e.g., if the target accuracy is 5m, then the small firm with less expensive equipment acquired 3.5m accuracy vs. the large firm with 1.5m accuracy may be able to do the job more economically and just as well.

Once a Contractor’s system has been validated for a certain accuracy level, they may be exempt from future validation requirements if key components and conditions affecting their GPS system are unchanged; 1) Key Personnel (Project Manager, Data Processor); 2) Type of rover hardware; 3) Processing software (type and version number); 4) Observational parameters such as DOPs, SNR, and elevation masks; 5) Separation distances between Reference Station and rover; and 6) Number of epochs (fixes) averaged at static points.

Some practical considerations when deciding to utilize a validation survey requirement include:

- ❖ It would be unreasonable to require this for a small project unless the features being collected are extremely important and accuracy is a premium.
- ❖ Firms located further away from the test site may be at a competitive disadvantage than companies located nearby.
- ❖ The test should take no longer than one day to complete including reasonable, round trip driving times.
- ❖ No one can operate a business at a loss so it is unreasonable to expect the cost of this extra level of effort will not be reflected somewhere in a Contractors proposal. Those that don’t charge it up front may simply charge a higher hourly rate.
- ❖ Contractor results should be within both the horizontal and/or vertical target accuracies, if applicable.

VI. PRE-FIELDWORK PROCEDURES

A. Proposal Meeting

It is *recommended* the Contract Administrator conduct a meeting upon release of a project Request for Proposals (RFP) to clearly define the feature(s) to be surveyed, to identify “High-Significance” from “Standard-Significance” points (if applicable), project extent and guidelines for interpretation of special features. In addition, this meeting will provide a clear definition of deliverables, services, work quality, payment schedule, and other relevant contract issues to minimize confusion of the nature and quantity of work expected. It is also important to establish the Quality Control and Assurance schedule at this point.

B. Auditing

It is *recommended* the RFP clearly detail the Auditing process, including the frequency and methods of the data/field inspections, as well as, the use of independent GPS or other surveys to be used in assessing accuracy compliance with the contract.

C. Field Inspection

Subsequent to project award, it is *recommended* the Contract Administrator conduct a field inspection with the Contractor to reiterate details regarding the nature and scope of work detailed in the contract.

D. Reference Markers

When physical reference markers are required to detail project specifics, it is *required* that the interval and type of markers be stated in the contract, making use of any pre-existing Agency guidelines or requirements.

E. Map Ties

It is *recommended* that all projects include a sufficient number of map ties to allow for accurate geo-positioning and reliability checks. Map Ties should be readily visible from the air, e.g., the Vermont Mapping Program's digital Orthophotography. Good candidates include stream junctions, road intersections, baseball diamonds or other publicly accessible, readily visible features. The signed contract should detail the number, location and nature of the tie points.

F. Legal Boundaries

GPS technology cannot be used to legally define parcel boundaries in New York unless the operator is a licensed land surveyor as defined by New York Statute. This in no way precludes boundaries from being captured with a GPS receiver by anyone, subject to permission by the land owner, but the results simply can't be used in any legal proceedings unless they are certified.

G. Required Survey Accuracies

Target accuracies (at the 95% confidence level) for the project are:

Interpretative Horizontal Accuracy = _____m (Class = _____)
Interpretative Vertical Accuracy = _____m (Class = _____)

Refer to Section B.1. Table B- 1 *Relative Accuracy Classification Standards* for determining the Class code to insert in the above. The target accuracy is defined by having at least 95% of the individual position fixes within the above-specified accuracies of the true position of the point. For a GPS traverses done in dynamic linear mode, at least 95% of the individual GPS position fixes must be within the specified accuracies from the line's true position.

VII. FIELDWORK

A. Critical Rover Settings

- ❖ The receiver will be set to only record observations using a minimum of four (4) satellites, e.g., "over determinate 3D" mode.
- ❖ The minimum satellite elevation angle/mask for the field GPS receiver is 15 degrees above the horizon.
- ❖ It is *required* the maximum Signal-to-Noise Ratio be _____.
- ❖ It is *required* that the DOP not exceed the following values:

DOP Component	Maximum DOP Value Allowed*
Geometrical DOP (GDOP)	
Positional DOP (PDOP)	
Horizontal DOP (HDOP)	
Vertical DOP (VDOP)**	

*Not all DOP values are required to be completed.

**VDOP limits are only required when accurate elevations are required

B. Data Collection

- ❖ During Static (point-mode) surveys, it is *required* that the feature be occupied according to the minimum values below, or the values used during the Validation survey, which ever is higher.

Point Significance	Minimum Occupation Time (sec)	Minimum Number of Fixes
Standard-Significance Point		
High-Significance Point		

- ❖ It is *required* that position fixes being mapped statically for linear features (i.e. static or point-to-point traverses) not be greater than _____ meters apart. Capture the traverse points according to the specs outlined for Standard Significance Points.
- ❖ It is *required* that position fixes being mapped dynamically for linear features in a dynamic traverse not be greater than _____ meters apart.
- ❖ It is *required* that both ends of a dynamic traverses be captured to the specs outlined for High-Significance points. These can be referred to as either the Point of Commencement (PoC) or the Point of Termination (PoT).
- ❖ It is *required* that any deviations in an otherwise straight line, point-to-point traverse must be mapped regardless of the minimum separation between points detailed above. This also applies to significant vertical breaks if elevations are required.
- ❖ Interpolated points - e.g., GPS Events are *recommended* to be accurate within _____ seconds.
- ❖ Point offsets - The following is *required* to be recorded:
- ❖ (see Section A: IV.3.C.8.Table IV-5 Offset Accuracy vs. Instrumentation Precision & Offset Distance for related information):
- ❖ The vertical angle *from* the GPS antenna *to* the feature. Many compasses also include an inclinometer for this purpose.
- ❖ If not automatically set, magnetic declination must be factored into any compass readings before computing offset coordinates. See the [magnetic declination calculator](http://www.ngdc.noaa.gov/seg/geomag/jsp/Declination.jsp) (<http://www.ngdc.noaa.gov/seg/geomag/jsp/Declination.jsp>) at the National Geophysical Data Center.
- ❖ The *maximum* distance allowed for a point offsets is _____ meters.
- ❖ Bearings accuracy must be at least _____ degrees
- ❖ Distance accuracy must be at least _____ meters.
- ❖ Linear offsets - The following is *required*:
- ❖ The horizontal distance and the true bearing to the direction of travel.
- ❖ The *maximum* horizontal distance allowable is _____ meters.
- ❖ For supplemental traverses it is *required* that:
- ❖ The PoC and PoT physically marked end points must be High-Significance GPS static points.
- ❖ The distance traversed is to be less than _____ meters.
- ❖ The traverse close between the end points by _____ of the linear distance traversed.

- ❖ The traverse must be balanced between the end points by an acceptable method (i.e., compass rule adjustment).
- ❖ If applicable, physical reference markers must be established at an interval of _____ meters along linear features. Enter “N/A” if this doesn’t apply. If the Contracting Agency has standards for reference markers they will be used unless other standards are agreed to.
- ❖ It is *required* that physical reference markers have static point features collected as STANDARD / HIGH (circle one) Significance points.
- ❖ The maximum allowable SNR mask CAN / CANNOT (circle one) be relaxed during a linear traversing.

VIII. GPS BASE STATION

It is highly *recommended* that users employ a CORS station either on Long Island, or one of the CORS stations in the two neighboring states. Temporary GPS Reference Stations established by the Contractor are not covered in the scope of the GPS guidelines document.

- ❖ It is *required* that the baseline distance between the CORS stations and the field receivers be reported in miles _____. If the project area covers a large geographic extent (greater than 10 miles in either direction) then this value should be broken down to minimum and maximum baseline distances. If the baseline distance is greater than that the distance present during Validation, and the validation accuracy was border line to the target accuracy then the Contractor must detail how the target accuracy will be met with the increase in baseline error.
- ❖ It is *recommended* that the *minimum* elevation angle/mask of the GPS Base Station be 10 degrees. This is the default setting for CORS stations.
- ❖ If real-time corrections are used, it is required that the Total Correction Age of the rover GPS system not exceed __15__ seconds. The larger the delay between the base station files used to correct the real time position, the larger the error introduced.

IX. PROCESSING AND QUALITY CONTROL

- ❖ All GPS positions are to be corrected by standard differential GPS methods (pseudorange or navigation corrections). If navigation corrections are used, the same GPS satellites must be used by the GPS Reference Station and the receiver for all corrected positions.
- ❖ If the GPS receiver and/or post-mission software provides the option for dynamic filtering, it is *recommended* the filters be set to reflect the speed of the operator or vehicle, and the software versions and filter settings are to be noted in the project returns.
- ❖ It is *required* that the Contractor implement a Quality Control (QC), or reliability assessment, program in order to show compliance to specified guidelines or standards (i.e. positional accuracy, content accuracy, completeness, data format adherence, and data integrity assurance).
- ❖ It is *required* that the Contractor be prepared to entirely re-survey those areas that do not meet the compliance standard at their own cost.

X. PROJECT MANAGEMENT and DELIVERABLES

Effectively managing the volume of data produced in a GPS project is critical for ensuring its future usability, especially when a majority of the data represents raw, intermediary or supporting data. It is *recommended* that the

Contracting Agency require all raw, intermediary or supporting digital data be retained by the Contractor and included on digital media in the deliverables.

This section details deliverable specifics present in the GPS contract including content, file format and media. It also describes requirements for managing and archiving data. In the absence of special requirements by the Contracting Agency these guidelines should be followed as closely as possible.

A. PROJECT REPORT

The elements of the recommended project report are identical to those detailed in the GPS Contractor Validation Report created during the pre-qualification survey. If a validation survey was not required by the Contracting Agency, the Contractor may still prefer to use the SAMPLE GPS CONTRACTOR REPORT located in Appendix J to fulfill these report requirements.

It is *recommended* that the Contractor submit a project report including the following information:

- ❖ “A brief description of the project work (i.e. purpose, target accuracy, location, etc.).
- ❖ A brief description of the Contract particulars, including the Contracting Agency that commissioned the work; the Contract Coordinator; a project name (if available) and a project identifier.
- ❖ A listing of all personnel (Contractor and Subcontractors) involved in the project detailing their particular duties and background (i.e. their educational background; formal GPS training details (courses with dates); their experience on similar projects, etc.). This could be a copy of what was provided with the pre-qualification package.
- ❖ A key map showing the project area and a description of any GPS Reference Stations used.
- ❖ A description of the GPS Reference Stations used.
- ❖ If using a temporary GPS Reference Station the issue of validating the GPS Reference Station will also have to be resolved (i.e. a GPS reference Station validation will have to be submitted).
- ❖ A schedule of events showing key dates (contract award, field data acquisition, data processing, and submission of the results, etc.).
- ❖ A list of all hardware and software used on the project; including but not limited to:
 - o GPS hardware (i.e. models, receivers numbers, data loggers, antennas, firmware versions, etc.);
 - o GPS software (i.e. name, version number, settings, etc.);
 - o mapping software (i.e. name, version number, settings, etc.); and
 - o utility software (i.e. name, version number, settings, etc.).
- ❖ A summary of the project including planning, field data collection methods and parameters (i.e. GPS receiver settings/defaults), data processing methods and parameters (i.e. post-processing settings/defaults), any project problems, anomalies, deviations, etc.
- ❖ A summary of the results, including repeatability test details.
- ❖ An explanation of the deliverables (digital and hard copy) including formats, naming conventions, compression utilities, media, etc.
- ❖ A copy of all field notes (digital or hard copy).
- ❖ A list of all features that have been mapped or surveyed.”²⁷

B. HARD COPY PLANS

If the Contracting Agency requires a final hard copy map then the media, scale, datum etc. must conform to Agency cartographic standards, if applicable, as outlined in the contract and presented with other deliverables. Providing the Contractor with a “map template” is the easiest way to achieve this.

The following map components are suggested:

- ❖ General project information in text boxes: project title; project number/identifier; Contracting Agency name; Contractor name; and date of survey.
- ❖ Datum, projection and units of measure, e.g., NAD83 ft.

²⁷ British Columbia Standards, Specifications and Guidelines for *Resource Surveys Using GPS Technology*. pp. C-8

- ❖ Scale bar
- ❖ North arrow with either or both True North and Magnetic North.
- ❖ Graticules, if requested, e.g., 1,000 or 10,000 intervals.
- ❖ Source information for non-GPS data, e.g., Roads or Surface Water data.

It is *required* that the accuracy of GPS acquired data be stated on the map.

C. GPS DATA AND PROCESSING DELIVERABLES

It is *required* that all raw rover files, originally corrected and interpreted (originally corrected with edits) GPS data and base station sampling files be kept for archive and Quality Assurance (QA) purposes in their original format. The raw GPS data is *required* to be stored in the manufacturer's original, proprietary format. It is acceptable to supply the one-hour block Base Station files merged for the time extent of the daily rover data files. The originally corrected GPS data is raw data post-differentially corrected with base station sampling files prior to any averaging, generalizing, filtering or editing, e.g., interpreted GPS data.

Data collected with customized data dictionaries that have GIS feature and attribute information may not be supported by the current RINEX format. In this situation, the manufacturer's proprietary format is *required* to preserve the integrity of the data.

It is *required* that digital data be submitted on the storage media and format required by the Contracting Agency.

Table X-1 below details the data *required* for submittal by the Contractor. See the respective Guidelines sections for details on these different data.

Deliverables	Format	Datum	Notes
GPS Base Station Data	DAT, SSF, or RINEX	WGS84	Merged if possible
Raw Field GPS Data	DAT, SSF, or RINEX	WGS84	Originally downloaded
Original Corrected GPS Data		NAD83	Unedited
Final Interpreted GPS Data		NAD83	Edited

Table X-1: Digital Deliverables

If the Agency requires any other local datum, the methods used to transform the data are to be explicitly described in the project report and approved by the Agency.

D. DATA OWNERSHIP

All project related data and submitted deliverables are the property of the Contracting Agency and access to project data prior to delivery, by the Contract Manager is *required* to be honored upon request. All the documents submitted to state, regional or local government entities will be subject to the disclosure provisions of state statutes governing the access to public records.

E. QUALITY ASSURANCE

All data submitted by the Contractor shall be validated by the Contracting Agency following guidelines in Section A.V.E Quality Assurance and Audit before integration with existing databases.

F. DATA MANAGEMENT AND ARCHIVING

It is highly *recommended* that the Contracting Agency archived the GPS base station data, raw field GPS data, original corrected GPS data and final interpreted GPS data in a consistent and organized manner to ensure ready access by the Agency itself or any project partners in case of questions about the features or their accuracy. Each Contracting Agency office must establish their own system for managing and archiving the deliverables. This is essential as the deliverables can present a large volume of data that can be difficult to use reliably and effectively if they are not stored in an organized manner.

G. DIGITAL MEDIA

The GPS deliverables and their archive should be stored on stable media, e.g., CD-ROM, DVD, backed up hard drives etc. It is recommended the Contracting Agency integrate specific project information into an existing data retrieval system or consider devising one that, at a minimum, affords quick access to basic project information, e.g., project name, Contracting Agency, Contractor, map reference, file names, formats, significant dates, physical storage location, etc.

The Contracting Agency will be responsible for transferring the data to archive quality media.

XI. **TECHNOLOGICAL/PERSONNEL CHANGE**

- ❖ If significant changes occur to the Contractor's GPS system components (i.e., hardware, firmware, software, methodology, etc.) or personnel during an active contract, it is *recommended* the Contractor consult with the Contract Administrator. A decision will be made as to whether the Contractor GPS System Validation and/or personnel qualification be reevaluated.

It is *required* that the Contractor and the Contract Administrator ensures that the most current versions of the GPS Data Collection Guidelines for Suffolk County, NY are used.

XII. METATADATA GUIDELINES

Simply defined, metadata is “data about data”, or information that describes the characteristics of a GIS data set. In describing a GIS data set, metadata usually provides information about its content and origins; it may also be used to track the updates, corrections or changes to a data set. In addition, metadata should also contain distribution information, which explains how a potential user can acquire the data set.

Metadata, created and updated according to the Federal Geographic Data Committee (FGDC)²⁸ standards is important and valuable. It is **required** that metadata accompany all data collected with GPS as it:

- Maintains the value of the data set over time;
- Preserves the data description (e.g. origin, format, use, purpose.)
- Allows users to search for and use existing geospatial data and contributed to an NSDI Clearinghouse (such as the NYS GIS Clearinghouse).

²⁸ “Content Standard for Digital Geospatial Metadata,” 20 Dec. 2006 <<http://www.fgdc.gov/standards/projects/FGDC-standards-projects/metadata/base-metadata>>

Appendix A - Glossary of Useful Terms

Accuracy

The degree of conformity with a standard or accepted value. Accuracy relates to the quality of the result, and is distinguished from precision which relates to the quality of the operation by which the result is obtained.

Autonomous Positioning

The least precise form of positioning that a GPS receiver can produce. The position fix is calculated in real time from satellite data alone. Autonomous positions are generally accurate to within 10 meters.

Base station

A base station is comprised of a GPS antenna and GPS receiver positioned at a known location specifically to collect data for differential correction. The purpose of the base station is to provide reference data for performing differential correction on data collected in the field. Base data need to be collected at the same time as you collect data with a GPS rover receiver. A base station can be a permanent installation that collects base data for provision to multiple users, or a GPS rover receiver that you temporarily locate on known coordinates for the duration of a specific project or datalogging session.

Bluetooth

A wireless technology capable of using short-range radio technology for Internet and mobile devices, aimed at simplifying communications among them. Some GPS receivers use Bluetooth to communicate with the datalogger.

Carrier Phase

The difference between the carrier signal generated by the internal oscillator of a roving GPS receiver and the carrier signal emitted from a particular GPS satellite.

Coarse/Acquisition (C/A) Code

A pseudorandom noise code (PRN) modulated onto a L1 signal which helps the GPS receiver to compute the distance from each satellite. Specifically, the difference between the pseudorandom number code generated by the GPS rover software and the pseudorandom number code coming in from the satellite is used to quickly compute the distance to a satellite and therefore calculate your position.

CORS (Continuously Operating Reference) Station

A network of GPS base stations coordinated by the National Geodetic Survey for the purpose of providing GPS reference data to permit end users to perform post-processed differential correction of GPS data collected with roving GPS receivers. Reference data are typically acquired via direct download from the Internet.

Data Dictionary / Feature Library

A term used to describe the schema, or structure, that defines the relationship between features and their descriptive attributes that will be located in the field with a professional GPS receiver. This description typically includes feature name(s), data type classification (point, line, or polygon), attribute names, attribute types, and attribute values. After being created on a PC, a data dictionary is transferred to a GPS datalogger and used when collecting data in the field.

Data Message

A message included in the GPS signal, which reports a satellite's location, clock correction, and health. It includes information on other satellites' health and their approximate positions.

Datum

A mathematical model of the earth's surface. World geodetic datums are typically defined by the size and shape of an ellipsoid and the relationship between the center of the ellipsoid and the center of the earth. Because the earth is not a perfect ellipsoid, any single datum will provide a better model in some locations than others. Therefore, various datums have been established to suit particular regions. For example, maps in the United States are often based on the North American datum of 1927 (NAD-27) or 1983 (NAD-83). All GPS coordinates are based on the WGS-84 datum surface.

Datum Transformation

A mathematical calculation that converts the coordinates of a position in one datum to coordinates in terms of another datum. Two types of datum transformations are supported by most professional grade GPS data collection and management software: three parameter and seven parameter. A datum transformation is used when the GPS results are required in terms of a local datum.

Declination

See magnetic declination.

Differential Correction

The process of correcting GPS data collected on a rover with data collected simultaneously at a base station. Because it is on a known location, any errors in data collected at the base station can be measured, and the necessary corrections applied to the rover data. Differential correction can be done in real time, or after the data has been collected by post processing.

Dilution of Precision (DOP)

An indicator of the quality of a GPS position, which takes account of each satellite's location relative to the other satellites in the constellation, and their geometry in relation to the GPS receiver. A low DOP value indicates a higher probability of accuracy.

Standard DOPs for GPS applications are:

PDOP - Position (three coordinates)

HDOP - Horizontal (two horizontal coordinates)

VDOP - Vertical (height only)

TDOP - Time (clock offset only)

Dual-frequency (GPS) Receiver

A type of GPS receiver that uses both L1 and L2 signals from GPS satellites. A dual-frequency GPS receiver can compute more precise position fixes over longer distances and under more adverse conditions by compensating for ionospheric delays.

Earth Centered, Earth Fixed (ECEF)

A Cartesian coordinate system used by the WGS-84 reference frame. The center of the system is at the earth's center of mass. The z axis is coincident with the mean rotational axis of the earth, the x axis passes through 0°N and 0°E, the y axis is perpendicular to the plane of the x and z axes.

EGNOS (European Geostationary Navigation Overlay Service)

A satellite-based augmentation system (SBAS) that provides a differential correction service for GPS users in Europe. EGNOS is the European equivalent of WAAS, which is available in the United States.

Elevation Mask

The angle above and relative to the horizon, below which your GPS rover will not track satellites. It is normally set to 15° to avoid interference problems caused by buildings and trees and multipath errors and avoid the rover GPS receiver using a GPS satellite that the base station is not tracking.

Ellipsoid

An ellipsoid is the three-dimensional shape that is used as the basis for mathematically modeling the earth's surface. The ellipsoid is defined by the lengths of the minor and major axes. The earth's minor axis is the polar axis and the major axis is the equatorial axis.

Ephemeris

The current satellite position predictions that are transmitted from a GPS satellite in the NAVDATA message.

Epoch

The measurement interval of a GPS receiver.

Geoid

A mathematical surface of constant gravitational potential that approximates sea level (See Mean Sea Level, below).
Or, the equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level.

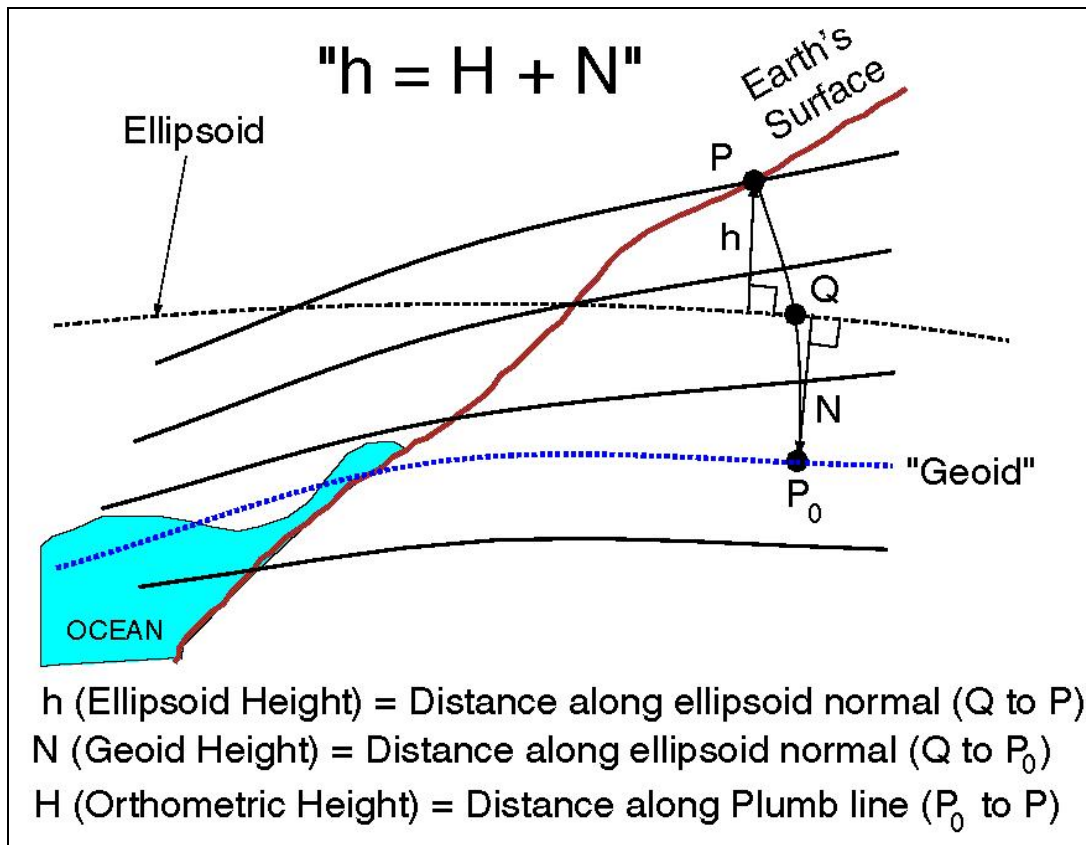


Image Source: National Geodetic Survey

Global Positioning System (GPS)

The generic term used to describe the satellite-based timing and positioning system operated by the United States Department of Defense (DoD).

Grid North

The meridian of any particular grid that is referenced to true north.

Height Above Ellipsoid (HAE)

Distance (h) above the reference ellipsoid. HAE is always measured orthogonal to the ellipsoidal surface. Three dimensional GPS positions reference HAE. Recreational grade GPS receivers calculate approximate orthometric height (elevation) for the user.

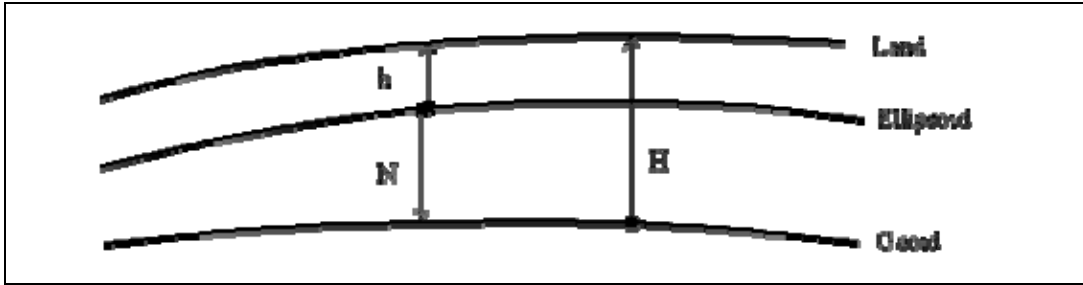


Image Source: National Geodetic Survey

Horizon

The line at which the earth and sky seem to meet for any particular observer.

Horizontal Dilution of Precision (HDOP)

See DOP.

L1

The primary L-band carrier used by GPS satellites to transmit satellite data. The frequency is 1575.42 MHz. It is modulated by C/A code, P-code and a 50 bit/second navigation message.

L2

The secondary L-band carrier used by GPS satellites to transmit satellite data. The frequency is 1227.6 MHz. It is modulated by P-code and a 50 bit/second navigation message.

Latitude

An angular measurement made from the center of the earth to north or south of the equator. It comprises the north/south component of the latitude/longitude coordinate system, which is used in GPS data collection.

Traditionally, north is considered positive, and south is considered negative. Example: 43° south of the equator may be expressed as either unsigned (-43°) or signed (43° S)

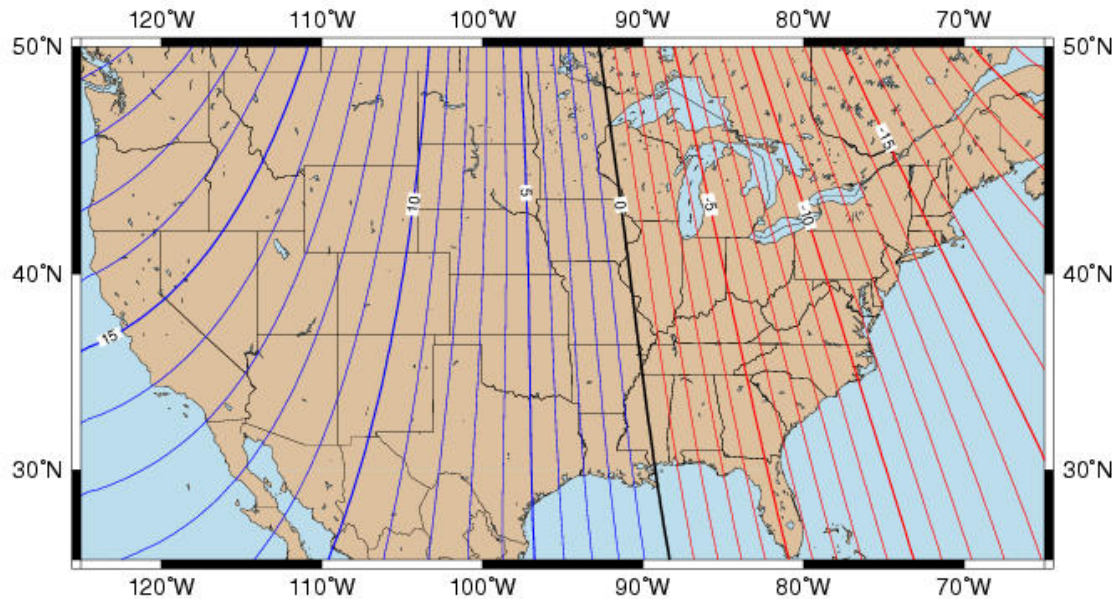
Longitude

An angular measurement made from the center of the earth to the east or west of the Greenwich meridian (London, England). It comprises the east/west component of the latitude/longitude coordinate system, which is used in GPS data collection. Traditionally, east is considered positive, and west is considered negative. Example: 74° west of the Greenwich meridian may be expressed as either unsigned (-74°) or signed (74° W)

Magnetic Declination

The local angular difference between magnetic and true north. Declination is expressed as a positive or negative angle, and varies by location and over time. In New York State, declination values range from approximately -10 degrees in western Chautauqua County to -15 degrees in northeastern Clinton County.

Magnetic Declination for the U.S. 2004



Mercator Projection

Contours of Declination of the Earth's magnetic field. Contours are expressed in degrees. Contour Interval: 1 Degree (Positive declinations in blue, negative in red)

Produced by NOAA's National Geophysical Data Center (NGDC), Boulder, Colorado

<http://www.ngdc.noaa.gov>

Based on the International Geomagnetic Reference Field (IGRF), Epoch 2000 updated to December 31, 2004

The IGRF is developed by the International Association of Geomagnetism and Aeronomy (IAGA). Division V

Image Source: National Oceanic and Atmospheric Administration (NOAA)

Magnetic North

The direction of the north-seeking end of a magnetic compass needle, not subject to transient or local disturbance
(Definitions of Surveying Terms Prepared by a joint committee of the American Congress on Surveying and Mapping and the American Society of Civil Engineers 1978)

Map Projection

A defined method of transforming positions defined on an ellipsoid to a map grid; for example, the Transverse Mercator and Parallel Lambert projections.

Mean Sea Level (MSL)

The average height of the surface of the sea at a tide station for all stages of the tide over a 19-year period, usually determined from hourly height readings measured from a fixed predetermined reference level.

Metadata

Simply defined, metadata is "data about data", or which information which describes the characteristics of a GIS data set. In describing a GIS data set, metadata usually provides information about its content and origins; it may also be used to track the updates, corrections or changes to a data set. In addition, metadata should also contain distribution information, which explains how a potential user can acquire the data set.

Minimum Elevation
See *Elevation Mask*

Multipath

Interference, similar to *ghosts* on a television screen, which occurs when GPS signals arrive at an antenna after traversing different paths. The signal traversing the longer path will yield a larger pseudorange estimate and increase positional error. Multipath occurs when GPS signals reflect off a surface before reaching the GPS antenna.

NAVDATA

The Navigation Message broadcast by each GPS satellite on both the L1 and L2 transmitters. This message contains system time, clock correction parameters, ionospheric delay model parameters, and the satellite vehicle's ephemeris and health. A GPS receiver uses this information to process GPS signals and thus obtain user position and velocity.

NAVigation Satellite Timing And Ranging (NAVSTAR) System

The formal name given to the United States Department of Defense's navigation and timing system comprised of GPS satellites, monitoring stations, and Master Control Station.

P-Code

The precise code transmitted by the GPS satellites. Each satellite has a unique code that is modulated onto both the L1 and L2 carrier waves. The P-code is replaced by a Y-code when Anti-Spoofing is active.

PDOP Mask

The highest level of PDOP that will allow the GPS receiver to compute a fix. For example, if the PDOP Mask is set to (6), the GPS receiver will not record a location when the PDOP exceeds (6).

Position Dilution of Precision (PDOP)

A unitless figure of merit expressing the relationship between the error in user position and the error in satellite position. Values considered *good* for positioning are small, such as 3. Values greater than 7 are considered *poor*. PDOP is related to horizontal and vertical DOP by the following formula: $PDOP^2 = HDOP^2 + VDOP^2$. See *also* DOP.

Postprocessing (Differential Correction)

The processing of satellite data after it has been collected in order to eliminate error. This involves using PC software to compare data from the rover to data collected at the base station. Because the base station is on a known location, systematic errors can be determined and removed from the rover data.

Precision

A measure of the repeatability or uniformity of a measurement. Precision relates to the quality of the operation by which the result is obtained, and is distinguished from accuracy which relates to the quality of the result. In order to comply with a specific standard, accuracy results must meet the minimum while complying with the precision required. Obtaining suitable accuracy results without complying with the precision is not acceptable to meet the standards.

Pseudorandom Noise or Number (PRN)

A signal that carries a code that appears to be randomly distributed like noise, but can be exactly reproduced. PRN codes have a low auto-correlation value for all delays or lags, except when they are exactly coincident. Each NAVSTAR satellite has its own unique PRN code.

Radio Technical Commission for Maritime Services (RTCM)

A commission established to define a differential data link for real-time differential correction of roving GPS receivers. There are two types of RTCM differential correction messages. Most modern GPS receivers use the newer Type 2.2 RTCM protocol.

Real Time (Differential Correction)

The processing of satellite data as it is being collected in order to eliminate error. This involves using software to compare data from the rover to data collected at the base station. Because the base station is a known location, systematic errors can be determined and removed from the rover data as it is being logged. This correction is not instantaneous and adequate time on station should be planned for accurate readings. Users should consult the

manufacturers' guidelines for their specific hardware for recommended time on station. Two free systems offering real time differential correction capabilities include the United States Coast Guard (USCG) beacon system and the WAAS system. The USCG beacon system has a greater accuracy than WAAS and is more reliable. *See Time on Station.*

Reference Station

See Base station.

Root Mean Square (RMS)

An expression of the accuracy of a point measurement. It is the radius of the error circle, within which approximately 68% of position fixes are to be found. RMS is typically expressed in distance units of feet or meters.

Rover/Roving (GPS) Receiver

Any mobile GPS receiver and data collector used for determining location in the field. A roving GPS receiver's position can be differentially corrected relative to a stationary base GPS receiver.

RTK (Real-Time Kinematic)

A real-time differential GPS method that uses carrier phase measurements for greater accuracy. RTK measurements typically yield relative horizontal accuracy of approximately one centimeter.

SBAS (Satellite Based Augmentation System)

The generic term that refers to differential GPS applied to a wide area, such as an entire continent. WAAS and EGNOS are examples of SBAS networks, and are comprised of a series of reference stations that generate GPS corrections which are broadcast to GPS rovers via geostationary satellites.

Selective Availability (SA)

The artificial and deliberate degradation of GPS satellite signals by the United States Department of Defense. Selective Availability was implemented in order to enhance national security, but was turned off on May 10, 2000 due to the presence of several sources of various differential correction (DGPS) messages, which rendered SA obsolete. The SA bias on each satellite signal is different, and so the resulting position solution is a function of the combined SA bias from each satellite used in the navigation solution. Because SA is a changing bias with low frequency terms in excess of a few hours, position solutions or individual satellite vehicle pseudo-ranges cannot be effectively averaged over periods shorter than a few hours. Differential corrections must be updated at a rate less than the correlation time of SA (and other bias errors).²⁹

Signal-to-Noise Ratio (SNR)

The signal strength of a satellite is a measure of the information content of the signal, relative to the signal's noise. The typical SNR of a satellite at 30° elevation is between 47 and 50 dBHz. The quality of a GPS position is degraded if the SNR of one or more satellites in the constellation falls below 39. This value is used to determine whether the signal strength of a satellite is sufficient for that satellite to be used by the GPS receiver. If a satellite's SNR is below the configured minimum SNR, that satellite is not used to compute positions.

SV

Satellite Vehicle or Space Vehicle, referring to the actual GPS satellite.

Time Dilution of Precision (TDOP)

See DOP.

Time on Station

The amount of time needed to be at a location in order to accurately collect an X,Y value per the project requirements.

²⁹ "Global Positioning System Overview," 20 Dec. 2006 <<http://www.colorado.edu/geography/gcraft/notes/gps/gps.html#SA>>

True North

A term used to define 1) an astronomic meridian; 2) a geodetic meridian; 3) the direction of north from magnetic north corrected for declination; 4) the meridional direction assumed in a survey description; 5) the cardinal directions run in the Public Land Survey. Since the term is subject to several interpretations it should not be used (*Definitions of Surveying Terms Prepared by a joint committee of the American Congress on Surveying and Mapping and the American Society of Civil Engineers 1978*)

Vertical Dilution of Precision (VDOP)

See DOP.

VRS (Virtual Reference Station)

A VRS system consists of GPS hardware, software, and communication links. It uses data from a network of base stations to provide corrections to each rover that are more accurate than corrections from a single base station. To start using VRS corrections, the rover sends its position to the VRS server. The VRS server uses the base station data to model systematic errors (such as ionospheric noise) at the rover position. It then sends RTCM correction messages back to the rover.

WAAS (Wide Area Augmentation System)

WAAS was established by the Federal Aviation Administration (FAA) for flight and approach navigation for civil aviation. WAAS improves the accuracy and availability of the basic GPS signals over its coverage area, which includes the continental United States and outlying parts of Canada and Mexico. The WAAS system provides correction data for visible satellites. Corrections are computed from ground station observations and then uploaded to two geostationary satellites. This data is then broadcast on the L1 frequency, and is tracked using a channel on the GPS receiver, exactly like a GPS satellite.

Waypoint

A geographical point that, unlike a feature, holds no attribute information beyond a name and location. Typically, waypoints are used to denote objects or locations of primary interest, such as a survey mark. Waypoints are most often used for navigation.

WGS-84

World Geodetic System (1984), the mathematical ellipsoid used by GPS since 1984. See also Ellipsoid.

Appendix B - Useful GPS and Related Websites

GPS TRAINING AND INFORMATION RESOURCES

1.) General GPS Information

- Trimble GPS Support and Updates (Terra Sync, Pathfinder Office, GPS hardware, etc.) - www.trimble.com/support
- ESRI Support for ArcPad/ GPS Analyst Extension - www.support.esri.com
- ArcPad Blog – <http://arcpadteam.blogspot.com>
- Long Island GIS – www.ligis.org
- National Geodetic Survey (NGS) – Continuously Operating Reference Stations (CORS) – <http://www.ngs.noaa.gov/CORS/>
- Historical Maps - www.historicmapworks.com
- Library of Congress Maps - <http://memory.loc.gov/ammem/gmdhtml/>
- Glossary of Terms - http://www.novatel.com/about_gps/glossary.htm
- GPS Information - <http://gpsinformation.net/>
- United State Coast Guard Navigation Center - <http://www.navcen.uscg.gov>
- US Naval Observatory (USNO) GPS Operations - <http://tycho.usno.navy.mil/gps.html>
- Positioning, Navigation, and Timing - <http://www.pnt.gov>

2.) GPS Publications

- GPSWorld Online Magazine – <http://www.gpsworld.com/>
- Point of Beginning - <http://www.pobonline.com/>
- GPS User Magazine - <http://www.gpsuser.com/>
- GPS Reviews - <http://www.gpsreview.net/>
- GPS Technology Reviews - <http://gpstekreviews.com/>
- GPS Gadgets - <http://gps.engadget.com/>
- Inside GNSS - <http://www.insidegnss.com/>
- The Problems with NAD27 - <http://www.dot.pima.gov/gis/data/about/nad27problem.htm>
- GIS/GPS Best Practices - <http://www.esri.com/library/bestpractices/using-gis-with-gps.pdf>

3.) Tutorials

- Trimble's Interactive On-line Tutorial - <http://www.trimble.com/gps/index.shtml>
- ESRI ArcPad Free Training - <http://training.esri.com/gateway/index.cfm?fa=search.results&searchterm=ArcPad&softwaretype=All+Software&trainingformat=1%2C2>
- ESRI GPS Analyst Free Training - <http://training.esri.com/gateway/index.cfm?fa=search.results&searchterm=GPS+Analyst&softwaretype=All+Software&trainingformat=1%2C2&search=search>

4.) Government GPS Sites

- F.A.A. – GPS Satellite Product Team – <http://gps.faa.gov/>
- National Spatial Reference System (NSRS) – Access info. To locate indiv. benchmarks - <http://www.ngs.noaa.gov/cgi-bin/datasheet.prl>
- NGS/NOAA GPS Site – <http://www.ngs.noaa.gov/orbits/>
- US Coast Guard - <http://www.navcen.uscg.gov/gps/default.htm>

- USGS Geographic Names Information System - <http://geonames.usgs.gov/>

5.) GPS Receiver Manufacturers

- Comprehensive List of all manufacturers - <http://gauss.gge.unb.ca/manufact.htm>
- Trimble – www.trimble.com
- Magellan – www.magellangps.com
- Garmin – www.garmin.com
- Leica – www.leica-geosystems.com
- Northstar – www.northstarnav.com
- Lowrance – www.lowrance.com
- Topcon – www.topcon.com
- Corvalis Microtechnology - www.cmtinc.com
- Tripod Data Systems - www.tdsway.com

6.) Standards

- Datum and Coordinate Standards - http://www.nysgis.state.ny.us/coordinationprogram/workgroups/wg_1/related/standards/datum.htm
- Metadata Standard: FGDC Content Standards and Digital Geospatial Metadata – <http://www.fgdc.gov/standards/projects/FGDC-standards-projects/metadata/base-metadata>
- Four Character County Code Standard - http://www.nysgis.state.ny.us/coordinationprogram/workgroups/wg_1/related/spcodes/4cntycode.html
- Federal Standards – www.fgdc.gov/standards

7.) Coordinate Translation

<http://jeeep.com/details/coord/>
http://www.teraserver.com/tools/degrees_converter.asp
<http://www.fcc.gov/mb/audio/bickel/DDDMSS-decimal.html>
<http://life.csu.edu.au/geo/dms.html>



NYSNET Map

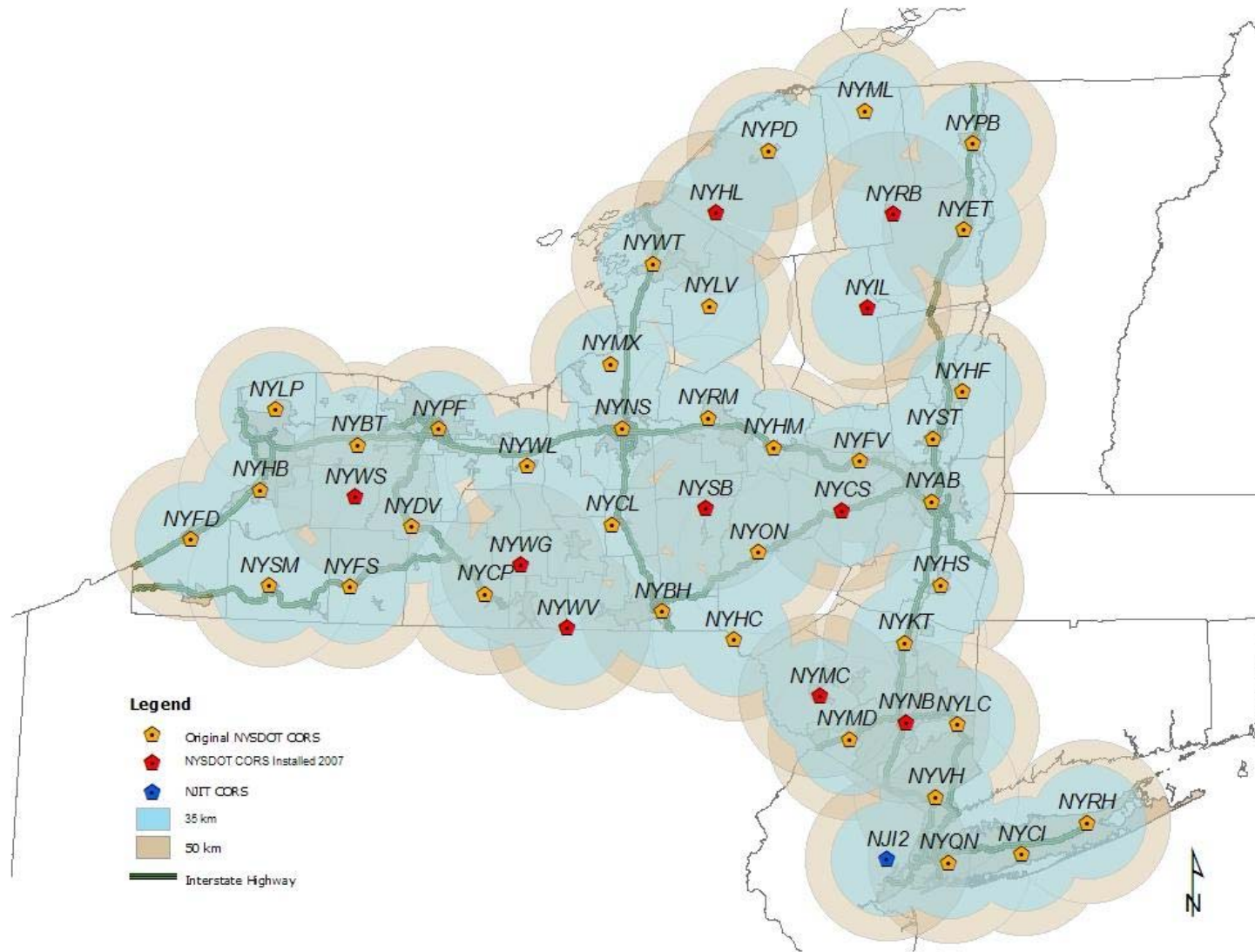


Image Source: New York State Department of Transportation (NYSDOT)



APPENDIX F - WIDE AREA AUGMENTATION SYSTEM (WAAS) OVERVIEW

This entire appendix is based on the Wisconsin Department of Natural Resources. WIDE AREA AUGMENTATION SYSTEM (WAAS), document with some minor reformatting.

I. WHAT IS WAAS?

The Federal Aviation Administration developed the Wide Area Augmentation System (WAAS) to improve its basic aviation global positioning system (GPS) service to meet accuracy, availability and integrity requirements critical to flight navigation and safety. WAAS consists of two geostationary communication satellites and a network of 25 wide-area ground reference stations (WRSs). Each WRS has a surveyed location, and receives signals from GPS satellites to determine if any data errors exist. The WRS then sends a GPS correction message to a master station that computes correction algorithms and transmits them to the two WAAS satellites. The WAAS satellites broadcast the correction data on the same frequency that GPS satellites use to transmit their data. WAAS-capable units receive both GPS data and WAAS corrections, and differentially correct the data in real-time. For more information about WAAS, see <http://GPS.faa.gov/Programs/WAAS/waas.htm>.

II. HOW DOES WAAS AFFECT GPS

WAAS was developed to support *real-time navigation* - not mapping activities. Most WAAS-capable GPS receivers are *recreational grade*. Users should consider the following issues when deciding if and how to use a WAAS-capable GPS receiver.

1.) WAAS AVAILABILITY:

WAAS supports aviation uses in which obstacles and terrain do not block WAAS satellites on the horizon (satellite #35 over the Atlantic Ocean and satellite #47 over the Pacific). In Vermont, WAAS-capable GPS receivers may be highly sensitive to terrain and obstacles blocking the horizon. These receivers also take about 10-30 minutes to acquire WAAS signals the first time, then about 1-2 minutes for subsequent uses.

2.) REAL-TIME DIFFERENTIAL CORRECTION METHOD:

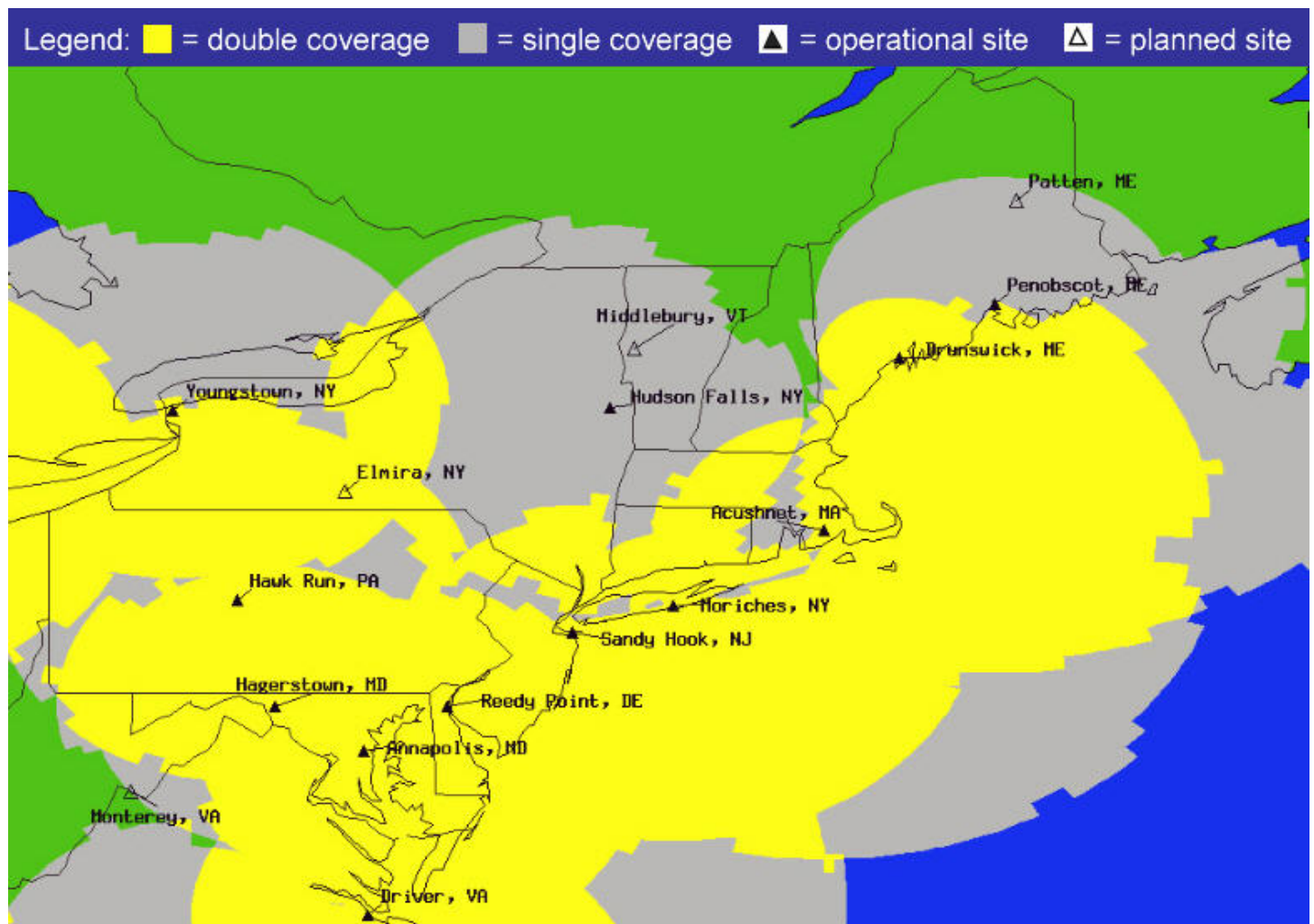
For real-time differential correction, WAAS-capable recreational GPS receivers are less expensive and bulky than recreational units with “beacon-on-the-belt”³⁵ (BoB) receivers. Depending on the site, however, a GPS with BoB may be less susceptible to obstacles and terrain interference, because ground-based beacons are physically closer and are located in several different directions around the data collection site.

3.) RECREATIONAL VS. MAPPING GRADE RECEIVER:

WAAS has the potential to improve the horizontal and vertical accuracy of recreational grade GPS data to *approximately 7 meters*. Differentially corrected mapping grade GPS data are still more accurate. Mapping grade receivers also have better data logging capabilities, such as allowing users to: (1) load customized data dictionaries, (2) capture lines and areas in addition to point data, (3) collect points along line and area features, and (4) export data directly in a GIS compatible format.

³⁵ Trimble registered trademark

Appendix G - United States Coast Guard Differential GPS Coverage of New York State³⁰



³⁰ USCG Navigation Center DGPC Coverage Page – New York,” 20 Dec. 2006
<http://www.navcen.uscg.gov/dgps/coverage/NYork.htm>

APPENDIX H - RECOMMENDED DATA COLLECTION PRACTICES

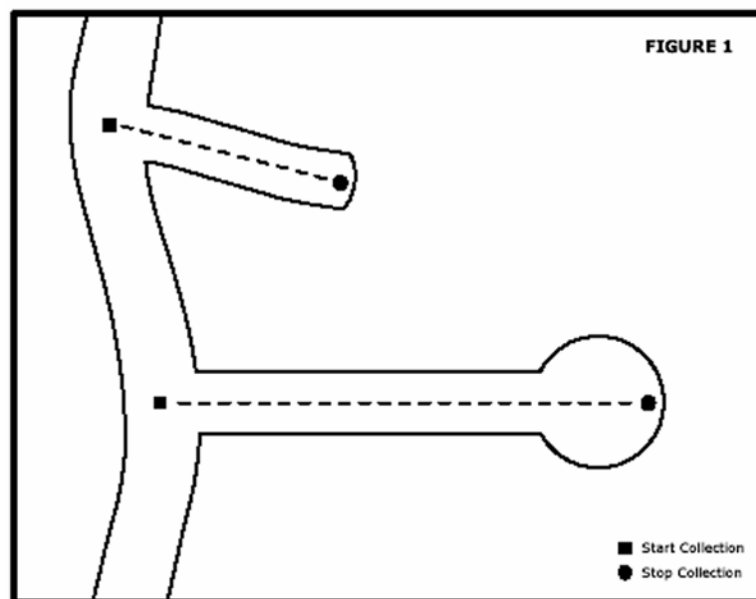
This entire appendix is based on a section of the Georgia Department of Transportation; GPS Data Collection Guideline and Standards: A Manual for Georgia Service Delivery Regions and Regional Development Centers, document with some minor reformatting.

“GPS Collection methods used to capture roads, sidewalks, and trails can vary depending on a variety of factors. Collection of road centerlines, under the data standard outlined in this manual, requires the use of a motorized vehicle (car/truck) capable of highway travel. Collection methods for sidewalks and trails can vary. Depending on environmental factors, congestion and accessibility, sidewalks and trails can be collected using foot, bicycle or motorized vehicle travel. Despite these differences, common best practices do exist for the collection of road, sidewalk and trail centerline collection. The following are data collection tips.

General Collection Tips

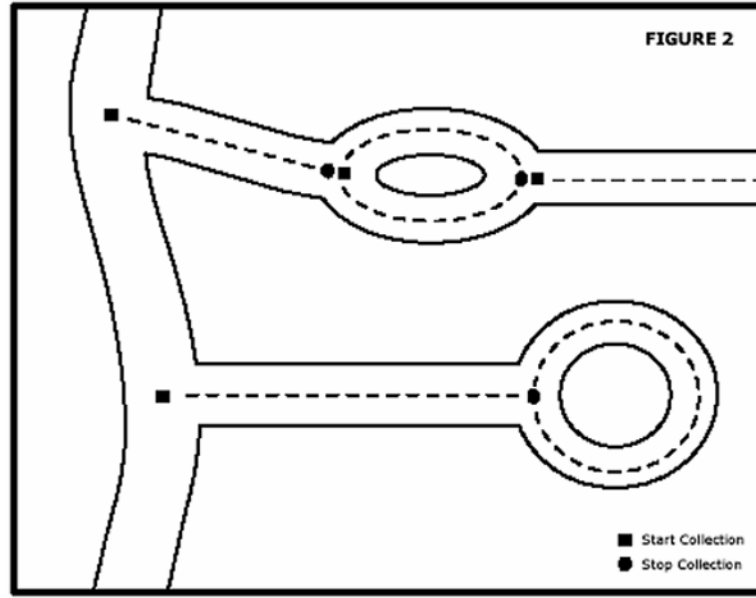
I. Centerline Collection from Beginning to End

When an intersection does not exist at the end of a road or trail, collect to the far end of the centerline (i.e., a road cul-de-sac or dead end to a trail). See Figure 1 for examples.



Road or Trail Collection from an Intersection to a Dead-End

When a cul-de-sac has an island or curbed circle in the center of the cul-de-sac, collect the centerline completely around the island. See Figure 2 for examples.



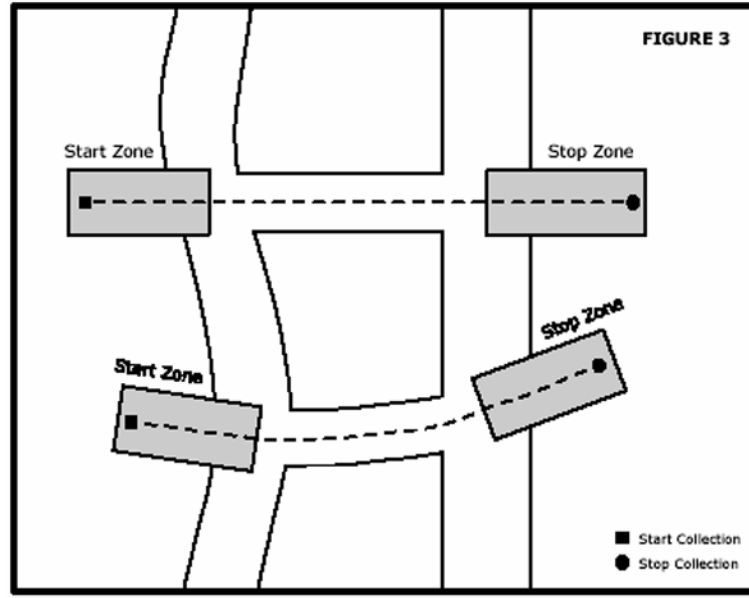
Collection Technique for Cul-De-Sacs and Islands

II. Under-Runs vs. Over-Runs

An under-run is created data collection stops prior to reaching an endpoint (i.e., road or trail intersection). Ideally, data collection should clearly start and stop at centerline intersections in order to prevent future confusion for staff attempting to integrate the data into the existing USGS DLG-F data set.

An over-run is created when data collection continues past the intended stop (i.e., road or trail intersection). Over-runs create less confusion during the data integration phase and are more easily edited out of the data set.

If it is not possible to collect data clearly from endpoint (intersection) to endpoint (intersection), then the intentional errors created by over-runs are preferred to the unintentional ones created by under-runs. GDOT will accept over-run errors within a range of 50 to 100 feet. See Figure 3 for a diagram showing the correct procedure for collection over-runs.

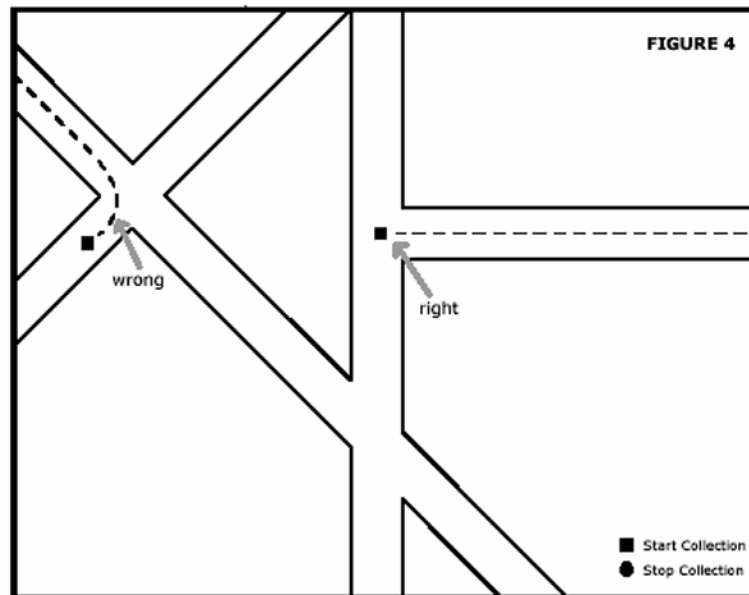


Over-Run Start and Stop Collection Zones

III. Turning vs. Head-On Approach

Collect centerline features using a head-on approach. As you approach a road, trail or sidewalk for collection, do not start collection until you are aligned in a straightforward fashion with the feature.

Do not start collecting data while you are approaching a feature. This will not accurately represent the feature being collected and will present problems for staff trying to integrate the data in to the USGS DLG-F data set. Figure 4 shows the correct way to approach a feature for collection.



Turning Versus Head-On Approach

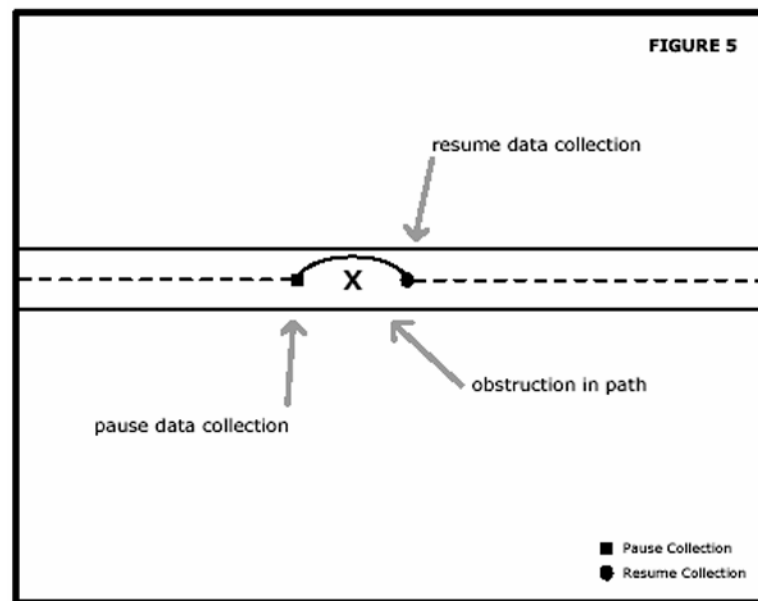
IV. Obstructions in the Collection Path

If a road, sidewalk or trail cannot be safely traveled, it is not considered accessible to the public and therefore is not eligible for collection under this data standard. However, some centerlines may have objects like tree limbs, built-up water, dead animals, or fallen rocks blocking the collection pathway.

A significant obstruction may require enough of a deviant movement to avoid the obstacle so as to cause an inaccurate data capture of the road. Hitting the pause button, avoiding the obstacle, and then resuming collection can avoid this.

The Pause feature is best used on straight a ways. Pausing GPS collection simply suspends data capture until an obstruction is passed. If several turns are made during the pause in data collection, the GPS unit will simply connect the dots from the point of last collection to the point at which the GPS unit is resumed. Figure 5 shows examples of how to correctly apply the Pause function.

If contingent situations arise and data collection must be temporarily suspended, the Pause function allows data collectors to take a break that can be resumed at a later time. Be careful to remember the general location where the pause function was executed. Forgetting the location of a pause may cause undesirable collection results if you incorrectly start collection in a different location.



Use the Pause Feature to Pass an Obstruction

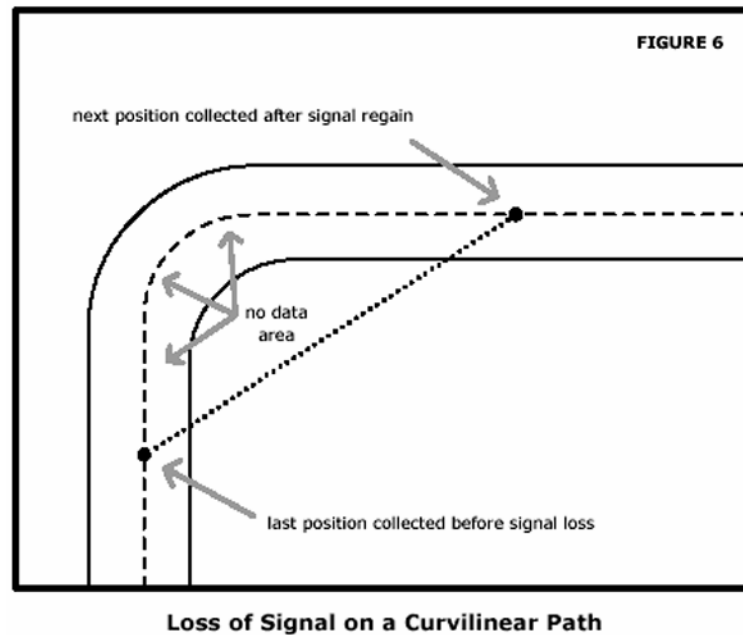
V. Loss of Signal

Use the distinctive audible capabilities of the GPS data logger to ascertain when signal is lost and regained. In areas of high multi-pathing (dense tree canopy, mountainous areas, urban areas, etc...) signal may be lost frequently.

During signal loss, attempt to slow the collection pace significantly- or even come to a complete stop- if conditions dictate that it is safe to do so in order to wait for signal to return.

Signal loss on long straight a ways is less of a problem than signal loss on curvilinear centerline paths. Therefore, it is advisable to slow the collection pace around curves if signal strength is weak. If loss of signal occurs more than several

hundred feet, the shape of the feature being collected may become distorted and will require recapture at a later date/time. See Figure 6 for an example of shape distortion due to signal loss on a curve.

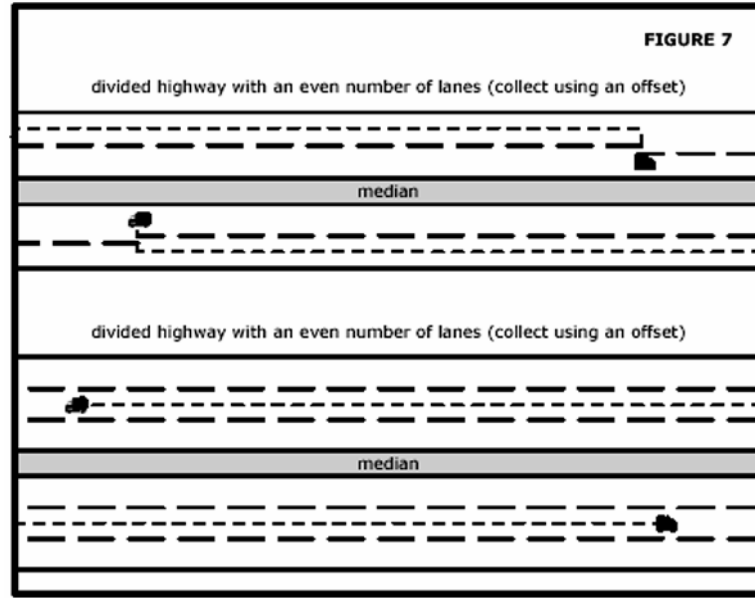


In the office, signal loss is easily detected. If the centerline appears coarse, jaunty or looks incorrect against the background image or data layer, examine the vertices. Since the positions are being collected between one and five seconds, long gaps between the vertices will be a strong indicator of loss of signal. In such a case, re-collection of the centerline may be necessary.

VI. Divided Highways (Road Centerline Collection)

A divided highway contains a median in the center that separates different directions of travel. Collect the centerlines of both sides of a divided highway. Each side of a divided highway is treated as a one-way road.

If a divided highway is represented by a single centerline in the existing USGS DLG-F data set, SDR data collectors are required to GPS capture both lanes of the divided highway as dictated by Section A above.



Collection of Divided Highways

VII. Offsets

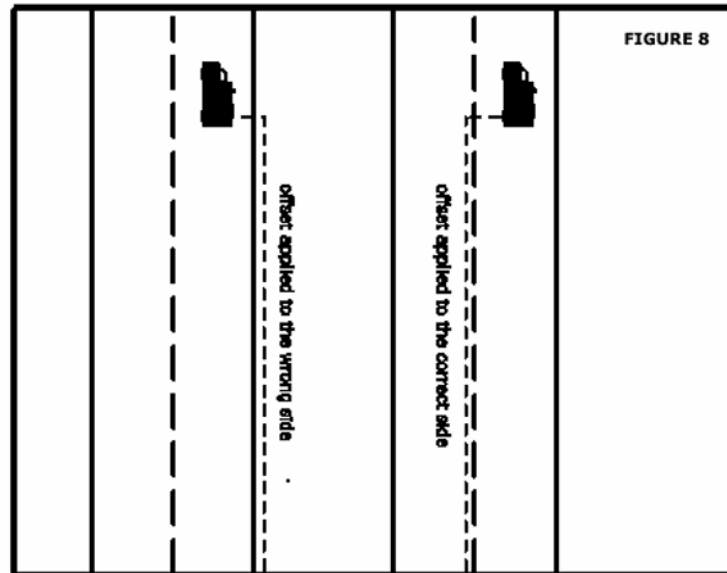
An offset is a known distance set away from the antennae location of the GPS unit that is used to collect data in areas of difficult accessibility. Offsets are either used at the time of data collection (instant offset) or prior to data collection (constant offset). Most often, instant offsets will be applied to the collection of long sidewalk centerlines when using vehicular travel. Also, instant offsets will be used while collecting road centerlines. Do not use offsets to capture trails, as they are usually more accessible.

During road data collection, use offsets to capture the true centerline for roads with an even number of lanes. Do not use an offset on roads with an odd number of lanes, as you will be able to drive the true centerline. Figure 7 describes the correct way to collect centerlines on multi-lane roads.

If it is necessary to apply an offset during the collection of long sidewalks using vehicular travel, drive in the lane nearest the sidewalk and apply an offset distance and direction that most accurately captures the true centerline of the sidewalk.

Exercise caution when applying offsets during data collection. Be certain to apply the correct side, measurement and units for the offset prior to data collection (see Figure 8). If unnoticed during data collection, offset errors can render an entire data collection effort useless. And, offset errors are hard to ascertain during the post-processing phase. If you suspect an offset error at the post-processing phase, use DOQQ or other aerial imagery to perform quality control.

If offset errors are detected during the post-processing phase, it may be possible to use Pathfinder Office to correct any mistakes made due to miscalculation of distance or direction. However, if too many offset errors are present and a clear method cannot be established to correct the mistakes, re-collect the centerlines.

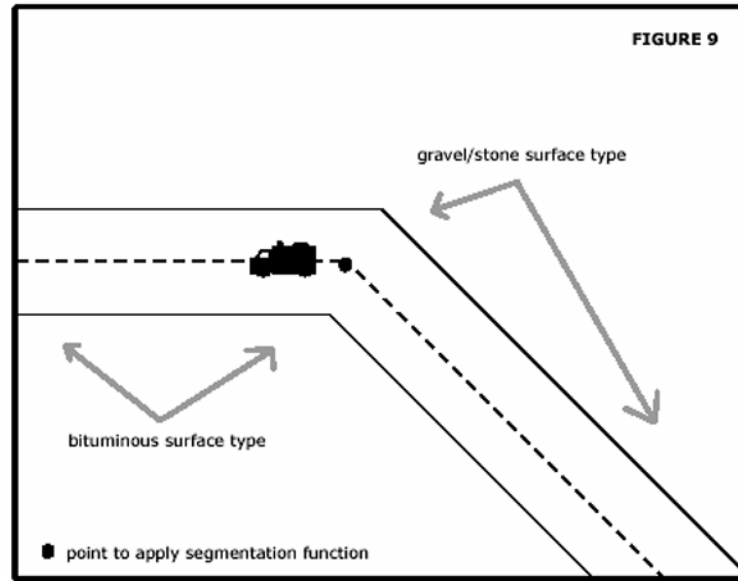


Common Offset Errors

VIII. Segmenting

The segmentation option is used to change one or many attributes that differentiate along any given road, sidewalk or trail centerline. For example, if the centerline lane width changes along a specific path during data collection, use the segmentation function to signify a new record to the attribute table. For example, if a paved (bituminous surface) road is being collected and the surface type suddenly changes to that of gravel or stone, apply the segmentation button at the exact location where the two surface types meet. This allows changes along a singular feature to be accurately reflected while allowing for the continuous collection of the feature.

Linear features like road, sidewalk and trail centerlines are dynamic and change often. Data collectors should use the segmentation feature of the GPS unit to reflect these changes. During the post-processing phase, be cautious of data that shows little differentiation along given linear features.



IX. Repeating

The repeat function allows data collectors to copy feature attributes from the most recently collected data feature to the one currently being collected. This function may improve efficiency in data collection if many roads, sidewalks and/or trails are to be collected that share like features attributes.

APPENDIX I - SAMPLE PROJECT SPECIFICATIONS

This entire appendix is based on the British Columbia Standards, Specifications and Guidelines for *Resource Surveys Using GPS Technology*, Appendix A, with some minor reformatting.

I. APPLICATION

The *Content Specifications* facilitate standardization and quality control for geo-spatial data acquired via GPS technology for Agencies contracting out GPS data collection. This document is provided for use by Contracting Agencies without a pre-established specifications geared to GPS data collection using differential GPS techniques with resource/mapping grade receivers and having target accuracy requirements from 1m to 20m horizontal accuracy classes (at 95% confidence) and the 5m to 20m vertical accuracy classes (at 95% confidence). The actual target accuracies required for the project or application are to be entered below.

The *Content Specifications* are supported by two documents: the *Accuracy Standards* and the *Guidelines*:

A. Accuracy Standards

Document outlining target accuracy categories in a standardized and uniform manner. Using the *Content Specifications* document, one may specify the target accuracies to be achieved based on the standardized categories established within the *Accuracy Standards* document.

B. Guidelines

The *Guidelines* support document provides relevant background information in order to complete those areas of the *Content Specifications* that vary project by project. This *Specification* document, when completed using the *Guidelines*, will form the technical section of a GPS survey contract.

II. INTERPRETATION

These *Content Specifications* may be interpreted with the help of the accompanying *Guidelines* document. In order to interpret the *Content Specifications* correctly, the reader must have prior familiarity with GPS operations. The *Guidelines* are intended to assist users in this regard.

In this document, the following definitions and abbreviations shall be used:

Agency	Agency, Department, Section or other entity administering the Contract.
Contractor	Corporation, firm, or individual that provides works or services to the Agency under terms and conditions of a contract.
Contract Administrator	Agency representative who has authority for issuing and managing the contract and for receiving the items or services delivered by the Contractor.
Data Processor	A trained employee of the Contractor who performs the calculations to convert raw field GPS data into processed maps / databases using DGPS procedures and QC checking / editing.
DGPS	Differential GPS (i.e. pseudorange code positioning differentially corrected either post-mission or real-time).
Dynamic-mode	Collection of GPS data while traveling along a linear feature to be surveyed (e.g. a road or watercourse).
Field Operator	An employee of the Contractor who performs the field portion of the data collection.
Geoid	The equipotential surface approximating Mean Sea Level. Consult GDBC for provincial standard geoid model.
GPS	Global Positioning System as operated by the United States Department of Defense (US DoD). Also called NAVSTAR.
GPS Event	A GPS Event is a single position instead of a group of positions averaged to a single position (i.e. Static survey). Events are typically used when the antenna cannot, or need not, be stationary over a point.
GPS Reference	A GPS receiver located at a known location collecting data continuously to be

Station	used for correcting field data (either in real-time or post-mission). Also known as a basestation.
NAD27	North American Datum of 1927, based on the Clarke 1866 ellipsoid.
NAD83	North American Datum of 1983, based on the Geodetic Reference System 1980 (GRS80) ellipsoid and as defined by the GRS in British Columbia.
NADV88	North American Vertical Datum of 1988
Static-mode	Collection of GPS data at a discrete point while remaining stationary.
Supplemental Traverse	Supplemental Traverses are conventional traverses (e.g. compass and tape) that are integrated with GPS surveys.
UTM	Universal Transverse Mercator projection (map projection system).

The statements in this document have been structured according to two levels of compliance:

<i>required</i>	Used to describe tasks that are deemed necessary and are good practice. Exceptions are possible, but only after <i>careful</i> consideration by the contracting Agency.
<i>recommended</i>	Used to describe tasks that are deemed desirable and good practice, but are left to the discretion of the contracting Agency.

III. GOALS

1. To establish realistic, reasonable levels of accuracy by task assignment, and to classify the surveys to be performed by end specifications aimed at achieving target accuracies.
2. To provide a capacity for integrating requirements across Vermont and to standardize those requirements where common standards are applicable.
3. To qualify GPS Systems (i.e. equipment, processing methods, and personnel) by a Contractor GPS System Validation survey to establish the accuracies achievable under various conditions.

IV. PRE-QUALIFICATION AND VALIDATION

1. Total System - It is *required* that any Contractor expecting to undertake GPS data collection be prepared to fulfill the requirements of the full "System", including: GPS hardware and software for field and office; field and GPS Reference Station receivers; and reporting techniques. All parts of the System are to be capable of meeting the contractual specifications below.
2. Field Operator Training - It is *required* that Field Operator(s) have a demonstrated proficiency in GPS data collection methods or, if the operator is in training, be accompanied by an individual meeting this requirement.
3. Data Processor/Project Manager Training - It is *required* that Data Processor/Project Manager(s) have demonstrated proficiency in the planning, management and execution of GPS projects - this includes the processing and management of GPS data.
4. It is *required* that any GPS System used be proven to meet the accuracy requirements through a GPS Contractor System Validation survey as outlined in *Section C Content Specification-IV*. For accuracy levels established during the validation and the conditions under which they were established, *it is recommended* they apply for all subsequent projects.

V. PRE-FILEDWORK PROCEDURES

1. It is *recommended* the Contract Administrator conduct a pre-fieldwork conference for all potential and qualified contractors. It is *recommended* the Contract Administrator provide a clear definition of the feature(s) to be surveyed, which point features are to be considered “High-Significance” and which are to be considered “Standard-Significance”, boundaries of the features, guidelines for interpretation of special features - if necessary, it is *recommended* a specimen layout for interpretative purposes. It is *recommended* the Contract Administrator also provide a clear definition of the deliverables, services, work quality, payment schedule, and other relevant contract issues. There should be no doubt or confusion as to the nature and quantity of work expected.
2. It is *recommended* the Contract Administrator advise the Contractor of the Audit process (i.e. the method and frequency of data/field inspections and surveys that will be used in determining achievement of end specifications in compliance with the conditions of the contract).
3. It is *recommended* the Contract Administrator conduct a field inspection with the Contractor, advising them of specific details to include or exclude in the contract work so that there is no doubt as to the nature and quantity of work expected in the contract.
4. If physical reference markers are required to be established, it is *required* that the interval and type of markers be stated in the contract, and be established according to existing Agency guidelines or requirements (e.g. the Forest Practices Code guidebooks for forest road engineering and boundary marking).
5. It is *recommended* all projects include sufficient map ties such as creek junctions, road intersections or other features to enable accurate geo-positioning and to provide reliability checks. It is *recommended* the Agency representative specifies the number of tie points required, and if possible, specify where and what these tie points should be.
6. *An official land survey may only be legally defined by a licensed land surveyor. None qualified individuals attempting to present a survey as official can result in legal action being taken against the Contractor or the Agency if damages occur on adjacent lands.*
7. The required survey accuracies (i.e. target accuracies at 95%) for the project are:

Network Horizontal Accuracy =	_____	(Class = <u>meter</u>)
	m	
Interpretative Horizontal Accuracy =	_____	(Class = <u>meter</u>)
	m	
Network Orthometric Height	_____	(Class = _____)
Accuracy =	m	
Interpretative Vertical Accuracy =	_____	(Class = _____)
	m	

For clarification, the definition of meeting the above accuracy class is that for GPS point features, at least 95% of the individual position fixes are within the above-specified accuracies (horizontal linear measure) of the true position of the point according to the National Spatial Standards for Data Accuracy. See *Section B: Accuracy Standards.III.B “Determining the NSSDA”*.

Similarly, for GPS traverses done in dynamic linear mode, at least 95% of the individual GPS position fixes are within the specified accuracies (horizontal measurements perpendicular to this line) from the true position of this line.

VI. FIELDWORK

1. The field GPS receiver is to be set to position or record observations with a *minimum* of four (4) satellites without constraining/fixing the height solution (sometimes known as “3D” positioning mode).

2. The *minimum* satellite elevation angle/mask for the field GPS receiver is 15 degrees above the horizon.
3. It is *required* that the DOP not exceed the following values:

DOP Figure	Maximum DOP Value
Geometrical DOP (GDOP)	---
Positional DOP (PDOP)	6.0
Horizontal DOP (HDOP)	---
Vertical DOP (VDOP)	---

Not all DOP values are required to be completed.

VDOP limits need be followed only in surveys where accurate elevations are required

4. During Static (point-mode) surveys, occupations will adhere to the minimum values below, or the values used during the Validation survey, which ever is higher.

Point Significance	Minimum Occupation Time (sec)	Minimum Number of Fixes
Standard-Significance Point	30 seconds	30 fixes
High-Significance Point	250 seconds	50 fixes

5. It is *required* that position fixes for linear features mapped statically (i.e. static or point-to-point traverses) be no more than _____ meters apart, with the traverse points defined as Standard Significance Points.
6. It is *required* that position fixes for linear features mapped dynamically (i.e. dynamic traverse) be no more than _____ meters apart.
7. It is *required* that dynamic traverses begin and end on a physically marked static High-Significance point (commonly referred to as the Point of Commencement (PoC), and the Point of Termination (PoT)).
8. All significant deflections required to delineate linear features at the required accuracy are to be mapped. This includes significant vertical breaks if elevations are required.
9. Times of GPS Events (i.e., interpolated points) on dynamic traverses *should* be accurate to at least _____ seconds.
10. It is *required* that for point offsets, the following specifications be observed:
 - ❖ The Field Operator is to record the following information: slope distance; vertical angle; and magnetic or true azimuth *from* the GPS antenna *to* the feature.
 - ❖ Magnetic Declination is to be applied to all compass observations before computing offset coordinates.
 - ❖ The *maximum* distances for point offsets are _____ meters, and _____ meters if offset observations are measured forward and backwards.
 - ❖ Bearings are to be accurate to at least _____ degrees, and distances to at least _____ meters.
11. It is *required* that for linear offsets, the following specifications be observed:

- ❖ The Field Operator is to record the following information: horizontal distance and the direction (left or right) perpendicular to the direction of travel.
 - ❖ The *maximum* linear offset (i.e. horizontal distance) allowable is _____ meters.
 - ❖ Linear offset distances are to be checked and adjusted periodically.
12. It is *required* that supplemental traverses meet these following rules:
 - ❖ The supplemental traverse is to begin and end on physically marked High-Significance GPS static points (PoC and PoT).
 - ❖ The distance traversed is to be less than _____ meters.
 - ❖ The supplemental traverse is to close between the GPS PoC and PoT by ____ **meters+1:____00** of the linear distance traversed.
 - ❖ The supplemental traverse is to be balanced between the GPS PoC and PoT by an acceptable method (i.e., compass rule adjustment).
 13. Physical reference markers are to be established every _____ meters along linear features (*enter N/A if not applicable*). These markers must adhere to contracting Agency standards, or be accepted before the work commences.
 14. It is *required* that static point features be collected at all physical reference markers. These static point features are to be collected as *STANDARD / HIGH (circle one)* Significance points.
 15. It is *required* that the GPS receiver's default Signal to Noise Ratio (SNR) mask (**6**) for high accuracy be used. This *CAN/ CANNOT (circle one)* be relaxed during traversing of linear features.

VII. GPS REFERENCE STATIONS

1. If the Contractor chooses to establish or use a previously established reference station and not a CORS Base station then it must be monumented (physically marked) to allow the contracting Agency or other Contractors to re-occupy the same location. Physical reference marks are to be left and the station referenced using adjacent features (i.e. road intersections, sign posts, bearing trees, etc.) to assist in the future location, and in determining that it has remained undisturbed. Suitable markers include iron bars driven into the soil, spikes in asphalt or concrete, or other markers that the Contractor and Agency determine will remain stable during and, for a reasonable time, after project completion.
2. It is *required* that the separation distance between the GPS Reference Station and field receivers be less than _____ kilometers, or the separation distance used during Validation, whichever is less.
3. The *minimum* elevation angle/mask of the GPS Reference Station *should* be 10 degrees.
4. If real-time corrections are used, it is *required* that the Contractor validate the GPS Reference Station according to accepted industry procedures.
5. If real-time corrections are used, it is *required* that the *RTCM-Age* of the rover GPS system not exceed _____ seconds. See Table IV-1: Suggested Maximum RTCM Correction Age Settings for information on correction ages appropriate for various accuracies.

VIII. PROCESSING AND QUALITY CONTROL

1. All GPS positions are to be corrected by standard differential GPS methods (pseudorange or navigation corrections). If navigation corrections are used, the same set of GPS satellites are to be used at the GPS Reference Station as at the field receiver for all corrected positions.
2. If the GPS receiver and/or post-mission software provides the option for dynamic filtering, the filters are to be set to reflect the speed of the operator or vehicle, and the software versions and filter settings are to

be noted in the project returns. If filtering is applied to GPS Reference Station data, this is also to be noted.

3. It is *recommended* the Contractor implement a Quality Control (QC), or reliability assessment, program in order to show compliance to specified standards (i.e. positional accuracy, content accuracy, completeness, data format adherence, and data integrity assurance).
4. It is *recommended* the Contractor be prepared to entirely re-survey those areas that do not meet the compliance standard at their own cost.

IX. PROJECT DELIVERABLES

1. It is *recommended* the Contractor submit a project report that includes the following information, as a minimum.
 - ❖ A brief description of the Contract particulars, including the contracting Agency that commissioned the work, the Contract Administrator, a project name (if available), and a project identifier (e.g. provincial government's ARCS/ORCS number, etc.).
 - ❖ A brief description of the project work (i.e. purpose, target accuracy, location, etc.).
 - ❖ A key map showing the project area and a description of any GPS Base Stations used.
 - ❖ A schedule of events showing key dates/milestones (i.e. contract award; field data acquisition; problems encountered; data processing; delivery of results; etc.).
 - ❖ A listing of all personnel (Contractor and Subcontractors) involved in this project detailing their particular duties and background (i.e. their educational background; formal GPS training details (courses with dates); their experience on similar projects, etc.) - this could be a copy of what was provided with the pre-qualification package.
 - ❖ A list of all hardware and software used on the project; including but not limited to:
 - o GPS hardware (i.e. receiver model, antenna, data logger, firmware versions, etc.);
 - o GPS software (i.e. name, version number, settings, etc.)
 - o Mapping software (i.e. name, version number, settings, etc.)
 - o Utility software (i.e. name, version number, settings, etc.)
 - ❖ Detail regarding the GPS Reference Station used (i.e. private, local and/or government, validation status, etc.).
 - ❖ A summary of the project including planning, field data collection methods and parameters (i.e. GPS receiver settings/defaults), data processing methods and parameters (i.e. post-processing settings/defaults), any project problems, anomalies, deviations, etc.
 - ❖ An explanation of deliverables (digital and hard copy) including data formats, naming conventions, compression utilities used, media, etc.).
 - ❖ A copy of all field-notes (digital or hard copy).
 - ❖ A list of all features that have been mapped or surveyed.
2. It is *recommended* the Contractor submit the following digital deliverables in the indicated format and datum (see APPENDIX D - DIGITAL MAPPING and GIS INTEGRATION for details).

Deliverables	Format	Datum	Notes
GPS Reference Station Data	Proprietary or RINEX	WGS84	Merged if possible
Raw Field GPS Data	Proprietary	WGS84	Unedited
Original Corrected GPS Data	Proprietary or ESRI Format	NAD83	Unedited
Final Interpreted GPS Data	ESRI Format	NAD83	Edited

As noted in the table above, two digital and/or hard copy data sets should be submitted. One dataset must show all the GPS data collected after it has been corrected; before there has been any “cleaning” (i.e. filtering, pruning, averaging, etc.). The second dataset must show the resulting GPS data that has been “cleaned” (and is eventually used in the final survey plans/plots). The provision of these products will allow the Contract Administrator to do a visual Quality Assurance check on the GPS data.

3. The Final Interpreted GPS data is to be provided in a digital format to be specified by the contracting Agency, and a hard copy map/plan may also be required. Map hard copies are to conform to Agency cartographic standards.

The following map submission is provided as a suggested minimum:

- o *Map Surround, which includes the following project information: Project Title; Project Number/Identifier (e.g. provincial government’s ARCS & ORCS identifier); contracting Agency name; Contractor name; and date of survey.*
 - o *Plan datum (e.g. NAD83) and the Map Projection (e.g. State Plane Long Island).*
 - o *Plan scale (e.g. 1:20,000) with BCGS map identifier.*
 - o *Plan orientation, (e.g. north arrow annotating True North, Magnetic North and Grid North).*
 - o *Geographic (e.g. latitude/longitude) and/or Mapping Projection (e.g. VCS) graticule as requested.*
 - o *Source of any non-project information (i.e. TRIM backdrop, Forest Cover data, etc.).*
4. Final data (i.e. Original Corrected GPS data and Final Interpreted GPS Data) is to be reduced and presented referenced to the NAD83 datum. If the Contract Agency requires data to be provided on the NAD27 datum, then it is *required* it be a *copy* of the data. If the Agency requires any other local datum, the methods used to transform the data are to be explicitly described in the project report and approved by the Agency.
 5. If orthometric elevations, i.e., Mean Sea Level, are required for submission, vertical data is to be referenced to the NAVD88 using the standard geoid model for the United States - with local geoid modeling if required (i.e. for high vertical accuracy projects).
 6. The data files created by this project are the property of the contracting Agency and access to all files created in the completion of the works is *required* to be made available to the Contract Administrator or designate. It is *recommended* the Agency forward a copy of none sensitive data to the Vermont Center for Geographic Information for distribution to the GIS user community. In addition, the Agency should be responsible for storage or destruction of the data files in accordance with government standards.
 7. It is *recommended* the data provided be catalogued with the following information for archiving purposes:
 - ❖ General project information; such as: the contracting Agency; the Contract Administrator; a project name; and a project identifier (e.g. Agencies internal project number, etc.).
 - ❖ Type, model and version number of hardware used to collect and store data.
 - ❖ GPS Reference Station used to correct field data (include coordinates and validation information).
 - ❖ Details of post-processing conversions used.
 - ❖ Software used in calculations and conversions and version number.
 - ❖ Any non-standard data handling method, technique or principle used.
 8. Digital returns are to be submitted on the storage media and format as required by the Agency.

X. TECHNOLOGICAL/ PERSONNEL CHANGE

1. If there are any significant changes in the Contractor’s GPS system components (i.e., hardware, firmware, software, methodology, etc.) or personnel during the period of the contract, the Contractor should consult with the Contract Administrator. A decision will be made as to whether the Contractor GPS System Validation; the personnel qualification, and/or the GPS Reference Station Validation survey are required to be repeated.

APPENDIX J - SAMPLE GPS CONTRATOR REPORT

1.) Company/ Agency Information

Company/ Agency:

Contact:

2.) Field Operator Information

Field Operator Name:

Company/Agency:

Formal Credentials:

Experience:

3.) Data Processor Information

Data Processor's Name:

Company/Agency:

Formal Credentials:

Experience:

4.) Field GPS Receiver Information

FIELD GPS RECEIVER - GENERAL INFORMATION

GPS Manufacturer/ Model:

GPS Mobile Software:

FIELD GPS RECEIVER - DATA COLLECTION SETTINGS

Data Rate Used:

Data Format:

Satellite Elevation Mask: _____ Degrees

PDOP Mask: _____

Minimum Number of SVs: _____

SNR Mask: _____

5.) GPS Base Station Used

GPS Base Station Used: _____

6.) Deliverables

GPS CONTRACTOR REPORT

DATA

1.) Uncorrected Data

2.) .SSF File

3.) Corrected Data (Shapefile or Geodatabase in NAD83 State Plane New York Long Island FIPS 3104 feet)

APPENDIX K - FIELD EQUIPMENT LIST

GPS Equipment

- | | |
|---|--|
| ☐ GPS Datalogger | ☐ Real-Time GeoBeacon |
| ☐ Integrated GPS Antenna | ☐ Antenna Cable |
| ☐ TSCI Data Cable | ☐ Vehicle Magnet |
| ☐ Dual Battery Cable | ☐ Backpack |
| ☐ Data Power Cable | ☐ GPS Carrying Case |
| ☐ NMEA/RTCM Cable | ☐ Range Pole |

Safety Equipment

- | | |
|--|---|
| ☐ Safety Vest and Hats | ☐ Cellular Phone |
| ☐ Rotating Safety Light | ☐ Tire Chains |
| ☐ Rear Safety Sign | ☐ First Aid Kit |
| ☐ Road Flare | |
| ☐ Sunglasses | |

Miscellaneous Items

- | | |
|---|--|
| ☐ Pencils (standard and colored) | ☐ Calculator |
| ☐ Pens | ☐ Extra Clothing |
| ☐ Compass | ☐ Food |
| ☐ Field book | ☐ Water |
| ☐ Highlighters | ☐ Bug Spray |
| ☐ Tape Measure | ☐ Sun block |
| ☐ Road Maps | ☐ Tripod |
| ☐ Topographic Maps | ☐ Property Access Papers |
| ☐ Paper Clips | ☐ Purpose of Project letter |
| ☐ Clipboard | ☐ 2-Way Radios |

APPENDIX L - EVALUATING GPS PROFESSIONALS

ITEMS TO BE CONSIDERED IN EVALUATING GPS PROFESSIONALS

1. Responsiveness to the specifications and the contractor's proposed plan of performance. The plan of performance should include a schedule for accomplishing the work, including the time required for each phase.
2. Experience. Request a client list. Review one or two of the most recent projects, by examining the work and discussing the client's satisfaction with the mapping contractor's work.
3. Equipment and production facilities. Request a written statement of how maps are prepared. Ask for a listing and description of equipment to be used on the project.
4. Personnel. Ask for a listing of full-time employees of the firm available to work on the specified project and brief resumes of key mapping personnel. The caliber of workforce can be an important factor in a firm's ability to produce acceptable products.
5. Financial status. Request a current financial statement. Check the statement and the contractor's credit rating.
6. Bonding. Bonding should be required for the bid price and 100 percent performance.
7. Support programs. Technical assistance and questions regarding the delivered data should be provided.
- 8.) Cost. Cost should be measured in relation to the service to be provided.