VGIS HANDBOOK

PART 3 - GUIDELINES
SECTION L

VERMONT GPS GUIDELINES

Vermont Center for Geographic Information, Inc.

Guideline History

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- **April 20, 2005** – Public comment period ends.
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EXECUTIVE SUMMARY

The Vermont Technical Advisory Committee (VTAC) has developed Global Positioning System (GPS) guidelines, data collection specifications and data accuracy standards to accomplish the following objectives:

1. Promote the development, adoption and maintenance of common guidelines for GPS technology and data gathering in Vermont in order to:
    a. Enhance data exchange and data sharing between the private, academic and non-profit sectors, and town, regional and government agencies;
    b. To avoid the duplication of effort in the establishment of guidelines, formats, processing methodologies, data communications, and other related concerns
    c. To provide minimum specifications for collecting GPS data.
2. Reduce known and potential systematic errors in GPS data collection efforts at the sub-meter to 20m levels of accuracy;
3. Provide educational information about GPS technology, mapping principles, and mapping techniques, in order to mitigate the risk of misinterpretation of the specifications.
4. Provide standards for supplying metadata about GPS data and the receivers used to collect spatial data (features);
5. Supply GPS users with common GPS terms and abbreviations.
6. Provide templates for contract documents and information on the contracting process to assist entities seeking GPS services

This document targets the use of mapping/resource grade GPS activities and does not address guidelines for survey or recreational grade use. However, information on recreational based use is included as a resource due to the many users in this category. This document defines guidelines for land-based pedestrian or vehicle-based field collection efforts using GPS and does not address aerial GPS data collection or control. These guidelines apply to current GPS technology. The guidelines will require periodic review and possible revision as GPS technologies evolve.

Surveying level activities are governed by strict standards beyond the scope of this document and it is worth mentioned that GPS technology cannot be used to legally define parcel boundaries in Vermont, except by a licensed land surveyor as defined by Vermont Statute[1]. Any representation of points associated with a legal survey should contain a disclaimer that the work product is not a surveyor's map and is therefore not a legal map.

[1] Vermont Statutes : TITLE 26 Professions and Occupations : CHAPTER 45. LAND SURVEYORS :

PREFACE

This document suggests recommendations vs. mandating rules and is therefore a guideline, not a standard. There are three main sections to this document: A) Guidelines, B) Data Accuracy Standards and C) Content Specifications. Section A can be used as a stand-alone reference for users seeking to improve their knowledge of the technology and utilize commonly accepted practices to maximize their efficiency and accuracy while employing GPS technology. Sections B and C are technical resources for any entity contracting out GPS data collection that define data accuracy and specify how these targets can be met by a Contractor. Correspondingly, these latter sections are also a resource for Contractors responding to, and successfully achieving the requirements detailed in an Agency's Request For Proposals (RFP's). It should come as no surprise that achieving higher levels of confidence in field-collected GPS data will result in higher data collection costs. Users of this document should realize that simply referring to this document in a contract specification (e.g. "contractor shall meet the VCGI GPS guidelines") is likely to be a poor (and possibly expensive) strategy. These guidelines are intended to educate and provide options to contracting agencies and contractors. *Contract specifications should be tailored to the needs of the project, balancing the desire for accuracy and reliability with data collection cost and efficiency.*

GPS data acquired in the field without any "real time" correction mechanisms is defined as "autonomous" data, whereas data "post-differentially" corrected with base station data is referred to as "differential" data. This document assumes that data will always be corrected, i.e., "differential", in order to achieve the best accuracy possible.

- **Section A** - ***Guidelines***: Can be used as a stand-alone reference and provides a general overview of the technology, a brief review of GPS receivers, appropriate values for settings that affect performance and accuracy of field observations, best practices and good organizational habits. This section provides a general foundation for the Specifications and Accuracy Standards sections. User with experience or familiarity with the document will likely move directly to the latter two sections.

- **Section B** - ***Data Accuracy Standards***: Resource for entities contracting out GPS data collection, responding Contractors or individual users. It provides a means to classify the estimated accuracy of different GPS data capture efforts. Both the Guidelines and Content Specifications sections support this section.

- **Section C** - ***Content Specifications***: Supports Section B and contains the rules that convey how the data accuracy standards can be met and facilitate the standardization of data collection procedures and quality control. This can serve as the basis for a formal contract document between the Contracting Agency and the Contractor performing the fieldwork. Supported by both the Guidelines and Accuracy Standards sections.

This document has been created in response to the growing need for a set of Vermont guidelines to help guide the consistent and accurate capture of field data using GPS. GPS technology has greatly extended the capacity of individuals to capture a vast array of digital data representing real world features in recent years, but the lack of a corresponding understanding of the technology has often resulted in inconsistent data of dubious quality and accuracy. This is due, in part, to the common misconception that the technology is foolproof and with little or no training anyone can pick up a GPS receiver and start capturing high quality, accurate and useful data. Unfortunately, the old adage "junk in, junk out" is true here as well. Hopefully, this document will help to remedy some of these issues and demystify the technology so that it can meet user objectives. It has been designed as a resource for both the novice and intermediate user, a guiding document for entities wishing to contract GPS related services, and as a reference document for the contracting party engaged in the capture and delivery of GPS field data.

It is important for the user to understand that this document has been crafted relative to currently available technology and the nature of that technology is very dynamic. New capabilities will evolve and functionality currently available in higher priced receivers will migrate to less expensive ones blurring the recreational, resource/mapping and survey grade categories defined in this document.

This document borrows heavily from the Canadian province of British Columbia's Ministry of Environment, Lands and Parks (now the Ministry of Sustainable Resource Management) "British Columbia Standards, Specifications and Guidelines for Resource Surveys Using Global Positioning System Technology"[2], as well as, state level efforts in Minnesota and Georgia.

[2] British Columbia Standards, Specifications and Guidelines for *Resource Surveys* Using GPS Technology

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SECTION A – GUIDELINES

I. PURPOSE

This section can be used as a stand-alone reference to aid users of Global Positioning Technology (GPS) in gaining a better understanding of the technology and to improve the quality and accuracy of the data they acquire. It also provides the foundation for **Section B -** ***Data Accuracy Standards*** and **Section C -** ***Content Specifications*** that are geared to support project where GPS data is acquired through contractual agreements.

Nearly everyone who's ever used a map has had some exposure to GPS. It's practical value for natural resource management, military logistics, vehicle tracking, recreational navigation, and a plethora of other uses has been proven beyond question. Technology barely accessible to "techies" and engineers a decade ago now seems a part of the common lexicon. GPS has also matured along with GIS technology, and together, the two are powerful tools for asset management, resource inventory, and planning. In fact, a case could be made that it is now too easy to collect spatial data with GPS! Inexpensive receivers capable of less than a 10-meter accuracy (primarily designed for navigation) are now within the financial reach of even the most cash-strapped business or agency. Site-specific spatial data are now so easy to collect that more people are asking for it and more people are providing it. But are all receivers equally capable? How does one assess the reliability of the data being collected? How does an individual or agency interested in acquiring GPS data evaluate the requirements of the project or the capabilities of the Contractor? Should GPS data come with user caveats? With more and more people interested in using GPS data for more purposes, the need for answers to these questions have become acute.

VCGI has a responsibility to provide guidance to the developers and users of spatial data in Vermont. In some cases, the public nature of these data has resulted in "standards" that dictate how the data will be developed, coded, and maintained. In other cases, "guidelines" offer a more flexible way to provide users with information that can be tailored to a wide range of projects and products. This document is definitely a guideline. It provides some basic background information on GPS technology to assist the user in matching project requirements to equipment and methods. It recommends receiver hardware, default settings, and field and post-field methods to insure data quality. It also attempts to emphasize a variety of choices facing developers and users—choices that often have a significant impact on the cost of data acquisition. Finally, it suggests how to document data collected with GPS so that present and future users can assess the appropriateness of the data for unanticipated purposes.

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. Myriad 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 goal of this document is to review the primary factors that can be influenced by users: receiver type, receiver settings, field procedures, correction and validation procedures, quality assessment options, and documentation. With this information those performing the data collection can do so with greater confidence and those receiving the collected data can be assured of getting data that meet specifications. The goal of **Section A** ***(Guidelines)*** is to provide individuals, field staff or project managers with enough background to orient their data capture goals and understand the foundation that the specifications in **Section C -** ***Content Specifications*** are built upon to ensure data quality and accuracy (**Section B -** ***Accuracy Standards***). For work that gets contracted, sections B and C become especially valuable to the project manager in charge of scoping and oversight, as well as, to the sub-Contractor who must meet the specifications or risk failing to meet the terms of the contract.

1) WHAT IS GPS?

GPS is a system of satellites, ground control stations, and receivers that allows users to determine their position. By capturing and storing that position, GPS receivers "digitize" spatial data as they walk, drive, or otherwise traverse the land. For this reason the term "rover" receiver unit is often used to describe a GPS field receiver. For the sake of consistency, the term "GPS receiver" or "receiver" will be used to identify the GPS "rover" receiver from this point forward. Perhaps the most important characteristic that GIS data developers need to realize about GPS is that it is a highly dynamic system with new satellites being launched and old ones being retired. The constellation of satellites available to users throughout the day is constantly changing as the satellites move through their orbits. Occasionally, satellites are shifted into new orbits. Collecting GPS data in Vermont often adds the complications of vegetative cover, topography, and relatively northern latitude to the inherent variability in the system. Receivers differ in their ability to receive and process GPS signals, and users can have a huge affect on accuracy depending on the methods used to collect and process data.

It may help to think of a GPS receiver as similar to a standard radio. Like the radio in your car, a GPS receiver is collecting radio signals from the "ether" and magically turning these signals into information we can use. In the case of a GPS receiver the "stations" are satellites broadcasting 11,000 miles away in space and the music is a binary code, but the antenna and radio hardware are subject to similar kinds of interference that affect your car radio's ability to produce a clear sound. In your car speaker we hear this interference as "static"; in your GPS receiver the interference may result in positional "static", i.e., degradation of accuracy. A better radio receiver and antenna system, fewer terrain obstructions, a stronger connection to the broadcasting station all result in better sound quality for your car radio and better positional quality for your GPS radio. A GPS receiver derives its location or positional "fix" with distance measurements (called pseudoranges) from multiple satellites at precisely the same time, a "measurement epoch". Attributes collected and stored with the position for each feature can be used in GIS map making and analysis. While there are only so many things you can do to improve your car radio's performance, by contrast there are many more things users can do to influence GPS positional quality.

This document presumes the reader has only minimal GPS experience. Section II begins with a discussion of GPS receiver types and their appropriateness for different types of data collection. Section III covers other features of GPS that can affect accuracy and can be controlled by the user.

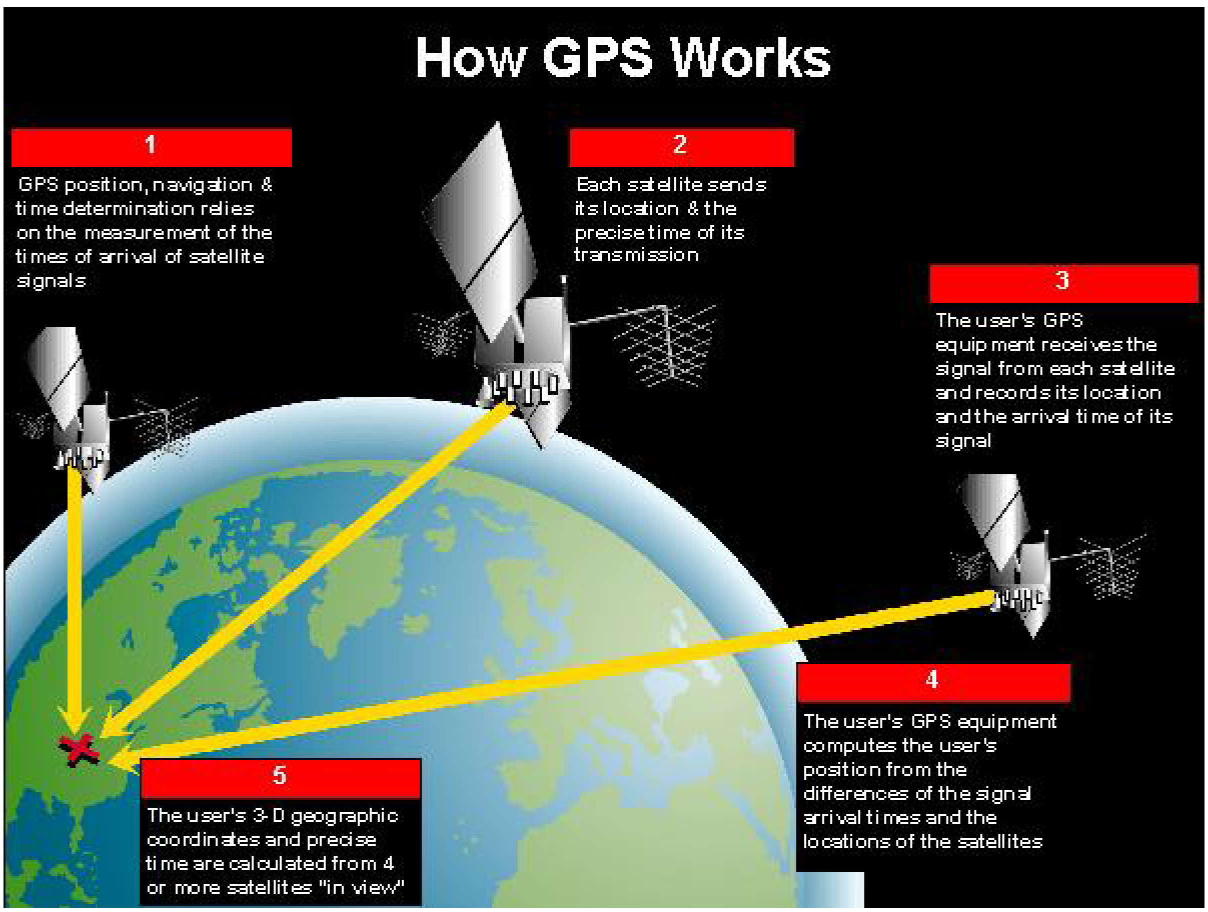

Figure I-1 GPS Overview[3]

[3] From Dan Martin – awaiting reference info 12/4/03 email

II. GPS RECEIVER GRADES and CHARACTERISTICS TO CONSIDER

1) *CLASSES OF RECEIVERS*

GPS receivers and software can be used to obtain positions with accuracies from centimeter to tens of meters. The mapping/resource grade receivers that are the focus of this document are generally able to obtain positions with accuracies from five decimeters to ten meters. Some mapping/resource grade receivers can also be used as remote base stations. There are estimated to be over 500 GPS receiver models available from over 100 different manufacturers around the world. Competition has improved the products and reduced the cost, but has also confused the buyer. The table, illustrated in Part D below, is offered as a generic guideline to available GPS products.

A civilian GPS receiver is generally categorized as (1) recreational grade, (2) mapping/resource grade, or (3) survey grade, based on its functionality. The characteristics of each of these GPS "grades" are briefly described below, and then listed in a table for easier comparison.

A) *Recreational Grade GPS*

Recreational grade GPS receivers are the least expensive and the simplest to use, because they have less functionality (and less associated software and hardware) than the other grades. As the name implies, these "handheld" GPS receivers are intended primarily for recreational purposes. These are useful for general navigation and surveillance purposes because they can quickly collect the *x-y* coordinates of point features, and can be used to pre-plan routes and/or navigate to specific locations using waypoints. They are not, however, recommended for most data field collection or mapping activities. Though some of the more expensive recreational grade receivers come with a communication port that allows for the download and post-processing of data or come with a radio receiver that provides for real-time differential correction of data, most receivers in this class do not. This fact not only limits the accuracy of features collected but also prevents the user from downloading captured features digitally. The only recourse to creating spatial data with these receivers is to manually transcribe feature coordinates into a format that can be imported into a GIS.

Popular recreational receivers can be expected to produce horizontal positions with an accuracy of approximately 10 meters under clear tracking conditions. Positioning under canopy can reduce this accuracy to approximately 30 meters, or worse, depending on tracking conditions.

B) *Mapping/Resource Grade GPS*

This guideline recommends that GPS data being collected for GIS utilize mapping/resource grade receivers. Mapping/resource GPS tools capture data of higher positional accuracy than recreational receivers, and all have post-processing differential correction capabilities. Unlike recreational GPS, these receivers also collect locations for features represented as points (e.g., sample point), lines (e.g., trail), ***and*** areas (e.g., field boundary), complimenting GIS database organization schemes. Mapping/resource GPS equipment required in the field ranges from "handheld" to "backpack" systems. The more expensive mapping/resource grade GPS receivers are designed to: (1) collect and store large volumes of data, (2) be used in extreme environmental conditions, (3) perform real-time differential correction of data; and 4) act as a field reference base station. The average accuracy for this grade of GPS receivers varies and changes as technology develops, but at this time accuracy is generally between .5-5 meters when data is "post-processed" or acquired "real time", under typical data collection constraints.

Most professional-grade receivers differ from the lower-end resource or mapping grade receivers in the hardware and techniques used to process the GPS signal. Often called "narrow correlation" receivers, these "high-end" receivers provide better performance under difficult conditions (especially tree canopy) while reducing multipath interference (see section below on this subject for details). Both these narrow-correlation receivers and the so-called "standard-correlation" receivers are suitable for most resource grade mapping (2-5 meters), though the narrow-correlation receivers generally achieve these accuracies with less time spent at each point.

C) *Survey Grade GPS*

This document does not address survey grade activities. Survey grade GPS tools are only used for surveying-related activities requiring a high degree of accuracy. For example, licensed land surveyors use these GPS tools for geodetic surveys, and to measure elevations. These systems produce data of the highest horizontal and vertical positional accuracy, but are very expensive and complex. The use of a survey grade system requires specialized training, and one or more dedicated staff to oversee its use and maintenance. Survey grade GPS data are almost always post-processed to increase their accuracy.

D) *Comparing GPS Receiver Grades*

RECREATIONAL GRADE	MAPPING/RESOURCE GRADE	SURVEY GRADE
Primary Uses		
• Navigation; hunting; fishing; camping; backpacking; hiking	• resource mapping; navigation	• resource mapping; site mapping; surveying; navigation (stakeout); vertical measurement
Horizontal Data Accuracy		
• 10 to 20 m *(no correction)* • 5 m *(real-time correction only)*	• 5 to 20 m *(no correction)* • 0.5 to 5 m *(real-time or post-processing correction)*	• <2 cm *(real-time correction)* • additional post-processing may improve accuracy to <1 cm
Vertical Data Accuracy		
• not used to collect vertical data	• 2 to 15 m *(2 to 3 times less accurate than horizontal data)*	• <2 cm *(real-time correction)* • additional post-processing may improve accuracy to <1 cm
Differential Correction Options		
• some have post-processing capabilities • real-time correction in some receivers	• post-processing in all receivers • real-time in some receivers	• real-time in all receivers • additional post-processing to improve accuracy is in all receivers
Type of Features Collected		
• points only	• points, lines and areas	• points, lines and areas *(primarily used for point data!)*
Option to Load Custom Data Dictionary with Feature Attributes		
• unavailable at this time	• all receivers	• all receivers
Option to Load Custom Coordinate Systems, Projections, Datums/Spheroids		
• some receivers	• all receivers	• all receivers
Option to Navigation Using Waypoints		
• all receivers	• all receivers	• not practical for navigation
Time Required to "Lock on" to Satellites before Collecting Data		
• 5 to 10 minutes	• 2 to 5 minutes	• 2 to 10 minutes
Number of Data Points Collected/Stored before Download Required		
• <1,000 at this time	• 10,000 to 50,000	• >50,000
Training Requirements		
• minimal	• moderate	• advanced
Cost		
• $200 to $500 at present	• $2,500 to $12,000 at present	• $5,000 to $75,000 at present

Figure II-1 Comparative table of GPS receivers by Grade[4]

[4] WI-DNR. Comparing GPS Tools. pp. 5

2) *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.

A) *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**.

B) *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 mean more data needs to be collected, increasing storage needs.

- **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**, 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.

C) ***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.

D) ***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.

E) ***Data Dictionary Of Feature Attributes***

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. For a detailed overview on data dictionaries see *Section V.1 Data Dictionary of Feature Attributes.*

F) *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.

3) SELECTING THE RIGHT DATA COLLECTION TOOL FOR THE JOB

A data capture effort intending to collect locations of real-world features must choose a tool capable of capturing data that adequately support its needs. 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 data collection tool for a specific project requires serious consideration of the following:

- Need to identify and use existing data collection procedures or standards.
- Anticipated uses 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.
- Need to 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 areas).

The "decision tree" outlined in figure III-1 below is intended to help users select an appropriate receiver grade particular to their GPS data collection project. <u>This is only a general guide, however, and you must also consider several other factors (listed in this document) before making your final choice</u>!

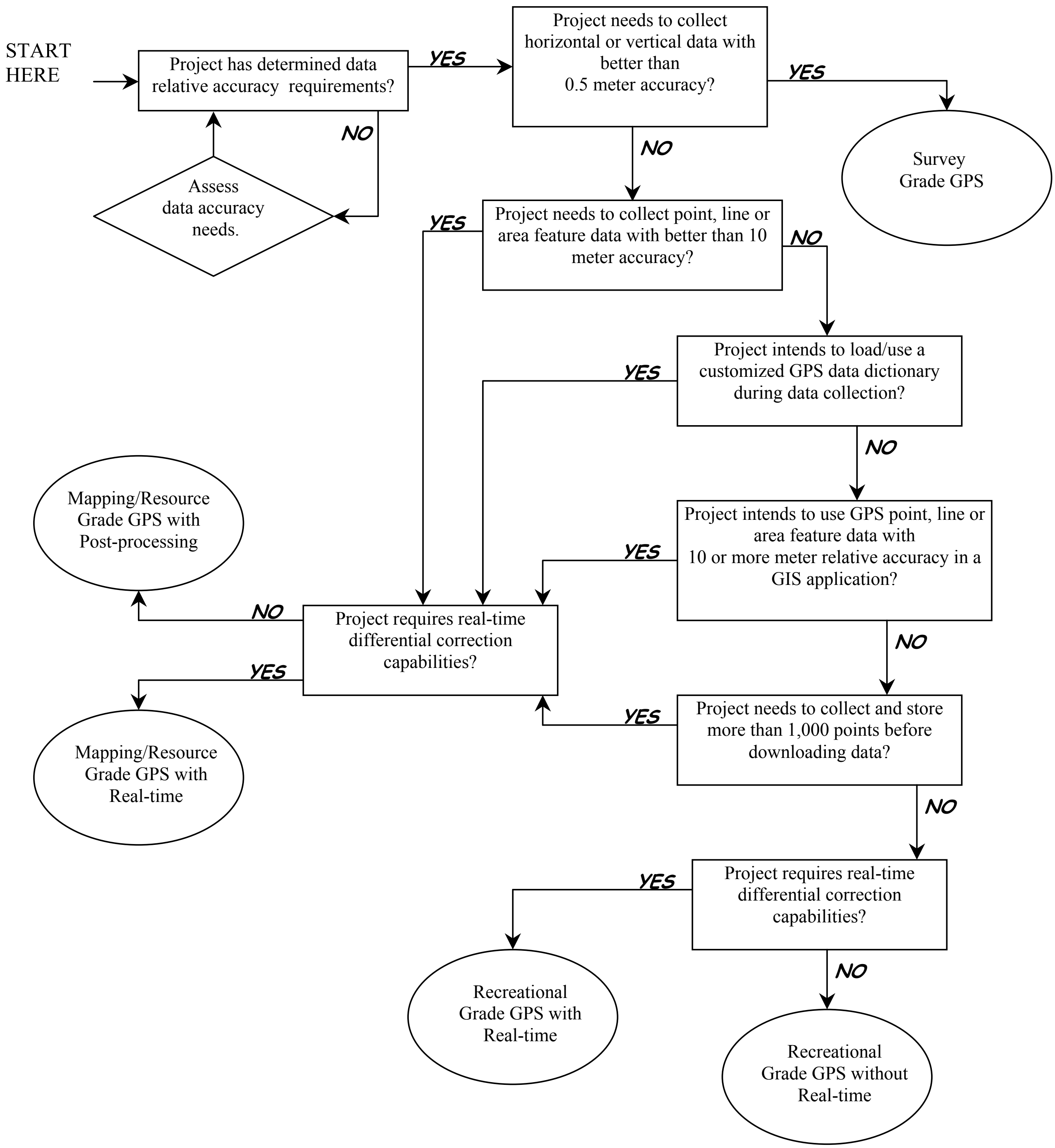

Figure III-1 Decision Tree[5]

[5] WI-DNR. Comparing GPS Tools. pp. 12.

III. GPS ACCURACY CONSIDERATIONS

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.

1) 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.*

A) *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**.

B) *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 15º or greater.**

C) ***Number of Points Collected Versus Data Collection 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 aerial features the rate may vary between one and five seconds depending on your speed of ground travel

D) ***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 these 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. (See Section V.1., Satellite Availability Planning.)

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. See section IV.3.C.8 "Point Offsets" for details on how to capture an offset and minimizing the amount of introduced error.

2) *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.

A) *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 Vermont, the VERMONT CAPITAL CORS (VCAP) located in Montpelier is within 100 miles of all Vermont borders, records data using a 1 second sampling rate and should be considered the default CORS station for acquiring correction values. Data for VCAP are available from the National Geodetic Survey and also from the Vermont Agency of Transportation at http://vcap.aot.state.vt.us. 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.

B) *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. 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. Access to WAAS is limited in Vermont. 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 D - 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.

3) *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 IV.4 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.

A) *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**.

B) *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 IV.2. Differential Correction to Improve GPS Data Accuracy*** above and ***IV. 3.C 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:

(1) **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 manufacturer's 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.

(2) **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.

(3) **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.1. 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.

(4) **Digital Imagery Comparison**
An alternative to reobserving points, when accuracy validation isn't a project requirement, is the use of the Vermont Mapping Program (VMP) digital orthophotography[6]. 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 your 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 Standards[7], 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.

(5) **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 benchmarks coordinate accuracy, does not apply to other points in a typical GPS data collection survey. Instead, the utility of this comparison may be

[6] http://www.state.vt.us/tax/mapping.shtml
[7] http://www.oh.nrcs.usda.gov/technical/gis/natl_map_accuracy.html

limited to simply ensuring the receivers 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.

C) *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. At one extreme, a road that is straight for two miles ultimately only needs two endpoints to accurately represent it. These are rare in Vermont where curvy roads are the norm and road features would be better represented by points spaced at an interval close enough to effectively capture the feature relative to the accuracy desired. This same issue applies to polygons, e.g., lakes or parking lots. 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.

(1) **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."[8]

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. For a detailed discussion on the relationship between total number of fixes collected, sampling rate and collection duration see Section IV.1.C - Number of Points Collected Versus Data Collection Rate. 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

(2) **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.

"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.

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

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."[9]

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 Separation[10]

(3) **"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 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.

(4) **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.

(5) **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.

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

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

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.

(6) **GPS Events**

An additional method for logging point features is the "GPS Event" 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)."[11]

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 Accuracy[12]

(7) **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 and 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

[11] British Columbia Standards, Specifications and Guidelines for *Resource Surveys* Using GPS Technology. pp. D-38
[12] British Columbia Standards, Specifications and Guidelines for *Resource Surveys* Using GPS Technology. pp. D-39

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 remediate 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.

(8) **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.
- 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	0.3° - 0.5°	1.0°	25m	0.6m

e.g. MapStar, Laser Atlanta			50m	1.1m
			100m	2.3m

Table IV-5 Offset Accuracy vs. Instrumentation Precision & Offset Distance[13]

(9) **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 a managed individually and does not necessarily have to be a constant value.

D) ***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 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.

(1) **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 other 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.

(2) **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.

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

The goal of most edits to linear of 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.

4) 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; Introduction* for details.

A) *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 were 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.

(1) **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 multipathing 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.

(2) **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.

B) *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.

(1) **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.VI.3.C.1 - Table IV-2 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 Audit[14]:

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

- ❖ 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.
- ❖ 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).

(2) **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.

(3) **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.

(4) **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.

IV. IMPORTANT CONSIDERATIONS

1) SATELLITE AVAILABILITY PLANNING

The two most important factors in maximizing the accuracy of your GPS data are having a minimum of four satellites in view, and the lowest possible Dilution Of Precision (DOP) values (discussed earlier) when obtaining positions.

With the current full constellation of satellites available, GPS planning is less crucial than it used to be. Users can generally assume there will be at least four satellites with reasonable geometry at most times of the day. However, this does not guarantee the best coverage at all times. There are certain periods of the day that may be better than others so it is important to assess satellite availability to identify these periods. This is more important in a state like Vermont with mountainous terrain and heavy forest cover where terrain obstructions can have an adverse effect on data collection. Planning fieldwork during optimum satellite coverage in these areas can prevent a very unproductive day where a lot of time may have been spent to reach a location only to find data couldn't be collected or is of poor quality.

"The number and location of satellites and corresponding DOP values can be predicted for any location and time using satellite prediction software and a current GPS almanac. This software comes with most commercial receiver/software packages. Also, there are free programs available on the Internet (downloadable versions, and on-line predictions). The more sophisticated planning packages will allow a user to apply variable satellite elevation thresholds, disable / enable individual satellites, simulate local obstructions, and generate detailed reports and PDOP, HDOP, and VDOP plots.

A current GPS almanac is needed in order to use satellite prediction software. An almanac file contains the parameters describing the individual orbits of each GPS satellite, and with this their positions can be predicted for any time. The almanac should be reasonably current (few weeks), as satellites are occasionally launched, moved, or decommissioned. Current almanac files can be obtained directly from a GPS receiver (the receiver should track satellites for at least 15 minutes before collecting an almanac file to ensure that the current broadcast almanac message is complete). It is also possible to obtain almanac files from other sources including manufacturers' websites and the U.S. Coast Guard's Navigation Information Center (NAVCEN).

The U.S. Coast Guard's NAVCEN is the official source of civilian information for GPS (http://www.navcen.uscg.gov/gps/default.htm). The NAVCEN publishes daily GPS status messages known as NANUs (Notice Advisories to NAVSTAR Users), which alert users of planned satellite outages (e.g. down time for maintenance), as well as unplanned satellite outages. NANU bulletins occur fairly often (sometimes more than 1 a day), and it is recommended that the NAVCEN email list server be used to automatically receive these messages as they are published. NANUs should be checked before using the satellite prediction software, and any planned outages should be tested to see the local effect on coverage.

Terrain obstructions can also be considered in planning. Often it is sufficient to work out plans and schedules for general aspects (e.g., N-S-E-W with 30 degree obstructions) rather than try to simulate specific site conditions.

Canopy blockage can be predicted in a similar way. It is impossible to accurately predict exact tracking conditions that will be experienced in the field, so planning should be generalized. It is common to have periods of weaker satellite coverage, and if the field crews are aware of this, they can schedule a lunch break or travel during this period. In very difficult observing conditions, it is helpful to give the field crews satellite visibility plots for specific times and they can adjust their schedules in the field accordingly."[15]

2) *DATA DICTIONARY OF FEATURE ATTRIBUTES*

A data dictionary is extremely useful in organizing and expediting the field data collection effort component of a project, but it also serves to ensure data integrity and compatibility with GIS databases by requiring the developer to thoroughly define its scope. The amount of effort, or lack thereof, will not likely show up any more poignantly than in the success or failure of a field data collection effort utilizing a data dictionary. In essence, the data dictionary gives a project its structure by requiring the user to determine: 1) what features are to be captured (points, lines or areas); 2) what attributes are desired; and 3) the values for each of the attributes. The features, their attributes and range of values should only be entered into a data dictionary after a thorough needs assessment has been conducted for the receiving organization or client, to ensure the resulting GIS database will meet the intended objectives and stand the test of time. Determining these variables up front will prevent confusion, frustration and the loss of time and limited project resources. These savings will be realized through each step of field data collection, processing, integration with existing GIS databases and through the end uses of spatial analysis and cartographic production. When creating a dictionary it is useful to thoroughly answer the following questions for your project: What features should be captured? How should they be represented, i.e., points, line or areas? What information about each feature is desired? What descriptive values for each attribute should be used? Are their pre-existing databases that should provide the data structure for the dictionary attributes, values and definitions?

A simple alternative to the data dictionary, that serves the same purpose, is a printed form with all of the attributes and their values that can be filled out individually for each feature and entered into a database back in the office.

A) *Data Dictionary Structure*

If the assessment phase of a project is conducted adequately, the dictionary will be well composed and seamlessly become the organizations initial database that can be updated well into the future. A dictionary gives the project manager a great deal of control in defining the types of attributes and the values that can be entered for each feature.

(1) Feature Types

As previously mentioned, there are three feature types used to represent real world information; points, lines and areas (a.k.a. polygons). In defining feature types it is best to group features "thematically" rather than creating a unique feature type for each individual real world occurrence, e.g., trails, dirt roads and paved roads should all be one feature type called "transportation" vs. three individual features. Practical field considerations relating to features being captured must be accounted for when designing a dictionary, e.g., small pools in a stream may be better represented as a point vs. an area feature or patches of thorny or poisonous plants may be undesirable or impossible to capture as an area feature. Limitations of access, terrain and environmental factors should also be considered in relation to the mode of capture, i.e., walking, driving, riding or skiing when composing the dictionary.

(2) Attribute Types

The five types of attributes that can be assigned to a feature are: Menu, Character, Numeric, Date and Time. All types can have a default value assigned in the absence of user input. In defining attribute types it is best to reduce feature elements into as many individual attributes as is reasonable possible. For example, to express

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

the type of trail and its condition "single track and eroded", it is better design form to depict this information in two separate attributes than a single one, i.e., "type_of_trail" and "condition" vs. "type_cond". This approach allows for a higher level of query and analysis where "single track" trails can be distinguished collectively from their conditions of "eroded" or "stable". The combined approach of the single attribute would not permit this due to the concatenation of the information. The ultimate caveat to this approach is that it is easier to combine the individual elements in separate attributes than it is to extract elements from a single attribute.

- Menu - Allows for an explicit list of values (domain values) that the user can select from in the field that ensures a highly level of integrity in the data. This provides for a much faster mode of entry than selecting individual characters via the keypad for character fields.
- Character - A text field with a user defined width.
- Numeric - A numerical string with a user defined width, decimal places, and lower and upper value limits
- Date - A date string with a user defined format, and lower and upper value limits
- Time - A time string with a user defined format.

B) *GPS Receiver Keyboard/Keypad/Barcode Scanner Options*

If you intend to use a data dictionary, you must also consider the GPS receiver's data entry keyboard, keypad or "wand" barcode scanner options. For example, if you need to type in a lot of alphanumeric characters, you may want to consider using a GPS receiver with an alphanumeric keypad, rather than one that requires you to use arrow keys to scroll through letters, numbers, and symbols. Another approach is to print out your data dictionary in bar code format, with accompanying text that can be read with a "wand" barcode scanner connected to the receiver via a communications port.

3) *EXPORTING GPS DATA IN A GIS FORMAT*

Data collected using a mapping/resource grade GPS is managed, analyzed, and displayed using GIS tools. In order for your GPS data to integrate easily with standard GIS software, this Guideline recommends that you use a GPS that includes software to convert your field data into ArcView® shapefile, ArcInfo® coverage, AutoCad DXF or other common formats.

4) *COORDINATE SYSTEMS, PROJECTIONS, DATUMS/SPHEROIDS*

With the ability to capture, store and export GPS data in a number of custom projections, coordinate systems and datums comes the responsibility of understanding specific issues regarding how newly created data integrates with existing digital geospatial data. Vermont has addressed this issue by establishing a single, consistent coordinate system to be used in the state as a common foundation for all geospatial data, called the Vermont Coordinate System (VCS83).

All data captured via GPS in the state of Vermont should ultimately be output using the Vermont Coordinate System (VCS83) and units of meters. While this is actually required by law for all publicly funded projects, it is also highly recommended for all GPS data collection projects to ensure consistency with the wealth of data already stored in the VCS83[16]. Recreational receivers without the ability to post-differentially correct or download their data (no communication port) will have to convert their latitude/longitude data. Using the VCS83 enables users to overlay their data with existing digital data available from the state, Regional Planning Commissions, the Vermont Mapping

[16] Certain GIS software can now integrate numerous coordinate systems "on-the-fly" but they are expensive, and therefore not readily available to small scale users. Data management is also complicated by numerous coordinate systems.

Program's digital Orthophotography and the numerous, free datasets available on the Vermont Geographic Information System.

The VCS83 is a state plane coordinate system established by the National Ocean Service/National Geodetic Survey and based on the 1983 North American Datum. The statute governing the VCS83 can be found under Chapter 17. VERMONT COORDINATE SYSTEM of the TITLE 1 General Provisions where sections 671 through 679 provide specifics. Sections "§ 679. Transition." and "§ 672. Coordinates defined." specify: 1) "…the Vermont Coordinate System 1983 will be the sole system for projects commenced after this date. Added 1987, No. 169 (Adj. Sess.), § 9, eff. May 3, 1988."; and 2) The plane coordinate values for a point on the earth's surface, used to express the horizontal position or location of such point on the Vermont Coordinate Systems, …expressed in meters and decimals of a meter when using the Vermont Coordinate System 1983".

For a generic discussion on projections, coordinate systems and datums refer to the following link: www.colorado.edu/geography/gcraft/notes/coordsys/coordsys_f.html.

For more information on the VCS83 specifically refer to one of the following sources:
1) Vermont statutes document "Title 1: General Provisions; Chapter 17: VERMONT COORDINATE SYSTEM" (www.leg.state.vt.us/statutes/fullchapter.cfm?Title=01&Chapter=017); or
2) The ***VGIS Standards, Section B – Map Coordinate System*** (www.vcgi.org/techres/standards/partii_section_b.pdf).

V. GPS MODERNIZATION

The first GPS demonstration satellite was launched in 1974 and the full constellation of 24 satellites became officially operational in 1995. Since that time up until 2004 three signals were available, L1 C/A, L1 P/Y and L2 P/Y. The L1 C/A or Coarse/Acquisition signal is the only signal available to civilian users, the other two P or Precise Code contain Y code that is available to special government hardware.

In 2004 the first IIR-M modernized satellite, containing three additional signals, is scheduled for launch. Additional L1 and L2 military signals and a L2 C/A signal designated as L2 civil (L2C) will also become available for general use. The net effect will be a doubling in the availability of existing signals. An additional L5 civil signal is designated for satellites scheduled for launch in 2005. This signal will be in the aeronautical radio navigation band and will therefore be protected for safety-of-life applications as well as navigation. It will take some time to fully replace the existing satellite constellation with the newer versions so initial operational capacity probably won't be achieved until 2010 or later.

The L2C signal is expected to dominate civilian use when it is fully operational. The signal differs from the older C/A signal in that its is divided into 2 components with only one carrying data whereas the L1 C/A design carries all the signal and code data together. The newer technique uses less power and signal clarification is easier with a separate data component. A separate data component also allows for a longer data code. In the earlier C/A design a shorter code length was required and this allowed stronger GPS signals to block acquisition of weaker signals or for hardware to favor tracking stronger signals. Longer code segments will provide for much better performance in weak signal situations such as in forest canopy or inside buildings. The L5 frequency will accommodate better signal tracking and better performance, but will also require 4 times more power. The L2C signal will allow for small, low power and low cost consumer applications that will result in more users of the signal.

While the newer signals will not be fully operational until around 2010 or later, expensive dual-frequency receivers will be able to utilize the new signals as each new satellite is launched. These receivers are typically used for geodesy, scientific monitoring applications, construction surveying, machine guidance, etc. They are able to track both the L1 and L2 frequencies to determine signal delay differences due to the ionosphere. More typical single-frequency receivers will need to wait until enough satellites are available. As more satellites are launched carrying the new signals receiver manufacturers will be able to differentiate their equipment by focusing on the fully operational L1 C/A signal or partial constellations of newer, better performing L2C and L5 signals. Manufacturers will need to design receivers that are able to switch or mix signal types to achieve the best performance during transition. Recorded data will need to track the signal source to employ the best correction measures. Users will have more receiver choices available but they will need to be educated about the best signal type for their application.

The quality of the stand-alone civilian positioning will dramatically improve over the coming years. From the start of GPS on, one can distinguish the following accuracies prior to post-differential corrections:

20 - 100 meters : using C/A-code and with SA (Selective Availability) (prior to May 2002)

10 - 20 meters : now, using C/A-code and with SA off (turned-off May 2002)

5 - 10 meters : by 2010, using C/A-code and L2C-code on L2, using to dual-frequency ionospheric correction

1 - 5 meters : by 2013, using C/A-code, L2C-code on L2 and additional civil code on L5

Miniaturization of receiver components will continue and users can look forward to the benefits of smaller receivers and higher accuracies.

VI. GPS TRAINING AND INFORMATION RESOURCES

The following Internet sites provide useful information about GPS principles and receivers, as well as links to other helpful GPS websites. A large number of these links were reproduced from the GPSY.COM website and VTAC would like to thank Karen Nakamura for her permission in reproducing them here.

1) *QUICK REFERENCE FOR VERMONT GPS USERS*

- Vermont Agency of Transportation - Geodetic Survey. (http://vcap.aot.state.vt.us/)
- Vermont OnLine Geodetic Information System **(VOLGIS)** – "A web-based, GIS application that allows users to search for, and retrieve geodetic control information using a graphical interface." (http://vtransmap.aot.state.vt.us/website/geodetic/newmap2.asp?action=Zoom+Full)
- National Geodetic Survey (NGS)– Continuously Operating Reference Stations (CORS), Software utilities and Benchmark datasheets. Graphic shows 100, 200, 300 & 400km buffers from each station. (http://www.ngs.noaa.gov/CORS/)
- NGS Benchmark Datasheets – Find detailed information about benchmarks. (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl)
- Computing Magnetic Declination - National Geophysical Data Center. Calculates historic, present and future declinations! (http://www.ngdc.noaa.gov/cgi-bin/seg/gmag/fldsnth1.pl)
- Canadian Geodetic Survey - (http://www.geod.emr.ca/)

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2) *CONTRACTING RESOURCES*

- GIS Consultants List for VT and the surrounding region - Available from VCGI to provide a list of consultants in the area that provide GPS and other GIS related services. (http://www.vcgi.org/commres/publications/consultants_04.pdf)
- Project Management Resources - VCGI Resource page containing links to resources designed to help plan and manage GIS related projects. Resources include: Powerpoint shows; Budgeting Guidelines, Budget Worksheet, Project Specifications, Sample Contract, Task Guidelines, Task Checklist Template, Milestone Chart Template, Sample RFP and Sample Workplan. (http://www.vcgi.org/project_management/)

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3) *GLOBAL POSITIONING SYSTEMS FAQS*

- Creating a Data Dictionary using Trimble Pathfinder Pro software – The Sierra College Geography Department. (http://geography.sierra.cc.ca.us/booth/GIS/gps/protocol_home.htm)
- Peter Bennet's NMEA/GPS FAQ FTP Directory – Many FAQ references. (http://vancouver-webpages.com/peter/idx_faq.html)

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4) *GENERAL GPS INFORMATION*

- The Geographer's Craft – A superb GPS overview paper - University of Colorado , (http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html)

- Garmin's Introduction on GPS – (http://www.garmin.com/aboutGPS/). Also see their GPS Guides. (http://www.garmin.com/aboutGPS/manual.html)
- GPS: A New Constellation - National Air & Space Museum – (http://www.nasm.edu/gps/)
- GPS World Online Magazine - (http://www.gpsworld.com/)
- IEEE Special Issue on Global Positioning System - Introduction to GPS. (http://teaser.ieee.org/pubs/trans/9902/gps.html)
- Joe Mehaffey and Jack Yeazel's GPS Information - Resource for handheld GPS information. (http://joe.mehaffey.com/)
- The Institute of Navigation - Non-profit professional society dedicated to the advancement of the art and science of navigation. (http://www.ion.org/)
- Trimble's interactive, on-line GPS Tutorial. (http://www.trimble.com/gps/index.htm)
- US Naval Observatory GPS System Description. (http://tycho.usno.navy.mil/gps.html)
- University NAVSTAR Consortium – (http://www.unavco.org/relatedlinks.html#web%20site)

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5) GOVERNMENT GPS SITES

- F.A.A. - GPS Satellite Product Team – (http://gps.faa.gov/)
- International GPS Service for Geodynamics (IGS) – (http://igscb.jpl.nasa.gov/)\
- Metric to Imperial conversion (http://www.wsdot.wa.gov/Metrics/factors.htm)
- National Spatial Reference System (NSRS) – Access information to locate individual benchmarks that are part of the NSRS. (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl)
- NGS / NOAA GPS Site (http://www.ngs.noaa.gov/GPS/GPS.html)
- Satellite Predictor - **Naval Air Warfare Center Weapons Division (NAWCWPNS). (**http://sirius.chinalake.navy.mil/cgi-bin/satpred-query**)**
- US Census US Census GIS FAQ (http://www.census.gov/geo/www/faq-index.html)
- US Coast Guard (official GPS site). (http://www.navcen.uscg.gov/gps/default.htm)
- U.S. Forest Service – GPS Information Page; Accuracy reports on many GPS receivers
- US Geologic Survey – Tools (http://edcdaac.usgs.gov/education/GIS-GPS Tools.html)
- USGS Geographic Names Information System - The GNIS is our Nation's official repository of **domestic** geographic names information. Includes coordinates, elevation, population etc. (http://geonames.usgs.gov/)

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6) GIS MAPPING PROGRAMS

- ArcView®/ESRI and ArcInfo® - High end GIS tool for the Macintosh and PC. (http://www.esri.com/)
- DIMPLE 3.0 - A remote sensing image analysis system for Mac OS and Windows. (http://www.process.com.au/)

- Geo&Soft - Windows geoengineering and earth sciences software. (http://www.geoandsoft.com/english/software.htm)
- GPSy Pro - Macintosh GPS/GIS solution (US$30-$55+). (http://www.gpsy.com/pro/index.html)
- Route 66 - a Macintosh/Windows map route planning package of Europe and the U.S. (has no GPS feature). (http://www.66.com/route66/products.php?cid=US)
- FlightMath - a flight calculator for pilots (Macintosh only) (http://members.macconnect.com/users/b/bobw/flightmath.shtml)
- **GeoTIFF:** Niles Ritter's list of GeoTIFF Format Readers - last updated in 1996, so it's a bit stale. (http://home.earthlink.net/%7Eritter/geotiff/software.html)
- R. Petschick's Assorted (Mac) Software for Geoscientists (http://servermac.geologie.uni-frankfurt.de/Rainerssoftlist.html)
- NGS Homepage - Many resources. (http://www.ngs.noaa.gov/)
- NGS Free Geodetic Software – A veritable slew of free utilities thru the NGS. (http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml)
- FME - a general purpose spatial data translator (Windows). (http://www.safe.com/)

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7) GPS DATA EXTRACTION, MAPPING AND UTILITIES

- Software for Macintosh, Windows, Newton and other machines. (http://www.gpsy.com/gpsinfo/software.html)

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8) DIFFERENTIAL GPS (DGPS)

- U.S. Coast Guard - Navigation Center: Differential GPS for Mariners (and others close enough to get the signal!). (http://www.navcen.uscg.gov/dgps/default.htm)
- Garmin sells consumer DGPS receivers. (http://www.garmin.com/)
- StarLink is a manufacturer of DGPS receivers. (http://ravenind.com/RavenPrecision/gps/index.cfm)

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9) GPS RECEIVER MANUFACTURERS

- Comprehensive list of manufacturers – Alphabetical search index. A good central resource. (http://gauss.gge.unb.ca/manufact.htm)
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- Corvallis Microtechnology - High-accuracy, ruggedized field GPS receivers for GIS work. (http://www.cmtinc.com/)
- DeLorme Publishing - Manufacturers of the Tripmate GPS receiver (for automobile use). (http://www.delorme.com/)
- Eagle GPS – Geared for Anglers. (http://www.eaglegps.com/)

- Garmin- General purpose, boating and aviation GPS receivers. (http://www.garmin.com)
  - Official Garmin Owner's Manuals for all of their receivers. (http://www.garmin.com/manuals/)
  - Purple Project's Garmin GPS connectors. (http://pfranc.com/projects/g45contr/beans.htm)
- Lowrance GPS - Fishing/marine, avionic, and general purpose GPS receivers. (http://www.lowrance.com/)
- Magellan (http://www.magellangps.com/)
- NavTech - Dedicated automobile GPS navigators. (http://www.navteq.com/)
- Northstar Technologies - A long time GPS/Loran-C manufacturer. (http://www.northstarcmc.com/)
- Silva sells under the name Brunton in the U.S. and has a line of GPS receivers with built-in compasses. (http://www.brunton.com/catalog.php)
- Sokkia – http://www.sokkia.com
- Thales - High end GPS and GLOSNASS manufacturer. (http://products.thalesnavigation.com/en/)
- Trimble Navigation Ltd. - makers of Scoutmaster and high-end GPS receivers for avionics, GIS, etc. (http://www.trimble.com/)

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10) INTERNET MAPPING PROGRAMS

- CyberAtlas - By DeLorme (place name and zip code info but no lat/long). (http://atlas.delorme.com/)
- Geocode - By ETAK. (http://www.geocode.com/index.php)
- MapsOnUs - Waypoints, turnpoints, it has it all. (http://www.mapsonus.com/)
- MapQuest - Also does map to lat/long. (http://www.mapquest.com/)
- NIMA GNS (Geographical Name Server). (http://www.nima.mil/gns/html/index.html)
- Geodetic Control Locator - Search NGS vertical (elevation) and horizontal geodetic control points. (http://www.gwi.net/GeodeticControl/)
- Buffalo.edu - Map to lat/long. (http://wings.buffalo.edu/geogw)
- US Census Data – Include lat/long info. (http://tiger.census.gov/)
- GSD Online Demonstration: GSRUG - Geographic to UTM (http://www.geod.nrcan.gc.ca/html-public/GSDapps/English/gsrug-gtou.html)
- USGS National Mapping Info (http://mapping.usgs.gov/)
- National Imagery and Mapping Agency (NIMA - http://www.nima.mil/)
- Color Landform Maps of the US (http://fermi.jhuapl.edu/states/about.html)
- FCC Topographic Databases (ftp://ftp.fcc.gov/pub/Bureaus/Mass_Media/Databases/)
- Trails in VT - An excellent resource for people using various trails in VT. (http://www.americantrails.org/resources/statetrails/VTstate.html)

- Univ. of CT - Map And Geographic Information Center. (http://magic.lib.uconn.edu/)
- Rand McNally – Atlas gurus. (http://www.randmcnally.com/home)

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11) MAPS ON CD-ROM & MAP VENDORS

- MapTech Charts (formerly BSB/ChartKit) - NOAA charts in CD-ROM format. (http://www.maptech.com/)
- TOPO Maps on CD-ROM (http://www.topo.com/)
- PepperWhite - Supplier of mapping and geographic information system components for software developers. (http://www.pepperwhite.com/)
- Spot Image - images from French SPOT Satellites ($295++). (http://www.spot.com/)

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12) DISTANCE/BEARING/GREAT CIRCLE CALCULATORS

- Javascript Great Circle Calculator **-** Compute true course and distance between points with lat/long inputs. (**http://www.best.com/%7Ewilliams/gccalc.htm**)

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*

While state law requires that all GPS data captured in Vermont store coordinate values in the Vermont Coordinate System, adjusted to the North American Datum of 1983 (VCS83)[17], for publicly funded projects, it does not suggest that all GPS data be "tied into" or "benchmarked" to known, surveyed control points to derive true accuracy. These are two separate

[17] According to Title 1 of Vermont Statutes Annotated, Chapter 17, sections 671-679, the VCS "is a transverse Mercator projection of the GRS 80 ellipsoid, having a central meridian 72 degrees 30 minutes west of Greenwich…".

issues and as stated earlier this document does not cover surveying grade accuracies or methods and only covers the determination of relative accuracy.

This accuracy standard pertains to the VCS83[18] with units in meters, and provides a means to estimate both horizontal and vertical absolute coordinates. For details and links on the VCS83 refer to Section A: IV. 4. COORDINATE SYSTEMS, PROJECTIONS, DATUMS/SPHEROIDS.

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 application 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

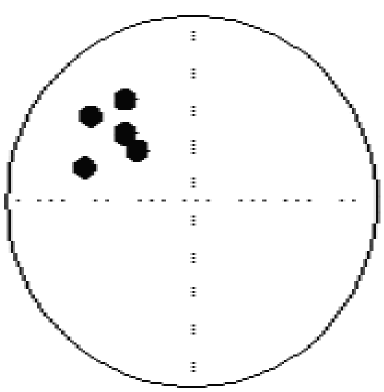


Figure B-2: Accurate but not precise

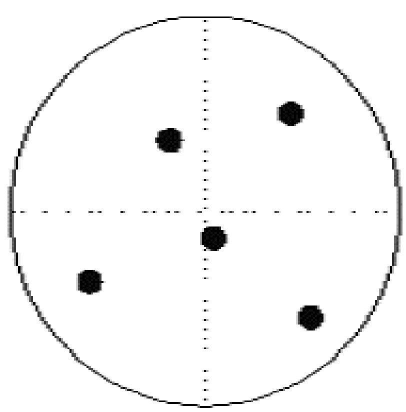
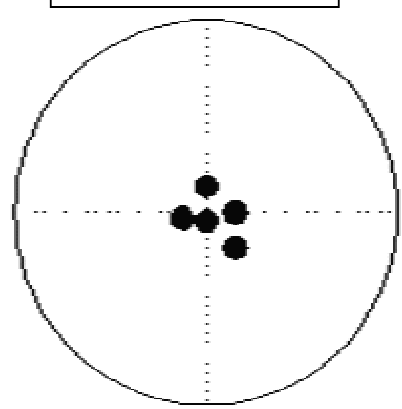


Figure B-3: Precise AND accurate



[18] According to Title 1 of Vermont Statutes Annotated, Chapter 17, sections 671-679, the VCS "is a transverse Mercator projection of the GRS 80 ellipsoid, having a central meridian 72 degrees 30 minutes west of Greenwich…".

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); 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).

The different relative accuracy classes listed in Table B- 2 *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[19] (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). 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.

1) 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

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

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*

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

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.

2) *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.”[20]

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.”

Reporting

This value can be reported in one of two ways, refer to either the FGDC NSSDA standard or the MLMIC’s Positional Accuracy Handbook[21] 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

[20] MLMIC. Positional Accuracy Handbook. pp. 8.
[21] MLMIC. Positional Accuracy Handbook. pp. 7.

(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.

3) 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.

There are two CORS stations in Vermont, the "VERMONT CAPITAL CORS PHASE CENTER" (VCAP - http://vcap.aot.state.vt.us/pages/cors.htm) and "UVM COOLIDGE CORS" (VTUV – website to be active 6/05), and three nearby CORS stations; HDF1 – Hudson Falls, NY; NHDT – Concord, NH; and HAMP – Northampton, MA. Of these stations, only VCAP and VTUV record base data every second while **the others having a five second sampling rate.**[22]

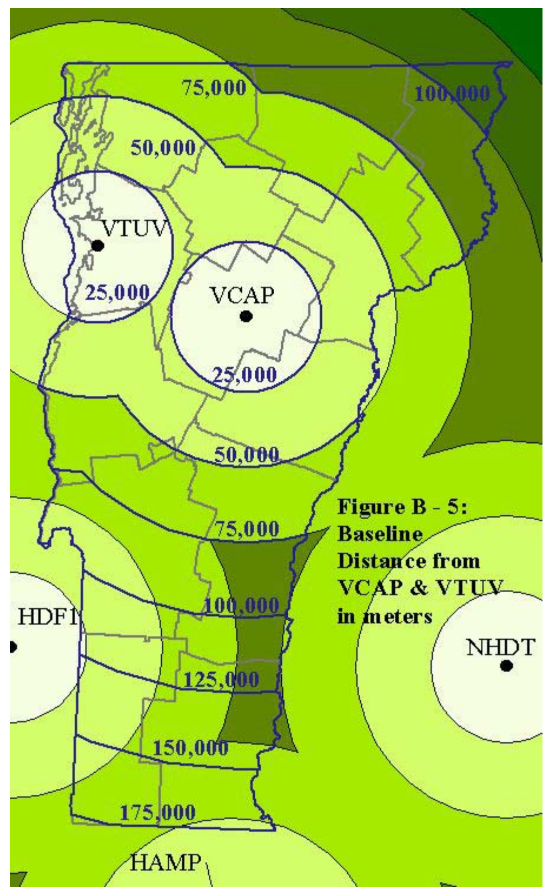


Figure B - 5: Baseline Distance from VCAP & VTUV in meters

[22] Using these base stations would require your GPS unit sampling interval to be set to 5 seconds

Distance from Base Station (m)	PPM Baseline Error (m)			
	GPS Unit rating			
	1ppm	**2ppm**	**5ppm**	**10ppm**
25,000	0.03	0.05	0.13	0.25
50,000	0.05	0.10	0.25	0.50
75,000	0.08	0.15	0.38	0.75
100,000	0.10	0.20	0.50	1.00
125,000	0.13	0.25	0.63	1.25
150,000	0.15	0.30	0.75	1.50
175,000	0.18	0.35	0.88	1.75

Figure B-4: PPM Baseline Error

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. Figure B-4 details the level of error associated with varying distances from the four closest CORS stations and Figure B-5 shows these distances graphically. The baseline error for the VCAP station is represented in blue thick lines while the color-shaded regions represent distances from any of the four CORS stations. It is possible to keep the baseline error to within those values shaded in grey in Figure B-4 if alternatives to the VCAP station are used. This is feasible in the southern third of Vermont where neighboring states have CORS stations that are closer than VCAP but these stations do not record base data every second and require that a data collection of at least five seconds be used. While this is a perfectly viable option it comes with the overhead of increased observation times, e.g., 30 fixes with a 5 second collection rate requires 150 seconds per feature vs. 30 seconds for a 1 second collection rate. See the CORS map (http://www.ngs.noaa.gov/CORS/cors-data.html) for base station locations nationwide.

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 stations with a one second sampling interval are located in Montpelier, VT (VCAP) and Burlington, VT (VTUV) and permit 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"). The CORS stations in surrounding states are desirable in the southern part of the state where baseline errors from VCAP and VTUV 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 – CONTENT SPECIFICATIONS

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.

Once the specifications section has been integrated into the technical section of a Contracting Agencies RFP, the following resource available from VCGI can provide a starting point for creating a distribution list for the RFP - GIS Consultants List for VT and the surrounding region. (http://www.vcgi.org/commres/publications/consultants_04.pdf)

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).
VCGI	Vermont Center for Geographic Information, Inc. (maintains the VGIS)
VCS	Vermont Coordinate System

VGIS	Vermont Geographic Information System
VTAC-GPS	GPS Users Committee established by VT Technical Advisory Committee

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

required	Used to describe tasks that are deemed necessary and are good practice. Exceptions are possible, but only after ***careful*** consideration by the Contracting Agency.
recommended	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 section 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

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 (when applicable); and reporting techniques. All parts of the System are to be capable of meeting the contractual specifications below.

2) 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.

3) 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.

4) 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 field work. For a large enough project the validation exercise could simultaneously provide an additional means of assessing a Contractors 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 ***V. Validation Surveys*** below.

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 tradition 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 Validation Survey* resides in *Appendix H* 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 field work and must accompany the deliverables. Regardless, the parameters outlined in the specifications must be followed for both pre-qualification and contracted field work.

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), these can be identified using the Vermont Geodetic Survey web application the Vermont OnLine Geodetic Information System **(VOLGIS -** http://vtransmap.aot.state.vt.us/website/geodetic/newmap2.asp?action=Zoo**)**. 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. STANDARD GPS DATA COLLECTION METHOD CODES

The following "collection method" codes define how data is captured using GPS tools. Including the "GPSCODE" field and the respective collection method choices in a data dictionary provides insight to the accuracy of the resulting data. If the same approach is used for each field data collection effort, e.g., same GPS receiver and correction method, then a default code can be set to avoid having to enter the code for each feature. However, if different features are collected using different methods than this provides the flexibility to detail them.

GPSCODE	GPS POSITIONING CODE
GPS01	Survey grade receiver stationary during data collection (i.e., carrier phase static relative position).
GPS02	Survey grade receiver moves during data collection (carrier phase kinematics relative position).
GPS03	Mapping/resource grade receiver with real-time differential correction (pseudo range differential GPS or "DGPS").
GPS04	Mapping/resource grade receiver with post-processing differential correction.
GPS05	Recreational grade receiver with real-time differential correction (pseudo range differential GPS or "DGPS").
GPS06	Mapping/resource or recreational grade receiver with no differential correction (pseudo range standard position).
GPS07	GPS receiver grade and/or differential correction procedures unknown.
GPS08	L1 Carrier Smooth Code/Phase processing

Table VI-1 GPS Data Collection Codes

VII. PRE-FIELDWORK PROCEDURES

1) 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.

2) 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.

3) 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.

4) 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.

5) 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.

6) Legal Boundaries

GPS technology cannot be used to legally define parcel boundaries in Vermont unless the operator is a licensed land surveyor as defined by Vermont Statute[23]. 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.

7) *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.

VIII. FIELDWORK

1) *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

2) *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		

[23] Vermont Statutes : TITLE 26 Professions and Occupations : CHAPTER 45. LAND SURVEYORS :

- ❖ 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) 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.

IX. GPS BASE STATION

It is highly ***recommended*** that users employ a CORS station either within Vermont, e.g., "VCAP", or one of the three CORS stations in the three 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.

X. 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.

XI. 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.

1) 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 VALIDATION REPORT located in Appendix G 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:
  - GPS hardware (i.e. models, receivers numbers, data loggers, antennas, firmware versions, etc.);
  - GPS software (i.e. name, version number, settings, etc.);
  - mapping software (i.e. name, version number, settings, etc.); and
  - 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."[24]

2) *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, VSC and meters.
- Scale bar
- North arrow with either or both True North and Magnetic North.
- VCS 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.

3) *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.

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

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 XI-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		VCS83	Unedited
Final Interpreted GPS Data		VCS83	Edited

Table XI-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.

4) 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.[25]

5) QUALITY ASSURANCE

All data submitted by the Contractor shall be validated by the Contracting Agency following guidelines in Section IV.4 Quality Assurance and Audit before integration with existing databases.

6) 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.

7) 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 of 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.

[25] Vermont Statutes : TITLE 1 General Provisions : CHAPTER 5. COMMON LAW; GENERAL RIGHTS : Subchapter 3. Access to Public Records

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

XII. 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.

- The Contractor and the Contract Administrator ***recommended*** ensure that the most current versions of the VERMONT GPS GUIDELINES are used

LIST OF APPENDICES

APPENDIX A - REFERENCES

British Columbia, Canada. Ministry of Sustainable Resource Management; Base Mapping and Geomantic Services Branch. British Columbia Standards, Specifications and Guidelines for *Resource Surveys* Using Global Positioning System (GPS) Technology. Victoria, BC, Canada. ISBN 0-7726-4547-7.

Georgia Department of Transportation. GPS Data Collection Guideline and Standards: A Manual for Georgia Service Delivery Regions and Regional Development Centers. Atlanta, GA. October 2002.

Hurn, J. 1989. GPS: A Guide To The Next Utility. Sunnyvale, CA: Trimble Navigation, Ltd.

Minnesota Planning; Land Management Information Center (MLMIC). Positional Accuracy Handbook. St. Paul, MN. <http://www.mnplan.state.mn.us/pdf/1999/lmic/nssda_o.pdf>

United States Geological Survey (USGS); Federal Geographic Data Committee (FGDC). Content Standard For Digital Geospatial Metadata. Reston, VA. 1998: Electronic document available for download or viewing at: http://www.fgdc.gov/standards/status/textstatus.html

United States Geological Survey (USGS); Federal Geographic Data Committee (FGDC). Geospatial Positioning Accuracy Standards; Part 3: National Standard for Spatial Data Accuracy. Reston, VA. 1998. Electronic document available for download or viewing at: http://www.fgdc.gov/standards/documents/standards/accuracy/chapter3.pdf

Wisconsin Department of Natural Resources. Comparing Global Position System (GPS) Tools. Madison, WI. 02/09/2001.

Wisconsin Department of Natural Resources. WIDE AREA AUGMENTATION SYSTEM (WAAS). Madison, WI. 06/22/2001.

Vermont Center for Geographic Information, Inc. (VCGI). 1998. *Vermont Coordinate System (VCS)*. Waterbury, Vermont: Vermont Statutes Annotated 1. General, Chapter 17, subsection 671-679. Electronic document available for viewing at: http://www.vcgi.org/techres/standards/partii_section_b.pdf

Vermont Center for Geographic Information, Inc. (VCGI). VGIS HANDBOOK; PART 3 – GUIDELINES SECTION A; MUNICIPAL PROPERTY MAPPING. Electronic document available for viewing at: http://www.vcgi.org/techres/standards/partiii_section_a.pdf.

APPENDIX B - LIST OF ACRONYMS

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

1D, 1-D	One-dimensional
2D, 2-D	Two-dimensional
2DRMS	Twice the distance RMS (Root Mean Square)
3D, 3-D	Three-dimensional
A-S	Anti-Spoofing (encryption of the P- code to the Y- code)
BC	British Columbia
BC ACS	British Columbia Active Control System
BCGS	British Columbia Grid System
BCGSR	British Columbia Geo-Spatial Reference
B.C.L.S.	British Columbia Land Surveyor
C/A	Coarse/Acquisition GPS signal (civilian)
CAD	Computer Aided Design
CEP	Circular Error Probable (50% confidence)
DGPS	Differential GPS
DOP	Dilution Of Precision
DRMS	Distance Root Mean Square (see 2DRMS)
DXF	Drawing eXchange Format (AutoCAD’s open format)
ECEF	Earth-Centered, Earth-Fixed
EDOP	East DOP
FPC	Forest Practices Code
FRBC	Forest Renewal BC
GALILEO	Proposed European satellite navigation system
GCM	Geodetic Control Monument
GDBC	Geographic Data BC, Ministry of Environment, Lands and Parks
GDOP	Geometric DOP (3D plus Time)
GIS	Geographic Information System
GLONASS	GLObal NAvigation Satellite System (Russian GPS counterpart system)
GPS	Global Positioning System (also called NAVSTAR)
GRS	Geodetic Reference System
GSD	Geodetic Survey Division, Natural Resources Canada (NRCan)
GSD95	Geodetic Survey Division 95 geoid model for NAD83 ellipsoid to CVD28 orthometric height conversion
GSR	Geo-Spatial Reference
GSRU	Geo-Spatial Reference Unit, Geographic Data BC, Ministry of Environment, Lands and Parks
HDOP	Horizontal DOP (2D)
HT97	Modified geoid model based on GSD95
Hz	Hertz (1/second)
IERS	International Earth Rotation Service
IGDS	Interactive Graphic Design System
INCOSADA	INtegrated COrporate Spatial and Attribute DAtabase (MoF)
I/O	Input/Output
ISA	Integrated Survey Area
ITRF	International (IERS) Terrestrial Reference Frame
L1	GPS L-band signal 1 (1575.42 MHz)
L2	GPS L-band signal 2 (1227.6 MHz)
L5	GPS L-band signal 5 (1176.45 MHz)…planned new civilian frequency & code
LAAS	Local-Area Augmentation Service
LADGPS	Local-Area Differential GPS
L-band	L-band frequency (about 1-2GHz) of the electromagnetic spectrum

MGSR	Municipal Geo-Spatial Reference
MoELP	Ministry of Environment, Lands and Parks
MoF	Ministry of Forests
MSL	Mean Sea Level
NAD27	North American Datum 1927
NAD83	North American Datum 1983
NANU	Notice Advisory to NAVSTAR (GPS) Users
NAVD88	North American Vertical Datum of 1988
NAVSTAR	NAVigation Satellite Timing And Ranging (original acronym for GPS)
NDOP	Northing DOP
NRCan	Natural Resources Canada
OEM	Original Equipment Manufacturer
P-code	Precise code – provided for military GPS users and selected others
PDOP	Position DOP (3D)
PoC	Point of Commencement
PoT	Point of Termination
PPM	Part Per Million (i.e. 1mm per 1km)
PPS	Precise Positioning Service (military)
PR	Pseudorange
PRC	Pseudorange Correction
PRN	Pseudo Random Noise (unique code for each satellite)
PSGUC	Public Sector GPS Users Committee
QA	Quality Assurance
QC	Quality Control
RIB	Resources Inventory Branch, Ministry of Forests
RIC	Resource Inventory Committee
RINEX	Receiver INdependent EXchange format
RMS	Root-Mean-Square
RTCA	Radio Technical Commission for Aeronautical services
RTCM	Radio Technical Commission for Maritime services
RT-DGPS	Real Time Differential GPS
RTEB	Resource Tenure and Engineering Branch, Ministry of Forests
RRC	Rate of the Range Correction (broadcast by RT-DGPS systems)
Rx	Receiver (i.e. GPS Rx)
SA	Selective Availability (removed 2nd May, 2000)
SAIF	Spatial Archive and Interchange Format (GDBC-MoELP)
SEP	Spherical Error Probable (50% confidence)
SNR	Signal to Noise Ratio
SPS	Standard Positioning Service (civilian)
TDOP	Time DOP
TRIM	Terrain Resource Integrated Management
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator
VSC	Vermont State Coordinates (NAD83; meters)
VDOP	Vertical DOP (1D)
WAAS	Wide-Area Augmentation Service
WADGPS	Wide-Area Differential GPS
WGS84	World Geodetic System 1984
Y-code	Encrypted P code (Anti-Spoofing)

APPENDIX C - GLOSSARY

A large majority of this appendix is based on Appendix A of the *"British Columbia Standards, Specifications and Guidelines for Resource Surveys Using GPS Technology"* document, with some minor reformatting.

95% Confidence Level
The region of certainty, centered on the estimated coordinate, within which the true coordinate falls 95% of the time - a 95% accuracy estimate.

Accuracy
The degree of conformance between the estimated or measured position, time, and/or velocity of a GPS receiver and its true time, position, and/or velocity as compared with a constant standard. Radio navigation system accuracy is usually presented as a statistical measure of system error and is characterized as follows:

Predictable - The accuracy of a radio navigation system's position solution with respect to the charted solution. Both the position solution and the chart must be based upon the same geodetic datum.

Repeatable - The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.

Relative - The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time.

Almanac
An almanac is a set of orbit parameters that allows calculation of approximate GPS satellite positions and velocities. The almanac is used by a GPS receiver to determine satellite visibility and as an aid during acquisition of GPS satellite signals.

Altitude
Altitude is the vertical distance above the ellipsoid or the geoid. It is always stored as height above the ellipsoid in the GPS receiver but can be displayed as height above ellipsoid (HAE) or height above mean sea level (MSL).

Analog
A type of transmission characterized by variable waveforms representing information, contrasted with digital. A standard clock with moving hands is an analog device, whereas a clock with displayed and changing numbers is a digital device. The human voice and audible sounds are analog. Modern computers are invariably digital, but when they communicate over telephone lines, their signals must be converted to analog using a modem (a modulator/demodulator). The analog signal is converted back into a digital form before delivering it to a destination computer.

Anti-Spoofing (A/S)
The method by which the US military uses of encrypting (i.e. denying) the precise-code, or P-code, to non-authorized users. The encrypted P-code is called the Y-code.

Application Software
These programs accomplish the specialized tasks of the user, while operating system software allows the computer to work. A computer-aided drafting (CAD) system is application software, as is a word processing program.

Attenuation
The reduction of signal strength.

Attribute
Characteristics of features in a Geographic Information System (GIS) or Coordinate GeOmetry (COGO) package. Every identifiable feature has attributes. One common attribute of all survey features is geographic position.

Automatic Vehicle Location (AVL)
A type of system using various technology to track or locate a vehicle.

Availability
The percentage of time that the services of a navigation system can be used within a particular coverage area. Signal availability is the percentage of time that navigational signals transmitted from external sources are available for use. Availability is a function of both the physical characteristics of the operational environment and the technical capabilities of the transmitter facilities.

Azimuth
Azimuth is the horizontal direction of a celestial point from a terrestrial point, expressed as the angular distance from 000° (reference) clockwise through 360°. The reference point is generally True North, but may be Magnetic North, Grid North, or Relative (ship's heading).

Baseline
In the context of these specifications and procedures presented, a baseline consists of a pair of stations for which simultaneous GPS data has been collected and precise 3D vector is computed. Baselines are typically not processed for Resource-type mapping surveys.

Base Station
See GPS Reference Station

Bandwidth
The range of frequencies in a signal.

Bearing
The bearing is the horizontal direction of one terrestrial point from another terrestrial point, expressed as the angular distance from a reference direction, usually measured from 000° at the reference direction clockwise through 360°. The reference point may be True North, Magnetic North, Grid North, or Relative (ship's heading).

Block I, II, IIR, IIR-M, IIF, III Satellites
The various generations of GPS satellites: Block I were prototype satellites that began being launched in 1978; 24 Block II satellites made up the fully operational GPS constellation declared in 1995; Block IIR are replenishment satellites (1998 to current); Block IIR-M and IIF are modified (modernized) replenishment satellites scheduled for launch after ~2003; and Block III refers to the next generation satellites (beyond 2010).

Broadcast Message
Information modulated onto the carrier frequencies. This information includes satellite health, clock corrections, the almanac for all satellites, orbit parameters (ephemeris) for individual satellites, and special messages.

C/A Code
The Coarse/Acquisition or clear/acquisition code modulated onto the GPS L1 signal. This code is a sequence of 1023 pseudo-random binary biphase modulations on the GPS carrier at a chipping rate of 1.023 MHz, thus having a code repetition period of 1 millisecond. The code was selected to provide good acquisition properties. Also known as the "civilian code".

Cadastral Boundary
A boundary of a parcel of land; also includes right-of-ways; easements; leaseholds; parks; and certain administrative boundaries.

Carrier
A radio wave having at least one characteristic (i.e. frequency, amplitude, phase), which may be varied from a known reference value by modulation.

Carrier-Aided Tracking
A signal processing strategy that uses the GPS carrier signal to achieve an exact lock on the pseudo-random code. Also known as Carrier-Aided Smoothing.

Carrier Frequency
The frequency of the unmodulated fundamental output of a radio transmitter.

Carrier Phase Measurement
The measurement of the change of phase, of an observed electromagnetic signal (the carrier frequency), with time. GPS measurements based on the L1 or L2 carrier signal.

Channel
A channel of a GPS receiver consists of the circuitry necessary to receive the signal from a single GPS satellite. (Hurn, J. 1989)

Chip
The length of time to transmit either a "0" or a "1" in a binary pulse code.

Chip Rate
Number of chips per second. For example, C/A code = 1.023 MHz.

Circular Error Probable (CEP)
Also known as Circular Error of Probability. In a circular normal distribution, the radius of the circle containing 50 percent of the individual measurements being made, or the radius of the circle within which there is a 50 percent probability of being located. CEP is the two-dimensional analogue of SEP.

Civilian Code
See C/A code.

Clock Bias
The difference between the clocks indicated time and true universal time.

Clock Offset
Constant difference in the time readings between two clocks.

Code Division Multiple Access (CDMA)
A method of frequency reuse whereby many radios use the same frequency but each one has a unique code. GPS uses CDMA techniques with Gold's codes for their unique cross-correlation properties.

Codeless Receiver
A receiver that does not require the ability to decipher the coded signal modulated onto the carrier signal. Rather, it uses carrier or code phase information only.

Code Phase GPS
GPS measurements based on the C/A code.

Computer-Aided Dispatch
An automated system for processing dispatch business and automating many of the tasks typically performed by a dispatcher. Abbreviated CAD (not to be confused with computer-aided design, which is also known as CAD) is application software with numerous features and functions. A basic CAD system provides the integrated capability to process calls for service, fleet management and geographical referencing.

Control Segment
A worldwide network of GPS monitor and control stations that ensure the accuracy of satellite positions and their clocks.

Confidence Level
A statistical probability level beyond, which a particular observation *should* be rejected as an outlier. See also 95% Confidence Level.

Continuously Operating Reference Station (CORS)
A network of continuously operating base stations, maintained by the National Geodetic Survey, that provide GPS correction data throughout the United States and its territories. See website at http://www.ngs.noaa.gov/CORS/.

Coordinates
Pairs of numbers expressing horizontal distances along orthogonal axes. (U.S. Geological Survey, 1998). ***Note:*** Refers to *x-y* coordinates.

Coordinate System
A reference system used to measure horizontal and vertical distances enabling features to be defined in projected space. A coordinate system is defined by three primary components, a map projection, a spheroid of reference and a datum. A projection provides the flat, two-dimensional surface upon which x,y values can be measured using information established by the datum. Related items - "Datum" and "Map Projection".

Course
The Course is the horizontal direction in which a vessel is to be steered or is being steered, the direction of travel through the air or water. Expressed as angular distance from reference North (either true, magnetic, compass, or grid), usually 000° (north), clockwise through 360°. Strictly, the term applies to direction through the air or water, not the direction intended to be made good over the ground (see *track*). Differs from heading.

Course Made Good (CMG)
Course-Made-Good is the single resultant direction from a given point of departure to a subsequent position, the direction of the net movement from one point to the other. This often varies from the track caused by inaccuracies in steering, currents, crosswinds, etc. This term is often considered to be synonymous with Track Made Good, however, track made good is the more correct term.

Course Over Ground (COG)
Course-Over-Ground is the actual path of a vessel with respect to the Earth (a misnomer in that courses are directions steered or intended to be steered through the water with respect to a reference meridian); this will not be a straight line if the vessel's heading yaws back and forth across the course.

Coverage Window
The period of time during which GPS satellites are above the horizon and "visible" to the observer.

Cross Track Error (XTE)
Cross-Track-Error is the distance from the vessel's present position to the closest point on a great circle line connecting the current waypoint coordinates. If a track offset has been specified in the GPS unit, the cross track error will be relative to the offset track great circle line.

Cycle Slip
A cycle slip is a discontinuity of an integer number of cycles in the measured carrier beat phase resulting from a momentary loss-of-lock in the carrier-tracking loop of a GPS receiver.

Data Dictionary: A menu of standard feature attributes (i.e., data elements) loaded on a GPS receiver and used to simplify and standardize data collection in the field. The data dictionary also defines the fill requirements, default values, and valid codes/values for each attribute.

Data Message
A message included in the GPS signal that reports the satellite's location, clock corrections and health. Included is approximate information (almanac) about the other satellites in the constellation.

Datum
A mathematically defined reference surface, e.g., "coordinate system", used to represent the size and shape of the Earth.. In particular a geodetic datum, chart datum, or tidal datum. With respect to GPS, a convention using ellipsoid to model the earth in an area (local or global); usually defined by monuments on the ground. A horizontal datum provides a frame of

reference for measuring locations on the surface of the Earth and a vertical datum provides for elevation or vertical measures. Related items - "Coordinate System" and "Map Projection".

Dead Reckoning (DR)
Dead reckoning is the process of determining a vessel's approximate position by applying from its last known position a vector or a series of consecutive vectors representing the run that has since been made, using only the courses being steered, and the distance run as determined by log, engine rpm, or calculations from speed measurements.

Differential Correction (Differential GPS, i.e., DGPS)
A technique used to improve positioning or navigation accuracy by determining the positioning error at a known location and subsequently incorporating a corrective factor (by real-time transmission of corrections or by post-processing) into the position calculations of another receiver operating in the same area and simultaneously tracking the same satellites.

Digital
Generally, information is expressed, stored and transmitted by either analog or digital means. In a digital form, this information is seen in a binary state as either a one or a zero, a plus or a minus. The computer uses digital technology for most actions.

Dilution of Precision (DOP)
A description of the purely geometrical contribution to the uncertainty in a position determination, given by the expression

$$DOP = \mathrm{Trace}(A^{T}A)^{-1},$$

where … A is the design matrix for the solution (dependent on satellite/receiver geometry).

The dimensional DOP factor depends on the parameters of the position solution. Standard terms in the case of GPS are:

GDOP	Geometric DOP - three position coordinates plus clock offset
PDOP	Position DOP - three coordinates
HDOP	Horizontal DOP - two horizontal coordinates
NDOP	Northing DOP – northing only
EDOP	Easting DOP – easting only
VDOP	Vertical DOP - height only
TDOP	Time DOP - clock offset only
HTDOP	Horizontal/Time DOP - horizontal coordinates and clock offset.
RDOP	Relative DOP normalized to 60 seconds.

Distance Root-Mean-Square (DRMS or 2 DRMS)
The Root-Mean-Square value of the distances from the true location point of the position fixes in a collection of measurements. As typically used in GPS positioning, 2 DRMS is the radius of a circle that contains at least 95 percent of all possible fixes that can be obtained with a system at any one place.

Dithering
The introduction of digital noise. This is the process the DoD used to add inaccuracy to GPS signals to induce Selective Availability (SA). SA was discontinued on May 2nd, 2000.

Doppler-Aiding
A signal processing strategy that uses a measured Doppler shift to help the receiver smoothly track the GPS signal. Allows more precise velocity and position measurement.

Doppler Shift
The apparent change in the frequency of a signal caused by the relative motion of the transmitter and receiver.

Dynamic Traverse
Linear mapping where the GPS receiver is constantly observing (collecting data) while being moved along some line.

Earth-Centered Earth-Fixed (ECEF)

A right-hand Cartesian coordinate system with its origin located at the centre of the Earth -- the coordinate system used by GPS to describe three-dimensional location. ECEF coordinates are centered on the WGS-84 reference ellipsoid, have the "Z" axis aligned with the Earth's spin axis, the "X" axis through the intersection of the Prime Meridian and the Equator and the "Y" axis is rotated 90 degrees East of the "X" axis about the "Z" axis.

Elevation

The perpendicular distance of a feature above or below a vertical datum, as defined in Federal Information Processing Standard 70-1. (modified from U.S. Geological Survey, 1998). ***Note:*** "Altitude" is often used to describe the distance of a feature above a vertical datum, while "depth" refers to distance of a feature below a vertical datum.

Elevation Angle

The elevation angle, or mask angle, is the angle below which satellites should not be tracked. Normally set to 15 degrees by rover receivers to limit propagation and multipath errors.

Ellipsoid

In geodesy, a mathematical figure formed by revolving an ellipse about its minor axis. It is often used interchangeably with spheroid. Two quantities define an ellipsoid, the length of the semi-major axis, a, and the flattening, f = (a-b)/a, where b is the length of the semi-minor axis.

Ellipsoid Height

The geometrical The ellipsoid height is the height above or below the reference ellipsoid, i.e., the distance between a point on the Earth's surface and the ellipsoidal surface, as measured along the normal (perpendicular) to the ellipsoid at the point and taken positive upward from the ellipsoid. This is the height obtained from GPS surveys (including LIDAR and IFSAR which utilize airborne GPS), prior to corrections for the undulation of the geoid. GPS receivers output position fix height in the WGS-84 datum.

Ephemeris

A list of accurate positions or locations of a celestial object (i.e. GPS satellite) as a function of time. Available as "broadcast ephemeris" or as post-processed "precise ephemeris". GPS ephemeris is necessary for all methods of receiver positioning.

Ephemeris Message Block

The block of ephemeris information which is modulated upon the carrier frequency. This block contains the Keplerian elements of the orbit and the deviations of the actual orbit away from the Keplerian representation. This message is intended to describe the orbit for a 1.5-hour period.

Epoch

A moment in time when a GPS receiver is logging data. It also refers to the measurement interval or data frequency, as in making observations every 15 seconds. "Loading data using 30-second epochs" means loading every other measurement (if observations are collected at 15second intervals).

Fast-Multiplexing Channel

See Fast-switching channel

Fast-Switching Channel

A single channel that rapidly samples a number of satellites ranges. "Fast" means that the switching time is sufficiently fast (2 to 5 milliseconds) to recover the data message.

Feature

A natural or man-made object, formation, or boundary of Earth.

Fiducial Point

A fiducial point is one of a small number of points in the network, which is used as a master or monitor station and is continuously occupied throughout several observing sessions. All independent baselines observed during those particular observing sessions then radiate outwards from this point. This does not generally apply to resource surveys.

Field Receiver
The field receiver, or rover, is the GPS receiver mapping locations to be computed during a GPS field survey.

Frequency Band
A particular range of frequencies.

Frequency spectrum
The distribution of signal amplitudes as a function of frequency.

Geodesy
The science related to the determination of the size and shape of the Earth and its gravity field.

Geodetic Datum
A mathematical model designed to best-fit part or all of the geoid. It is defined by an ellipsoid and the relationship between the ellipsoid and a point on the topographic surface established as the origin of datum.

Geodetic Control Monument (GCM)
A geodetic control monument is a monument with precisely known coordinates defining a local datum. It may be known in one, two-, or three-dimensions. A one-dimension control monument (only elevation is known) is also known as a Bench Mark (BM).

Geographic Information System
A system of software, hardware, data, and people used to collect, analyze, manage, and display locational and attribute data about features.

Geoid
The particular equipotential surface that coincides with mean sea level and that may be imagined to extend through the continents. This surface is everywhere perpendicular to the force of gravity.

Geoid Height
The height above the geoid is often called elevation above mean sea level.

Geostationary
A satellite orbit along the equator that results in a constant fixed position over a particular reference point on the earth's surface (GPS satellites are not geostationary).

Global Navigation Satellite System (GNSS)
A generic term describing space-based positioning systems (includes GPS, GLONASS, GALILEO, etc).

Global Positioning System (GPS)
The U.S. Department of Defense's Global Positioning System (GPS): A constellation of ~24 satellites orbiting the earth at a very high altitude. GPS satellites transmit signals that allow the user to determine, with great accuracy, the locations of GPS receivers. The receivers can be fixed on the Earth, in moving vehicles, aircraft, or in low-Earth orbiting satellites. GPS is used in air, land and sea navigation, mapping, surveying and other applications where precise positioning is necessary.

GPS ICD-200
The GPS Interface Control Document is a government document that contains the full technical description of the interface between the satellites and the user.

GPS Reference Station
A GPS receiver (and associated equipment) set up over a highly accurate, surveyed point. A base station may be permanent (e.g., Continuously Operating Reference Stations – CORS) or temporary (i.e., set up for a particular project). Data from the base station is used to correct errors in rover data, using either post-processing or real-time techniques.

Great Circle
The Great Circle route is the shortest distance between any two points along the surface of a sphere or ellipsoid, and therefore the shortest navigation distance between any two points on the Earth. Also called Geodesic Line.

Hand-over Word (HOW)
The word in the GPS message that contains synchronization information for the transfer of tracking from the C/A- to the P-code.

Hardware
The physical components of a computer system. Reference is often made to "hardware" and "software"; in that context, "hardware" consists of the computer, input and output devices and other peripheral equipment.

Heading
Heading is the direction in which a vessel points or heads at any instant, expressed in degrees 000° clockwise through 360° and may be referenced to True North, Magnetic North, or Grid North. The heading of a vessel is also called the ship's head. Heading is a constantly changing value as the vessel oscillates or yaws across the course due to the effects of the air or sea, cross currents, and steering errors.

Health Word
Inserted into the satellite message, the health word describes the health status of each individual satellite.

Hybrid Traverse
A GPS traverse which combines Dynamic traversing and Point-to-Point traversing.

Independent Baselines
A baseline derived from simultaneous observations at two points, when both sets of observations have not already been used in the formation of other baselines from the same session.

Independent Observing Sessions
Observing sessions for which all random errors are not common (i.e. time duration between occupations; different set-up parameters; etc.).

Ionosphere
The band of charged particles 80 to 120 miles above the Earth’s surface. (Hurn, 1989).

Integrity
The ability of a system to provide timely warnings to users when the system should not be used for navigation as a result of errors or failures in the system.

Interface
A shared boundary between various systems or programs. An interface is also the equipment or device that makes it possible to inter-operate two systems. For example, it is common to interface the 911-telephone system with a computer-aided dispatch (CAD) system. Both hardware and software are needed to provide that interface.

Ionosphere
The band of charged particles 80 to 120 miles above the earth's surface which represent a non-homogeneous and dispersive medium for radio signals.

Ionospheric Delay
A wave propagating through the ionosphere experiences delay. Phase delay depends on electron content and affects carrier signals. Group delay depends on dispersion in the ionosphere as well and affects signal modulation (codes). The phase and group delays are of the same magnitude but opposite sign.

Ionospheric Refraction
The change in the propagation speed of a signal as it passes through the ionosphere. A signal traveling through the ionosphere experiences a propagation time different from that that would occur in a vacuum.

Kalman Filter
A numerical method used to track / predict a time-varying signal in the presence of noise.

L-band
The radio frequency band extending from 1.0 GHz to 2.0 GHz as specified in the *IEEE Radar Standard 521*. The GPS carrier frequencies (1227.6 MHz and 1575.42 MHz) are in the L-band.

L1 Signal
The primary L-band signal transmitted by each GPS satellite at 1572.42 MHz. The L1 broadcast is modulated with the C/A- and P-codes and with the navigation message.

L2 Signal
The second L-band signal is centered at 1227.60 MHz and carries the P-code and navigation message. The C/A code will be modulated on L2 beginning with the Block IIR-M satellites scheduled to begin launching in 2003. This will allow direct civilian access to L2.

L5 Signal
The proposed L-band signal centered at 1176.45 MHz modulated with a new civilian access code. This signal will be available on Block II-F satellites scheduled to begin launching in 2005.

Line Feature
A line formed by connecting two or more GPS position fixes.

Linear Offset
Constant offset distance left or right of a GPS antenna path to a line feature.

Magnetic Bearing
Magnetic Bearing is the bearing relative to magnetic north; compass bearing corrected for deviation.

Magnetic Declination
Magnetic Declination is the angle between the magnetic and geographic meridians at any place, expressed in degrees and minutes east or west to indicate the direction of magnetic north from true north. The magnitude and accuracy of magnetic declination is dependent on geographic position. In Canada the accuracy of Magnetic Declination is about 0.5 degrees in the southern latitude and 1 degree in the northern latitudes.

Magnetic Heading
Magnetic Heading is the heading relative to magnetic north.

Magnetic Variation
Magnetic Variation is a local distortion in the magnetic field. Variation can be caused by natural features (local ore bodies), and also by man-made items (ferrous metals…e.g. screwdriver).

Map Projection
A method of representing the earth's three-dimensional surface as a flat two-dimensional surface. This normally involves a mathematical model that transforms the locations of features on the earth's surface to locations on a two-dimensional surface. Because the earth is three-dimensional, some method must be used to depict the map in two dimensions. Therefore such representations distort some parameter of the earth's surface, be it distance, area, shape, or direction. Related items – “Coordinate System” and “Datum”.

Mask Angle
The mask Angle is the minimum GPS satellite elevation angle accepted /tracked by a receiver. Satellites below this angle will not be used in position solution.

Measurement Error Variance
Measurement variance is the square of the standard deviation of a measurement quantity. The standard deviation is representative of the error typically expected in a measured value of that quantity.

Mobile Data Terminal (MDT)
A device typically installed in a vehicle that consists of a small screen, a keyboard or other operator interface, and various amounts of memory and processing capabilities.

Modem
A modulator/demodulator. When two computers communicate over telephone lines and similar media, digital signals must be converted to analog during transmission, then back again to digital at the destination. Modems are always used in pairs, one at each end. They are rated according to the speed, typically in "bits per second," at which the information can pass through the transmission medium.

Monitor Stations
One of the worldwide groups of stations used in the GPS control segment to track satellite clock and orbital parameters. Data collected at monitor stations are linked to a master control station at which corrections are calculated and from which correction data is uploaded to the satellites as needed.

Multi-channel GPS Receiver
A receiver containing multiple independent channels, each of which tracks one satellite continuously, so that position solutions are derived from simultaneous calculations of pseudoranges.

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

Multiplexing Channel
A receiver channel through which a series of signals from different satellites can be sequenced.

North American Datum 1927 (NAD27)
North American Datum, 1927 is the historical datum selected by co-operating governments in North American to represent the shape of the Earth for the North American continent. It is not a geocentric datum (i.e. origin as the centre of the earth).

North American Datum 1983 (NAD83)
North American Datum, 1983 is the datum selected by co-operating governments in North American to represent the shape of the Earth for the North American continent. NAD83 is a geocentric datum chosen to be accurately aligned with the WGS84 datum.

Nanosecond
One billionth of a second (10^{-9}).

NAV Message
The 1500-bit navigation message broadcast by each GPS satellite at 50 bps on the L1 and/or L2 signals. This message contains system time, clock correction parameters, ionospheric delay model parameters, and the vehicle's ephemeris and health. The information is used to process GPS signals to give user time, position and velocity.

Observation
The period of time over which GPS data is collected simultaneously by two or more receivers.

Observing Session
The period of time during which GPS data is collected simultaneously by two or more receivers.

Orthometric Height
The orthometric height is the height above the geoid as measured along the plumb line between the geoid and a point on the Earth's surface, taken positive upward from the geoid. Orthometric heights are traditionally obtained from conventional differential leveling where survey instruments are leveled to the local direction of gravity.

Outage
The occurrence in time and space of a GPS Dilution of Precision value exceeding a specified maximum and resulting in a deterioration of positioning accuracy.

Parallel Receiver
A parallel receiver is a receiver that monitors four or more satellites simultaneously with independent channels.

P-Code
The Precise (or Protected) GPS code, typically used alone by U.S. and allied military receivers - a very long (about 10^{14} bit) sequence of pseudo-random binary biphase transitions on the GPS carrier at a chip rate of 10.23 MHz which does not repeat itself for about 267 days. Each one-week segment of the P-code is unique to one GPS satellite and is reset each week.

Phase Lock
The technique whereby the phases of an oscillator signal is made to follow exactly the phase of a reference signal. The receiver first compares the phases of the two signals, then uses the resulting phase difference signal to adjust the reference oscillator frequency. This eliminates phase difference when the two signals are next compared.

Point Feature
A single set of coordinates averaged from more than one position fix.

Point Offset
A bearing, distance and an elevation difference (if required) from the remote GPS antenna to a point feature.

Point Positioning
A geographic position produced from one receiver in a standalone mode. Also called “autonomous positioning” or “autonomous positioning”.

Point-to-Point Traverse
A method of traversing (i.e. linear mapping) where the GPS receiver is moved between point features along a line, assuming straight lines between the points.

Polygon Feature
A closed figure connected by closing one or more lines on themselves.

Position Dilution of Precision (PDOP):
A mathematical factor, automatically calculated by GPS receivers, that indicate which satellites are available, and the geometry among them.

Position Fix
A GPS calculated position from four or more simultaneous pseudoranges.

Post-Processing
Differential GPS processed after completion of the GPS field survey, utilizing data collected at a GPS Reference Station to correct the field observations.

Precise Positioning Service (PPS)
The highest level of military dynamic positioning accuracy provided by GPS, using the dual-frequency P-code.

Projection: See “Map Projection”.

Pseudolite
A shortened form of pseudo-satellite is a ground-based differential GPS receiver that simulates and transmits the signal of a GPS satellite, which can be locally used for ranging. The data portion of the signal may also contain differential corrections that can be used by receivers to correct for GPS errors.

Pseudo-Random Noise (PRN)
A sequence of digital 1's and 0's that appear to be randomly distributed like noise but that can be reproduced exactly. Their most important property is a low auto-correlation value for all delays or lags except when they coincide exactly. Each GPS satellite has unique C/A and P pseudo-random noise (PRN) codes.

Pseudorange
A distance measurement, based on the correlation of a satellite-transmitted code and the local receiver's reference code, that has not been corrected for errors in synchronization between the transmitter's clock and the receiver's clock.

Quality Assurance (QA)
Data quality checks performed by the contracting Agency (or other person other than the Contractor) after the GPS survey has been submitted.

Quality Control (QC)
Data quality checks and procedures implemented by the Contractor during and after the GPS survey.

Radio-Navigation
The determination of position or the obtaining of information relative to position, for the purpose of navigation by means of the propagation properties of radio waves. GPS is a method of radio navigation.

Range Rate
The rate of change between the satellite and receiver. The range to a satellite changes due to satellite and observer motions. Range rate can be determined by measuring the Doppler shift of the satellite's carrier signal.

Real-Time DGPS or Differential Correction? (RT-DGPS)
The method by which Differential GPS (DGPS) corrections are transmitted from a GPS Reference Station to a field receiver during the field survey (i.e. in "real-time") for which the positions are corrected on-site.

Receiver Grade: The type (i.e., recreational, mapping/resource, or survey) of GPS receiver, based on its functionality.

Rover Receiver: A GPS receiver (and associated equipment) used in the field to collect feature location and attribute data. Some rover receivers also have a radio receiver for real-time differential correction.
Ruggedized: Equipment that has been reinforced for use in extreme (e.g., temperature) field conditions.

Relative Navigation
A technique similar to relative positioning, except that one or both of the points may be moving. A data link is used to relay error terms to the moving vessel or aircraft to improve real-time navigation.

Relative Positioning
The process of determining the relative difference in position between two locations, in the case of GPS, by placing a receiver over each site and making simultaneous measurements observing the same set of satellites at the same time. This technique allows the receiver to cancel errors that are common to both receivers, such as satellite clock and ephemeris errors, propagation delays etc.

Reliability
The probability of performing a specified function without failure under given conditions for a specified period of time.

Residual
In the context of measurements, the residual is the misclosure between the calculated measurements (using the position solution) and actual measurements.

RINEX
Receiver INdependent EXchange format. A set of standard definitions and formats that permits interchangeable use of GPS and GLONASS data from dissimilar GPS receiver models or post-processing software. The format includes definitions for time, phase, and range.

Root-Mean-Square (RMS)
Root-Mean-Square denotes that approximately 68% (1 sigma) of the positions are within a specified value.

Route
A planned course of travel usually composed of more than one navigation leg.

Rover
The field GPS receiver. The receiver performing the surveying/mapping tasks.

RTCM-Age
In real-time differential GPS this is the time between the GPS receivers receipt of a satellite signal and receipt of the base stations corresponding correction value for that same signal. This "lag" is a result of the time required for the base station to acquire, process and transmit the signal and corresponding correction value.

Satellite Configuration
The geometry of the satellite constellation at a specific time, relative to a specific geographic position (i.e. user).

Satellite Constellation
The arrangement in space of a set of satellites. In the case of GPS, the fully operational constellation is composed of four orbital planes, each containing six satellites. GLONASS has three orbital planes containing eight satellites each.

Selective Availability (SA)
A DoD program that controls the accuracy of pseudorange measurements, degrading the signal available to non-qualified receivers by dithering the time and ephemeris data provided in the navigation message. SA was discontinued on May 2nd, 2000.

Sequential Receiver
A GPS receiver in which the number of satellite signals to be tracked exceeds the number of available hardware channels. Sequential receivers periodically reassign hardware channels to particular satellite signals in a predetermined sequence.

Sigma
See Standard Deviation.

Signal-To-Noise Ratio (SNR)
A measure of the signal strength.

Simultaneous Measurements
Measurements referred to time frame epochs that are either exactly equal or else so closely spaced in time that the time misalignment can be accommodated by correction terms in the observation equation, rather than by parameter estimation.

Space Segment
The portion of the GPS system that is located in space, that is, the GPS satellites and any ancillary spacecraft that provide GPS augmentation information (i.e., differential corrections, integrity messages, etc.).

Spheroid
Sometimes known as ellipsoid - a perfect mathematical figure that very closely approximates the geoid. Used as a surface of reference for geodetic surveys. The geoid, affected by local gravity disturbances, is irregular.

Spread Spectrum
The received GPS signal is wide-bandwidth and low power (-160 dBW). The L-band signal is modulated with a PRN code to spread the signal energy over a much wider bandwidth than the signal information bandwidth. This provides the ability to receive all satellites unambiguously and to give some resistance to noise and multipath.

Spherical Error Probable (SEP)

Also known as Spherical Error of Probability. The radius of a sphere within which there is a 50 percent probability of locating a point or being located. SEP is the three-dimensional analogue of CEP. Thus half of the results are within a 3D SEP value.

Squaring-type Channel
A GPS receiver channel that multiplies the received signal by itself to obtain a second harmonic of the carriers that does not contain the code modulation. Used in "codeless" receiver channels.

Standard Deviation (sigma)
A measure of the dispersion of random errors about the mean value. If a large number of measurements or observations of the same quantity are made, the standard deviation is the square root of the sum of the squares of deviations from the mean value divided by the number of observations less one.

$$\sigma = \sqrt{\frac{\sum x_i^2 - x_m}{(n-1)}}$$

Standard Positioning Service (SPS)
The normal civilian positioning accuracy obtained by using the single frequency C/A code. Under selective availability conditions, guaranteed to be no worse than 100 meters (95% 2 DRMS). Since the removal of SA on May 2nd, 2000, this accuracy is now approximately 10m (95% 2DRMS).

Static Positioning
Location determination accomplished with a stationary receiver. This allows the use of various averaging or differential techniques.

Supplementary Traverse
Within the context of this document, a traverse which was executed with non-GPS methods used to fill in areas where GPS techniques are not possible or unproductive (usually a compass and chain traverse).

SV
Satellite vehicle or space vehicle.

Three-dimensional Coverage
The number of hours-per-day when four or more satellites are available with acceptable positioning geometry. Four visible satellites are required to determine location and altitude.

Three-Dimensional (3D) Navigation
Navigation mode in which altitude and horizontal position are determined from satellite range measurements.

Time-To-First-Fix (TTFF)
The actual time required by a GPS receiver to achieve a position solution. This specification will vary with the operating state of the receiver, the length of time since the last position fix, the location of the last fix and the specific receiver design.

Track
A planned or intended horizontal path of travel with respect to the Earth rather than the air or water. The track is expressed in degrees from 000° clockwise through 360° (true, magnetic, or grid).

Track Made Good (TMG)
The single resultant direction from a point of departure to a point of arrival or subsequent position at any given time; may be considered synonymous with Course Made Good.

Trivial Baseline
A baseline derived from simultaneous observations at two points, when both sets of observations have already been used in the formation of other baselines from the same session. Also called the “dependent baseline”.

True Bearing
The bearing relative to true north.

True Heading
The heading relative to true north.

Two-Dimensional (2D) Coverage
The number of hours-per-day with three or more satellites visible. Three visible satellites can be used to determine location if the GPS receiver can accept an external (fixed) altitude input.

Two-Dimensional (2D) Navigation
Navigation mode in which a fixed value of altitude is used for one or more position calculations while horizontal (2D) position can vary freely based on satellite range measurements.

Undulation
The distance of the geoid above (positive) or below (negative) the mathematical reference ellipsoid (spheroid). Also known as geoidal separation, geoidal undulation, and geoidal height.

Universal Time Coordinated (UTC)
An international, highly accurate and stable uniform atomic time system kept very close, by offsets, to the universal time corrected for seasonal variations in the earth's rotation rate. Maintained by the U.S. Naval Observatory. GPS time is directly related to UTC via the equation: UTC-GPS = seconds. (The changing constant = 13 seconds in January, 2001.)

Universal Transverse Mercator (UTM)
A universal globally defined system of mapping projection.

Update Rate
The GPS receiver specification, which indicates the solution rate, provided by the receiver when operating normally.

User Interface
The hardware and operating software by which a receiver operator executes procedures on equipment (such as a GPS receiver) and the means by which the equipment conveys information to the person using it, the controls and displays.

User Range Accuracy (URA)
The contribution to the range-measurement error from an individual error source (apparent clock and ephemeris prediction accuracies). This is converted into range units, assuming that the error source is uncorrelated with all other error sources. Values <6 indicate accurate measurements are possible to this satellite. Values > 30 normally indicate SA is active.

User Segment
The part of the whole GPS system that includes the receivers of GPS signals.

Waypoint
A point with known *x-y* coordinates used for GPS navigation purposes.

World Geodetic System (WGS)
A consistent set of parameters describing the size and shape of the Earth, the positions of a network of points with respect to the centre of mass of the Earth, transformations from major geodetic datums, and the potential of the Earth (usually in terms of harmonic coefficients).

World Geodetic System 1984 (WGS84)
The mathematical ellipsoid used by GPS since January 1987.

Y code
The encrypted version of the P-code.

APPENDIX D - 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"™[26] (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.

[26] Trimble registered trademark

APPENDIX E - RECOMMENDED DATA COLLECTION PRACTICES

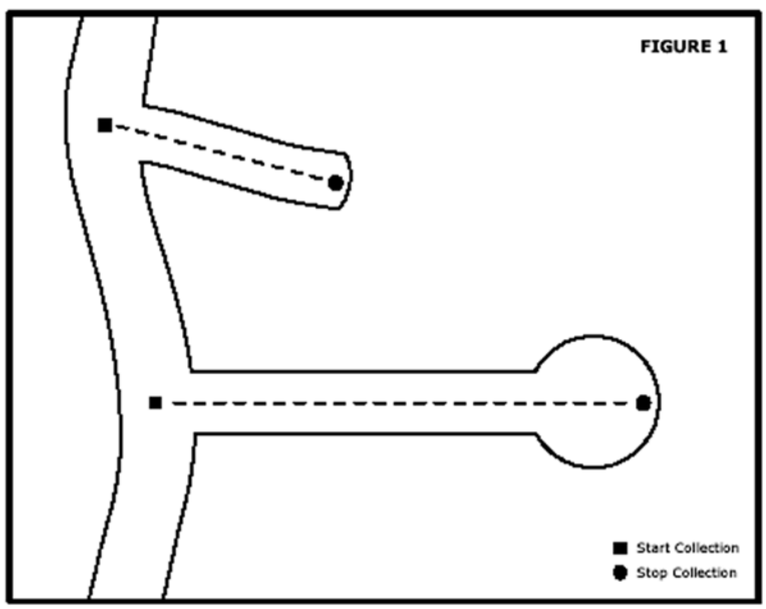
This entire appendix is based on a section of the Georgia Department of Transportation; GPS Data Collection Guideline and Standards: A Manual for Georgia Service Delivery Regions and Regional Development Centers, document with some minor reformatting.

"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

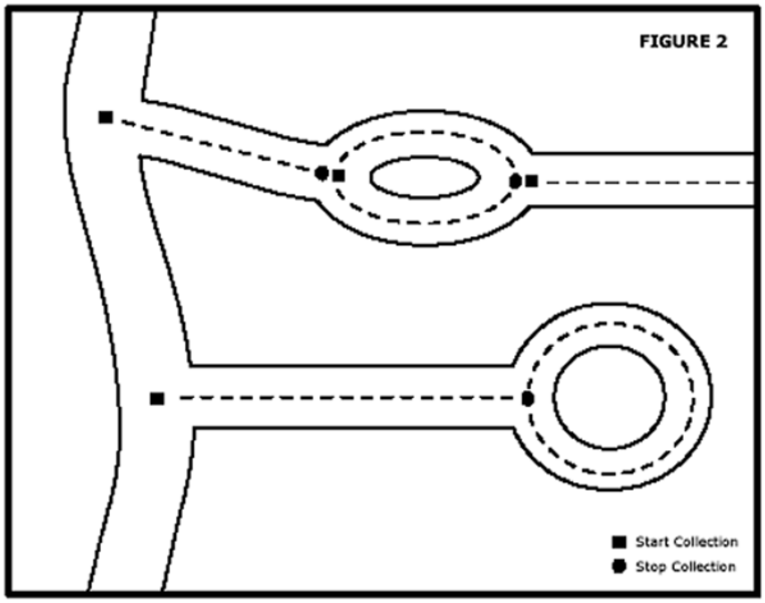
I. Centerline Collection from Beginning to End

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.



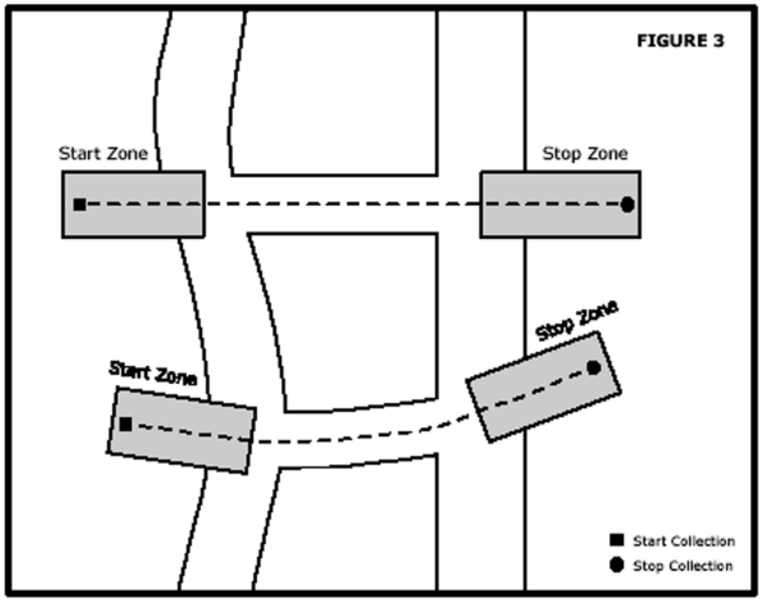
Collection Technique for Cul-De-Sacs and Islands

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.

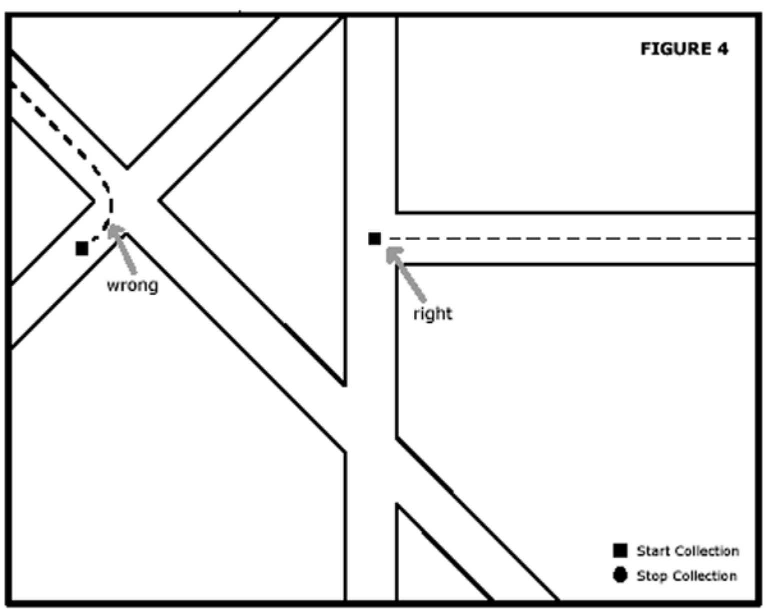


Over-Run Start and Stop Collection Zones

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

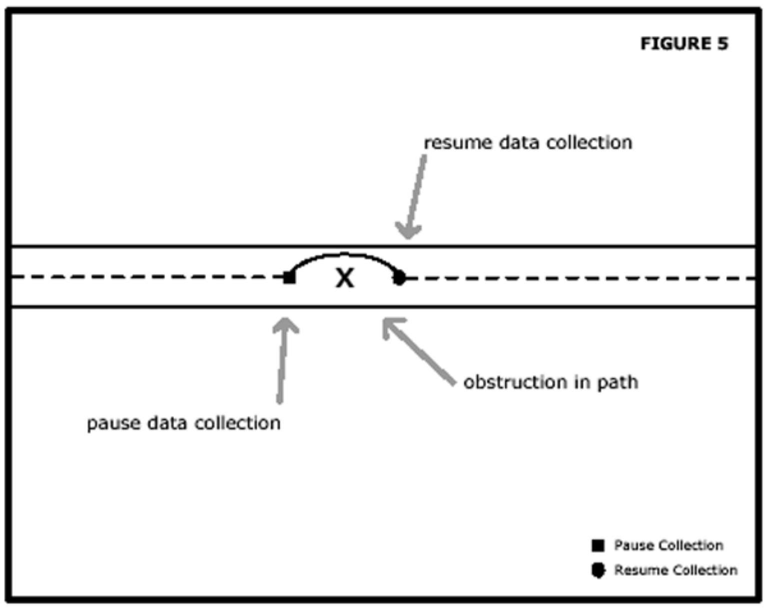
IV. Obstructions in the Collection Path

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.



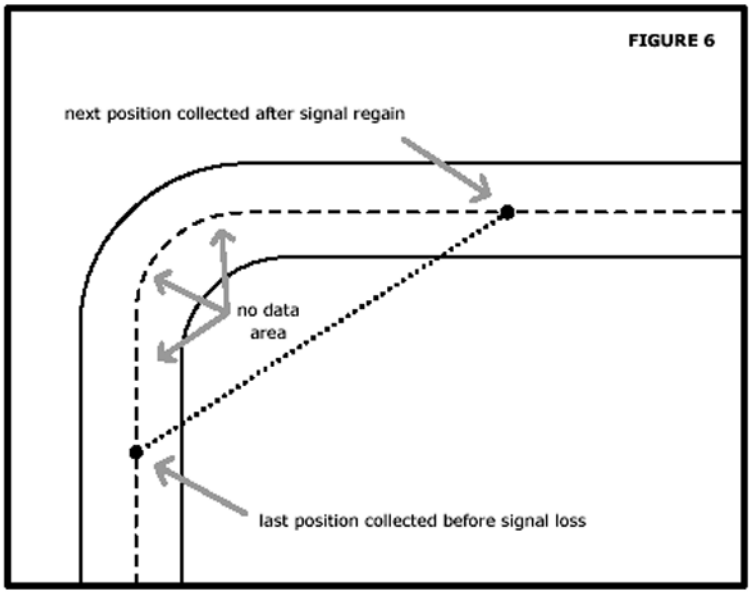
Use the Pause Feature to Pass an Obstruction

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.



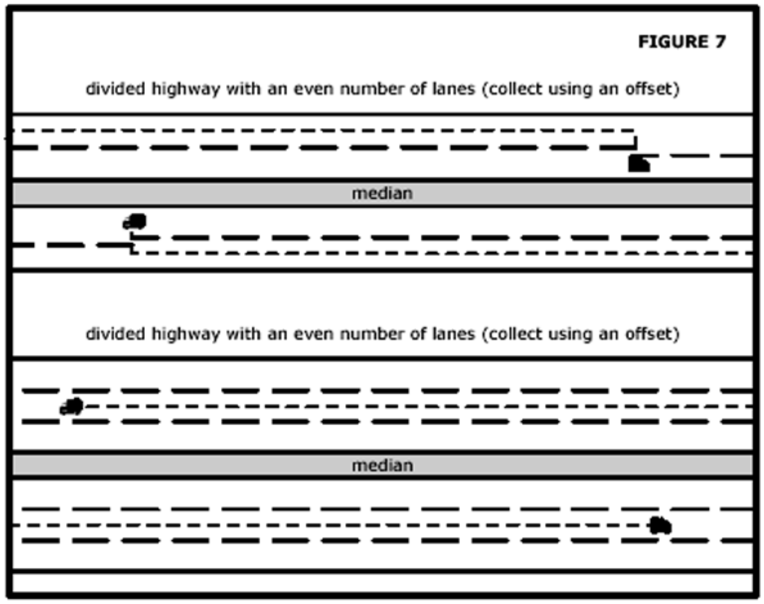
Loss of Signal on a Curvilinear Path

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

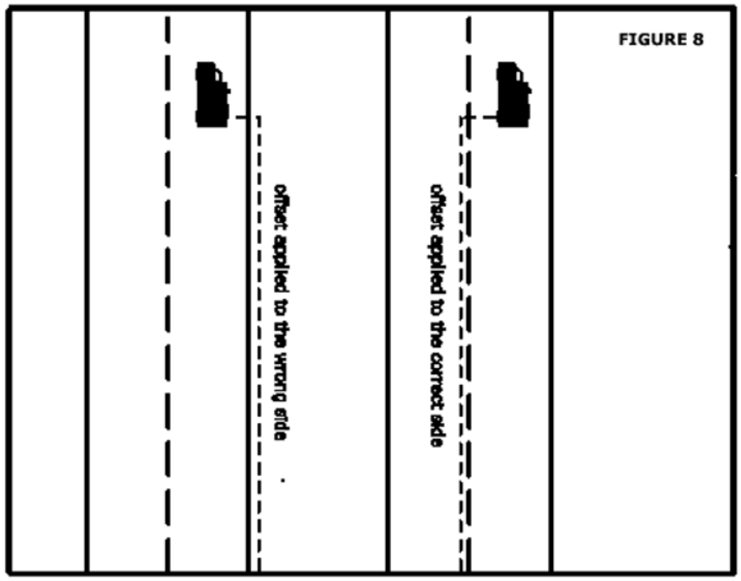
An offset is a known distance set away from the antennae location of the GPS unit that is used to collect data in areas of difficult accessibility. Offsets are either used at the time of data collection (instant offset) or prior to data collection (constant offset). Most often, instant offsets will be 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.

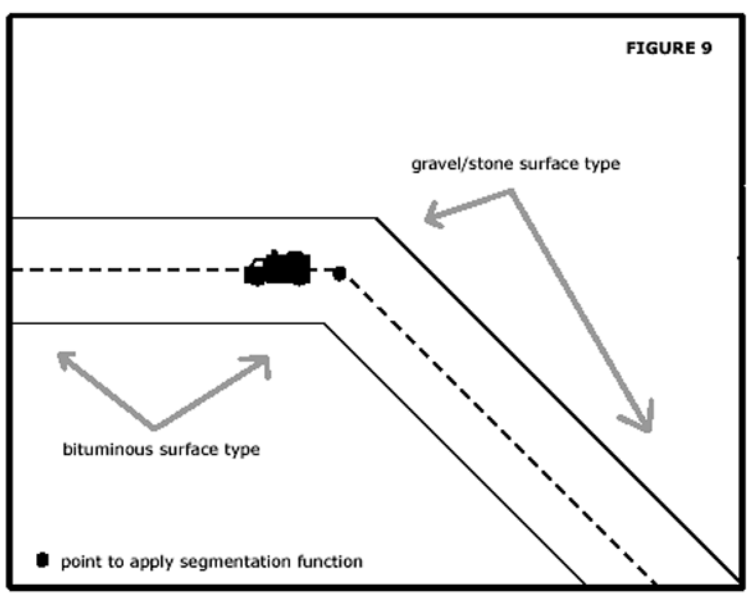


Common Offset Errors

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.



Use of the Segmentation Function

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 F - SAMPLE PROJECT SPECIFICATIONS

This entire appendix is based on the British Columbia Standards, Specifications and Guidelines for *Resource Surveys* Using GPS Technology, Appendix C, 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*:

1.) **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.

2.) **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 travelling 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 used for

Station	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).
VCS	Vermont Coordinate System based on NAD83

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

required	Used to describe tasks that are deemed necessary and are good practice. Exceptions are possible, but only after ***careful*** consideration by the contracting Agency.
recommended	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-Fieldwork 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 specify 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 = _______ m (Class = ___**meter**_)
   Interpretative Horizontal Accuracy = _______ m (Class = ___**meter**_)
   Network Orthometric Height Accuracy = _______ m (Class = __________)
   Interpretative Vertical Accuracy = _______ m (Class = __________)

   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.2 "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:
  - GPS hardware (i.e. receiver model, antenna, data logger, firmware versions, etc.);
  - GPS software (i.e. name, version number, settings, etc.)
  - Mapping software (i.e. name, version number, settings, etc.)
  - 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 Shapefile	**NAD83**	**Unedited**
Final Interpreted GPS Data	ESRI Shapefile	**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:
   - *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.*
   - *Plan datum (e.g. NAD83) and the Map Projection (e.g. VCS).*
   - *Plan scale (e.g. 1:20,000) with BCGS map identifier.*
   - *Plan orientation, (e.g. north arrow annotating True North, Magnetic North and Grid North).*
   - *Geographic (e.g. latitude/longitude) and/or Mapping Projection (e.g. VCS) graticule as requested.*
   - *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.

2. The Contractor and the Contract Administrator should ensure that the most current versions of the VT GPS Guidelines are used.

APPENDIX G - SAMPLE GPS CONTRACTOR VALIDATION REPORT

1. Company/Agency Information:

Company/Agency:

Contact:

2. Validation Purpose:

Validation Purpose:

Specific Purpose:

- Required Network Horizontal Accuracy = ____meter
- Required Network Orthometric Height Accuracy = ____meter

General Purpose:

3. "GPS System" Being Validated:

GPS Field Operator: ____________________ or (see particulars below)
GPS Data Processor: ____________________ or (see particulars below)
Field GPS Manufacturer/Model: ____________________ or (see particulars below)

Field GPS Processing Software:

Field Presentation Software:

GPS Reference Station Used: ____________________ or (see particulars below)

4. Field Operator Information:

Field Operator Name:
Company/Agency:

Formal Credentials:

Experience:

Certificates:

5. Data Processor Information:

Data Processor's Name:
Company/Agency

Formal Credentials:

Experience:

Certificates:

6. Field GPS Receiver Information:

FIELD GPS RECEIVER - GENERAL INFORMATION
GPS Rx Manufacturer/Model:
Field GPS Rx Specifics:

Field GPS Rx Firmware:
Field GPS Rx GPS Antenna Specifics:

FIELD GPS RECEIVER - DATA COLLECTION SETTINGS

Data Rate Used:	seconds
Data Format:	
Data Observables/Stored:	GPSCODE = ___________; *reference Table VI-1 GPS Data Collection Codes in Section C.VI of guidelines*
Satellite Elevation Mask:	degrees
PDOP Mask:	PDOP =

Minimum Number of SVs: Minimum 4 SVs (3D-mode)
Filter Settings:
SNR Mask: Manufacturers Default =
Other Settings:

7. GPS Base Station Used: (Circle those that apply)

GPS BASE STATION - GENERAL INFORMATION

Base Station Location:
VCAP - VT CORS; Montpelier, VT
NHDT - NH CORS; Concord, NH
HDF1 – NY CORS; Hudson Falls, NY
HAMP – MA CORS; Northampton, MA

Base Station Operator:
- VCAP - VT Agency of Transportation - Geodetic Survey
- HDF1 - US Coast Guard
- NHDT - NH Department of Transportation
- HAMP - Northampton Dept. of Public Works
- Other -

Base Station Information: See links below
Validation Date: See links below
- VCAP - http://vcap.aot.state.vt.us/pages/cors.htm
- HDF1 - http://www.ngs.noaa.gov/cgi-cors/corsage.prl?site=hdf1
- NHDT - http://webster.state.nh.us/dot/highwaydesign/GPS.htm
- HAMP - http://www.nohodpw.org/GPS/hamp.htm
- Other -

8. Validation Survey Particulars:

Validation Location:

Survey Ties:

GPS Base Station Separation: km (average)
Survey Methodology:
- -
- -
- -
- -
- - Benchmarks occupied include PID's: ____________________
  ____
- Standard Significance Point = ___ epochs/___seconds
- High Significance Point = ___ epochs/___ seconds

GPS Positioning Code GPSCODE(s) – GPS01-GPS08 (See Section C: Content Specifications/VI. Standard GPS Data Collection Method Codes)

Accuracy Achieved: Horizontal Network Accuracy at …
PID#_____ = _______m
PID#_____ = _______m
PID#_____ = _______m
Orthometric Height Network Accuracy at …

PID#_____ = _______m
PID#_____ = _______m
PID#_____ = _______m

- See ______________ for GPS processing and spreadsheet results
- See ______________ for GPS software plots
- See _______________for CAD/GIS plots

9. VALIDATION RETURNS

Item	Hard Copy	Digital Copy	Format	Comments
Project Report; includes: Report GPS Ref. Station Validation Field Notes/Logs Post-processing Output	1 copy	1 copy	WORD and ASCII files	•
GPS Base Station Data	N/A	see notes	RINEX SSF DAT	• digital data available upon request • hourly data files have been merged using _____________ utility (v2.1) • WGS84
Raw Field GPS Data	N/A	1copy	*._____	WGS84
Original Corrected GPS Data	1 copy	1 copy	*._____ *._____	• ________ format files • Audit/Log files included • Hard copy printouts provided • WGS84
Original Corrected Digital File	1 copy	1 copy	DXF NAD83	• All individual positions supplied • Averaged position color and symbology is different • VCS83 • -
Final Interpreted Digital File	1 copy	1 copy	DXF	VCS83
Final Coordinate List	1 copy	1 copy	MS Excel (v. __)	Horizontal: VCS83 Vertical: Mean Sea Level (calculated using ______geoid model)

SUMMARY:

_____________ is requesting that the above described system be Validated for Resource Surveys for all Agency GPS survey contracts requiring Network Horizontal Accuracies = ___.0m or greater and Network Orthometric Height Accuracies = ___.0m or greater.

Please see the attached Annexes listed below for supporting documentation:
Annex _ Company Information (Business Licences, Experience and Marketing material).
Annex _ GPS Base Station Validation Confirmation (CORS Web page).
Annex _ GPS Processing Reports (Intermediate & Final Processing Documentation).
Annex _ GPS Survey Plots (Intermediate and Final results).

APPENDIX H - FIELD EQUIPMENT LIST

GPS Equipment

__ GPS Datalogger
__ Integrated GPS Antenna
__ TSCI Data Cable
__ Dual Battery Cable
__ Data Power Cable
__ NMEA/RTCM Cable
__ 12-channel Receiver
__ Antenna Cable
__ Vehicle Magnet
__ Data logger Carrying Case
__ GPS Carrying Case
__ Range Poles (4 various lengths)

Safety Equipment

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

Miscellaneous Items

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

APPENDIX I - EVALUATING GPS PROFESSIONALS[27]

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.

[27] VCGI Municipal Mapping Guidelines. pp.35.